State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs

VERSION 3.3

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COMMERCE DEPARTMENT

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Acknowledgements

This document was primarily constructed from energy efficiency and conservation measure specifications developed by Cadmus and Franklin Energy Services with input from Minnesota Department of Commerce, Division of Energy Resources staff and Minnesota utilities. Commerce staff appreciates the significant contributions that Minnesota utilities, consultants, and other stakeholders have made to the Technical Reference Manual (TRM) through sharing information and participating in TRM advisory committee and technical work group meetings.

Purpose and Use of Manual

The purpose of this technical reference manual (TRM) is to put forth standard methodologies and inputs for calculating the savings impacts and cost-effectiveness of energy conservation improvement programs (CIP) in Minnesota. The TRM also documents the calculations that are embedded in the Minnesota Department of Commerce, Division of Energy Resources (DER) TRM Smart Measure Library on ESP®[1], a set of working models for real time savings calculations and tracking that is available to all Minnesota utilities on ESP®.

The TRM is not intended to define a single set of approved calculation methods; rather, the TRM is a standard set of methodologies and inputs that CIP administrators may reference when developing, implementing and reporting on CIP programs. Each measure herein represents a pre-approved calculation method when correctly applied in a program. While Commerce encourages utilities to use the TRM measure designs, utilities may propose, with justification, variations that reflect different program designs or enhanced calculation methods that will result in more accurate savings estimations. Utilities may also use the TRM to generate tables of unitary "deemed savings" figures for pre-defined pre- and post- equipment combinations, if their current tracking software requires this format.

Similarly, the TRM does not represent an exclusive set of measures that may be applied in CIP programs. Minnesota utilities may propose additional measures as standard offerings in their CIP plans, or implement custom measures without pre-approval from Commerce.

[1] ESP® is Cloud-based software application for energy efficiency program management and reporting developed by Energy Platforms, LLC with funding from the Minnesota Department of Commerce. ESP® is launched from www.energyplatforms.com. All Minnesota utilities are granted free access to all features within ESP®. Contact Commerce staff at CIP.Contact@state.mn.us to obtain a login to ESP®.

Summary of Changes from TRM V 3.2

Measure	Version/Description
Residential Measures	
ENERGY STAR Ceiling Fan	Updated to match current ENERGY STAR standards and federal standards
ENERGY STAR Dehumidifiers	Updated federal and ENERGY STAR criteria, and HOU and CF
Gas Water Heater	Allowed storage baselines for instant water heaters, added deemed UEF_{BASE} for when volume and draw are unknown
ENERGY STAR Clothes Washers	Slight reorganization
ENERGY STAR Clothes Dryers	Updated to reflect CARD study findings
Secondary Refrigerator/Freezer Removal	Updated to reflect more recent analysis in nearby state
Commercial and Industrial Measures	
Lighting - Controls	Added separate savings for LLLC, updated savings for NLC, added costs
Pipe Insulation	New measure
Demand Defrost Controls	New measure
Lubricants - Hydraulics	New measure
Lubricants - Gearbox	New measure
Electric Utility Infrastructure Measures	
Appendices	

Residential

Lighting

Residential Lighting - Lighting End Use

Measure Detail	Measure Value
Target Market Segments	Residential, Commercial, Multifamily
Target End Uses	Lighting
Required from Customer/Contractor	Existing fixtures and quatities (retrofits only), Installed fixtures and quantities, space type (interior living quarters, multifamily* common areas, or exterior/unconditioned space), HVAC System (heating only, heating & cooling, exterior/unconditioned) * Multifamily includes 3+ unit residential buildings
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	See each technology section
Unit Participant Incremental Cost	See each technology section

Measure Description

The residential lighting measures use a standard set of variables for hours of use, HVAC cooling interaction effects, In Services Rates, and coincident factors. The following section provides the algorithms used for energy savings and the tables of supporting information.

Algorithms

Unit kWh Savings per Year = (kW_Base - kW_EE) x Hrs x HVAC_cooling_kWhsavings_factor x ISR

Unit Peak kW Savings = (kW_Base - kW_EE) x CF x HVAC_cooling_kWsavings_factor x ISR

Unit Dth Savings per Year = (kW_Base - kW_EE) x Hrs x HVAC_heating_penalty_factor

Where:

kW_EE	=	Deemed average wattage efficient luminaire per each section kW_Base
	=	Deemed average wattage of baseline luminaire per each section
Hrs	=	Deemed annual operating hours from Table 2 based on building type.
CF	=	Coincidence Factor, the probability that peak demand of the lights will coincide with peak utility system demand. CF will be determined based on customer provided building type in Table 2.

HVAC_cooling_kWhsavings_factor = Cooling system energy savings factor resulting from efficient lighting from Table 1. Reduction in lighting energy results in a reduction in cooling energy, if the customer has air conditioning.

HVAC_cooling_kWsavings_factor = Cooling system demand savings factor resulting from efficient lighting from Table 1. Reduction in lighting demand results in a reduction in cooling demand, if the customer has air conditioning.

HVAC_heating_penalty_factor = Heating system penalty factor resulting from efficient lighting (Ref. 3).

ISR = In Service Rate, See Table 3.

Example:

A customer purchases at a retail store and installs a CFL to replace an incandescent lamp in a single family home with Central A/C.

kWh = (0.0467-0.019) * 938 *1.075 * 73% = 20.4 kWh

kW = 0.095 *(0.0467-0.019) * 1.248 * 73% = 0.0024 kW

Deemed Input Tables

Table 1. HVAC Interactive Factors by HVAC System (Ref. 1)

Space Type	HVAC Cooling kW Savings Factor		HVAC Cooling kWh Savings Factor		HVAC Heating Penalty Factor (Dth/kWh)
	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only or Heating & Cooling
Interior Living Quarters	1.00	1.248	1.00	1.075	-0.0029
Multifamily Common Areas	1.00	1.248	1.00	1.075	-0.0029
Exterior/Unconditioned Space	1.00	1.00	1.00	1.00	0
Interior Living Quarters-Cooling Unknown	1.16		1.048		-0.0029
Multifamily CommonAreas-Cooling Unknown	1.11		1.034		-0.0029

*For non direct install delivery methods use the Cooling Unknown HVAC values.

Table 2. Deemed Peak Demand Coincidence Factors (Ref. 2 and 5) and Annual Operating Hours by Space Type (see table for references)

Space Type	CF	Hrs	Reference
Interior living quarters	9.5%	938	3
Multifamily Common Areas	75%	5,950	4
Exterior/Unconditioned Space	0%	1,825	3

Table 3. In Service Rate

Delivery Method	ISR	Reference
Direct Install	97%	6
Retail/Time of Sale	73%	7
School Kits	61%	8
Direct Mail Kits	66%	9

Methodology and Assumptions

HVAC cooling and heating interactive factor data based on DOE2/Equest building simulation.

The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

References

1. Calculated through energy modeling be FES 2012
2. Based on lighting logger study conducted as part of the PY3 ComEd Residential Lighting Program evaluation. "ComEd Residential Energy Star Lighting Program Metering Study: Overview of Study Protocols" http://www.icc.illinois.gov/downloads/public/edocket/303835.pdf
   "Memo RE: Lighting Logger Study Results – Version 2, Date: May 27, 2011, To: David Nichols and ComEd Residential Lighting Interested Parties, From: Amy Buege and Jeremy Eddy; Navigant Evaluation Team" http://www.icc.illinois.gov/downloads/public/edocket/303834.pdf
3. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 Section 7.5 based on lighting logger study conducted as part of the PY3 ComEd Residential Lighting Program evaluation.
4. Multifamily common area lighting assumption is 16.3 hours per day (5950 hours per year) based on Focus on Energy Evaluation, ACES Deemed Savings Desk Review, November 2010.
5. Coincidence factor is based on healthcare/clinic value (used as proxy for multifamily common area lighting with similar hours of use) developed using Equest models for various building types averaged across 5 climate zones for Illinois for the following building types.
6. Based upon review of the Illinois PY2 and PY3 ComEd Direct Install program surveys and consistent with the annualization of savings for the first year savings claim; http://www.icc.illinois.gov/downloads/public/edocket/287090.pdf
7. 1st year in service rate is based upon review of PY4-6 evaluations from ComEd and PY5-6 for Ameren. The average first year ISR for each utility was calculated weighted by the number of bulbs in each year's survey. This was then weighted by annual sales to give a statewide assumption. http://www.ilsag.info/evaluation-documents.html

8. In Service rates provided for the CFL and LED lamps in a kit only. Kits provided free to students through the school, with education program. http://ilsagfiles.org/SAG_files/Evaluation_Documents/Ameren/AIU%20Evaluation%20Reports%20EPY6/AIC_PY6_EEKits_Report_FINAL_2015-07-20.pdf
9. Opt-in program to receive kits via mail, with little or no education. Based on 'Impact and Process Evaluation of 2013 (PY6) Ameren Illinois Company Residential Efficiency Kits Program', table 10. http://ilsagfiles.org/SAG_files/Evaluation_Documents/Ameren/AIU%20Evaluation%20Reports%20EPY6/AIC_PY6_EEKits_Report_FINAL_2015-07-20.pdf

Revision History

Version	Description	Author	Date

Residential Lighting - CFLs and ENERGY STAR Torchieres

Measure Detail	Measure Value
Target Market Segments	Residential, Commercial
Target End Uses	Lighting
Applicable To	Single family, duplex, townhome, and multifamily (3+ units) customers
Actions	Replace on Failure, Replace Working, New Construction
Delivery Methods	Direct Install, Coupon, Giveaway, Upstream, Kits
Version No.	3.0
Unit kWh Savings per Year	Refer to the algorithm and tables provided in the Lighting End Use section
Unit Peak kW Savings	Refer to the algorithm and tables provided in the Lighting End Use section
Unit Dth Savings per Year	Refer to the algorithm and tables provided in the Lighting End Use section

Measure Description

CFLs and ENERGY STAR qualified torchieres provide an energy efficient alternative to traditional incandescent and halogen lamps.

Algorithm

Refer to the algorithm and tables provided in the Lighting End Use section.

Deemed Input Tables

Table 1. Fixture Wattage (Ref. 1 and 2) and Costs (Ref. 3 and 4)

Equipment Type	kW_base	kW_EE	Incremental Cost
CFL (non Direct Install)	0.0467	0.0190	$1.32
CFL (Direct Install)*	Actual Existing	0.0190	$1.32
ENERGY STAR Torchiere	0.1900	0.0485	$41.97

*Where actual existing base wattage is not available in direct install delivery, use the non-Direct Install wattage.

Table 2. Measure Life

Equipment Type	Measure life	Source
CFL	9.4	5
ENERGY STAR Torchiere	9.4	6

Methodology and Assumptions

The baseline wattages in Table 1 were derived from extrapolating the approved baseline wattages for Xcel Energy's Home Lighting program for 2012- 2014 in a February 14, 2012 Order (Docket No. E,G002/CIP-09-198), shown below, and using the market share of each wattage range shown in Table 4. The wattages reflect the gradual depletion of traditional incandescent lighting from the market and were derived from the following report: United States Environmental Protection Agency, October 2011. *Next Generation Lighting Programs*: *Opportunities to Advance Efficient Lighting for a Cleaner Environment*.

Table 3. Approved Baseline Wattages for Xcel Energy's Home Lighting Program, 2012-2014, with Extrapolation to 2015 and 2016

Lumen Bin	Typical Incandescent Wattage	EISA-Compliant Halogen Wattage	2012	2013	2014	2015	2016+
1490-2600	100W	72W	90.5 W	80.5 W	76.0 W	72.0W	72.0W
1050-1489	75W	53W	72.0 W	64.0 W	57.5 W	53.0W	53.0W
750-1049	60W	43W	58.5 W	55.0 W	48.5 W	46.1W	43.0W
310-749	40W	29W	39.0 W	37.0 W	33.0 W	31.4W	29.0W

Tables 4-5: Composite wattages and costs for CFLs and baseline incandescents. Source: CFL METERING STUDY FINAL REPORT, Prepared for: Pacific Gas & Electric Company, San Diego Gas & Electric Company, Southern California Edison Company, 2005. Incandescent wattages updated for EISA 2007 new wattages and include market lag effect for gradual depletion of traditional incandescent wattages from the market per February 14, 2012 Order for Xcel Energy (Docket No. E,G002/CIP-09-198).

Table 4. Composite wattages and costs for CFLs and baseline incandescents 16

CFL Wattage Range Avg	Percent of Total Res CFLs	Composite CFL Wattage	Comparable Incandescent and Halogen Wattage2016+	Composite Baseline Wattage2016+
11	12.0%	1.32	29.0	2.8
17	57.0%	9.69	43.0	24.5
25	19.0%	4.75	53.0	10.1
27	12.0%	3.24	72.0	8.6
WeightedAverage		**19.0**		**46.7**

Table 5. Composite wattages and costs for CFLs and baseline incandescents 16

CFL Wattage Range Avg	CFL Cost	Incandescent cost	CompositeCFL Cost	Composite Incandescent Cost	Incremental
11	$2.23	$0.50	$0.27	$0.06	$0.21
17	$2.00	$0.75	$1.14	$0.43	$0.71
25	$1.87	$0.85	$0.36	$0.16	$0.19
27	$2.25	$0.50	$0.27	$0.06	$0.21
			$2.03	$0.71	$1.32

Table 6. Composite Wattages calculated from ENERGY STAR Qualified Product list accessed 10/27/2015

Brand	Model Number	Intended Use	Light Output	Total Input Power (Watts)
Kadium Lighting	VL-ET-41-01 X	Residential	1200	41.0
Maxlite	ML1G4523xxxx	Residential	3230	44.0
Maxlite	ML1G7033xxxx	Residential	3230	44.0
AutoCell Electronics, Inc.	57W-TOR-27KYN	Residential	1300	57.0
AutoCell Electronics, Inc.	57W-TOR-41KYN	Residential	1300	57.0
Cordelia Lighting Inc.	HBP1042P-x	Residential	3200	48.0
Average				**48.5**

Notes

Baseline incandescent lamp wattages are decreased through 2014 based on EISA 2007 legislation. Torchieres. Section 135(c) of EPACT 2005 amends section 325 of EPCA to add subsection (x) setting standards for torchieres. Torchieres manufactured on or after January 1, 2006, shall consume not more than 190 watts of power, and shall not be capable of operating with lamps that total more than 190 watts.

References

1. CFL Wattage and baseline are from the CFL METERING STUDY FINAL REPORT, Prepared for: Pacific Gas & Electric Company, San Diego Gas & Electric Company, Southern California Edison Company, 2005. Incandescent wattages are updated for EISA 2007 and reflective of the full phase in.
2. Torchiere ENERGY STAR Light Fixtures Product List - accessed 10/27/2015
3. 2006 MEEA Change A Light Change the World Program for 15W and 26W lamps.
4. Costs are based on a survey of manufacturers and Midwest program data.
5. Database of Energy Efficient Resources 2008 Effective Useful Life Summary 10-1-08 (range from 2-10, 9.4 years was selected)
6. Measure life: 9.4 years (calculated), based on 10,000 hour average lamp life

Revision History

Version	Description	Author	Date

Residential Lighting - ENERGY STAR Ceiling Fan

Measure Detail	Measure Value
Target Market Segments	Residential, Multi-Family
Target End Uses	Lighting
Applicable To	Residential and multifamily customers
Actions	Replace on Failure, New Construction
Delivery Methods	Direct Install, Coupon, Giveaway, Upstream, Kits
Required from Customer/Contractor	Space type (Single Family/Multi Family in Unit, Multi Family Common Area, Exterior/Unconditioned Space), HVAC System (Heating Only or Heating & Cooling)
Version No.	3.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	See Table 8

Measure Description

ENERGY STAR qualified ceiling fan/light combination units are 60% more efficient than conventional fan/light units by using improved motors and blade designs and meeting strict energy efficiency, quality, and performance criteria set by the U.S. Environmental Protection Agency, tested by accredited labs, and certified by a third party.

There are several defined fan types, including low-speed small-diameter (LSSD), high-speed small-diameter (HSSD), very small diameter (VSD), and hugger fans. Federal and ENERGY STAR requirements for energy use depend on fan type and diameter. The ENERGY STAR Certified Product List was analyzed to calculate average savings for each fan categories, as well as a weighted average savings across all categories.

Algorithms

Unit kWh Savings per Year = Fan Energy Savings + Lighting Energy Savings

Unit kW Savings per Year = Fan Demand Savings + Lighting Demand Savings

Unit Dth Savings per Year = Lighting Dth Penalty

Where:

$$\text{Fan Energy Savings} = [[(W_{BASE,HIGH} * OH_{HIGH}) + (W_{BASE,LOW} * OH_{LOW}) + (W_{BASE,STBY} * OH_{STBY})] - [(W_{ES,HIGH} * OH_{HIGH}) + (W_{ES,LOW} * OH_{LOW}) + (W_{ES,STBY} * OH_{STBY})]] / 1000 * 365$$

$$\text{Fan Demand Savings} = [(W_{BASE,HIGH}) - (W_{ES,HIGH})] / 1{,}000 * CF_{FAN}$$

If ceiling fan has a built-in light kit or has a lighting component:

Lighting Energy Savings = $(kW_{BASE} - kW_{ES}) * Hrs * SF_{HVAC,COOL,KWH}$

Lighting Demand Savings = $(kW_{BASE} - kW_{ES}) * CF_{LIGHT}$ * HVAC_cooling_kWsavings_factor

Lighting Dth Savings = $(kW_{BASE} - kW_{ES})$ * Hrs * HVAC_heating_penalty_factor

Where:

$W_{BASE,HIGH}$	=	Baseline fan wattage (W per fan) operating on high mode, see Table 10 in Notes
OH_{HIGH}	=	Fan daily operating hours on high mode, see Table 2
$W_{BASE,LOW}$	=	Baseline fan wattage (W per fan) operating on low mode, see Table 10 in Notes
OH_{LOW}	=	Fan daily operating hours on low mode, see Table 2
$W_{BASE,STBY}$	=	Baseline fan wattage (W per fan) operating on standby mode, see Table 10 in Notes
OH_{STBY}	=	Fan daily operating hours on standby mode, see Table 2
$W_{ES,HIGH}$	=	ENERGY STAR fan wattage (W per fan) operating on high mode, see Table 10 in Notes
$W_{ES,LOW}$	=	ENERGY STAR fan wattage (W per fan) operating on low mode, see Table 10 in Notes
$W_{ES,STBY}$	=	ENERGY STAR fan wattage (W per fan) operating on standby mode, see Table 10 in Notes
1000	=	Conversion from W to kW
365	=	Days per year
CF_{FAN}	=	Coincidence factor of the fan, the probability that peak demand of the fan will coincide with peak utility system demand, 0.75 (Ref. 6)
kW_{BASE}	=	Total lighting wattage of baseline ceiling fan, (see Table 11 or Residential Lighting - Lighting End Use section)
kW_{ES}	=	Total lighting wattage of ENERGY STAR ceiling fan, see Table 11
Hrs	=	Deemed annual lighting operating hours from Table 3 in Lighting End Use based on building type, see Table 4

HVAC_cooling_kWhsavings_factor = Cooling system energy savings factor resulting from efficient lighting from Table 1 in Lighting End Use. Reduction in lighting energy results in a reduction in cooling energy, if the customer has air conditioning, see Table 5.

HVAC_cooling_kWsavings_factor = Cooling system demand savings factor resulting from efficient lighting from Table 1 in Lighting End Use. Reduction in lighting demand results in a reduction in cooling demand, if the customer has air conditioning, see Table 5.

HVAC_heating_penalty_factor = Heating system penalty factor resulting from efficient lighting, see Table 5.

CF_{LIGHT} = Coincidence Factor, the probability that peak demand of the lights will coincide with peak utility system demand. CF will be determined based on customer provided building type in Table 2 in Lighting End Use, or see Table 4.

Example:

Install an ENERGY STAR qualified ceiling fan in an interior space

kWh = 108.20 + 35.70 = 143.90 kWh

kW = 0.0507 + 0.0040 = 0.0547 kW

Dth/year = - 0.10 Dth

Deemed Input Tables

Table 1. ENERGY STAR Ceiling Fan and Baseline Ceiling Fan Standards (Ref. 2, Ref. 3)

Ceiling Fan Type	Blade Span Category	Baseline Standard (CFM/W)*	ENERGY STAR 4.0 Standard (CFM/W)
Standard	Diameter (D) ≤ 36 inches	0.65 * D + 38.03	0.72 * D + 41.93
	36 inches < D < 78 inches		2.63 * D - 26.83
	D ≥78 inches		2.63 * D - 26.83
Low Mount HSSD	D ≤ 36 inches	4.16 * D + 0.02	0.72 * D + 41.93
	36 inches < D < 78 inches		2.63 * D - 26.83
	D ≥78 inches		2.63 * D - 26.83
Hugger	D ≤ 36 inches	0.29 * D + 34.46	0.31 * D + 36.84
	36 inches < D < 78 inches		1.75 * D - 15
	D ≥78 inches		1.75 * D - 15

* There are other categories of ceiling fans that have minimum federal standards but do not have ENERGY STAR standards. Those are exlcluded here.

Table 2. Ceiling Fan Daily OH for Different Fan Modes (Ref. 4)

Fan Mode	LSSD (Standard and Hugger Fans)	HSSD Fans
High	3.4	12
Low	3	0
Standby	17.6	12

Table 3. Ceiling Fan with Light Kit Lighting Standards (Ref. 2, Ref. 3)

Lumens	Baseline Lumens/Watt Requirement	ENERGY STAR 4.0 Lumens/Watt Requirement*
< 120 Lumens	50	65.0 for seperable light sources; 70.0 with integrated circutiry
≥ 120 Lumens	$(74.0 - 29.42 * 0.9983^{lumens})$	

* ENERGY STAR ceiling fans with lighting kits must output 800 lumens

Table 4. Ceiling Fan Lighting Hours of Use and CF (Ref. 7)

Space Type	Hrs	CF_Light
Interior living quarters	938	9.50%
Multifamily Common Areas	5,950	75%
Exterior/Unconditioned Space	1,825	0%

Table 5. HVAC Interactive Factors by HVAC System (Ref. 7)

Space Type	HVAC Cooling kW Savings Factor		HVAC Cooling kWh Savings Factor		HVAC Heating Penalty Factor (Dth/kWh)
	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only or Heating & Cooling
Interior Living Quarters	1.00	1.248	1.00	1.075	-0.0029
Multifamily Common Areas	1.00	1.248	1.00	1.075	-0.0029
Exterior/Unconditioned Space	1.00	1.00	1.00	1.00	0
Interior Living Quarters-Cooling Unknown	1.16		1.048		-0.0029
Multifamily CommonAreas-Cooling Unknown	1.11		1.034		-0.0029

*For non direct install delivery methods use the Cooling Unknown HVAC values.

Table 6. ENERGY STAR Ceiling Fan Default Fan Savings

Ceiling Fan Type	Blade Span Category	Fan Energy Savings Based on ENERGY STAR Certified Products List (kWh/yr)	Fan Peak Demand Savings Based on ENERGY STAR Certified Products List (kW/yr)	Weight in ENERGY STAR Certified Products List
Standard	D ≤ 36 inches	17.9	0.009	1%
	36 inches < D < 78 inches	111.0	0.052	82%
	D ≥78 inches	181.8	0.090	4%
Low Mount HSSD	D ≤ 36 inches	N/A, none in ES List	N/A, none in ES List	0%
	36 inches < D < 78 inches	23.1	0.004	5%
	D ≥78 inches	N/A, none in ES List	N/A, none in ES List	0%
Hugger	D ≤ 36 inches	N/A, none in ES List	N/A, none in ES List	0%
	36 inches < D < 78 inches	103.1	0.047	9%
	D ≥78 inches	N/A, none in ES List	N/A, none in ES List	0%
Weighted Average		**108.2**	**0.051**	

Table 7. ENERGY STAR Ceiling Fan Default Lighting Savings

Ceiling Fan Type	Installation Location	Lighting kWh	Lighting kW	Lighting Dth
Weighted Average Ceiling Fan with Light Kit	Interior living quarters – Unknown Cooling	52.1	0.0068	(0.14)
	Multifamily Common Areas – Unknown Cooling	325.8	0.044	(0.91)
	Exterior/Unconditioned Space	95.0	-	-
Weighted Average Ceiling Fan with Unknown Light Kit*	Interior living quarters – Unknown Cooling	35.7	0.004	(0.10)
	Multifamily Common Areas – Unknown Cooling	223.4	0.030	(0.63)
	Exterior/Unconditioned Space	65.2	-	-

* The ENERGY STAR Certified Products List analyzed found that 68% of all ceiling fans had light kits.

Table 8. ENERGY STAR Ceiling Fan Incremental Cost (Ref. 1)

Ceilng Fan Type	Incremental Cost
Ceiling Fan with Light Kit	$46.00
Ceiling Fan without Light Kit	$30.71
Ceiling with Unknown Light Kit	$41.20

Notes

Ceiling fan federal energy standards are based on CFM/W. However, CFM/W is not *directly* the means to calculate energy and demand savings. As shown in the algorithms above, fan energy is calculated via summing the wattages at different operating modes multiplied by the daily hours at each, respective operating mode.

The ENERGY STAR Certified Products List for ceiling fans reports each of the wattages at different operating modes. To determine the wattages at different operating modes for the baseline fan, the ratio

of the ENERGY STAR CFM/W to Baseline CFM/W is applied to each of the reported ENERGY STAR wattages at different operating modes. See Table 9.

Table 9. CFM/W to Different Wattage Operating Modes Estimate

Ceiling Fan Type	Blade Span Category	Average Blade Span in ES Certified Products List (Inches)	Average ENERGY STAR CFM/W	Federal Standard CFM/W	Federal Standard to ENERGY STAR CFM/W Ratio
Standard	D ≤ 36”	26.33	72.50	55.15	76%
	36”< D < 78”	57.63	229.59	75.49	33%
	D ≥ 78”	83.75	315.01	92.47	29%
Low Mount HSSD	D ≤ 36”	N/A	N/A	N/A	N/A
	36” < D < 78”	58.80	286.55	244.63	85%
	D ≥78”	N/A	N/A	N/A	N/A
Hugger	D ≤ 36”	N/A	N/A	N/A	N/A
	36” < D < 78”	50.58	159.57	49.13	31%
	D ≥78”	N/A	N/A	N/A	N/A

Table 10 shows the fan wattages at different fan modes for ENERGY STAR and baseline fans.

Table 10. CFM/W to Different Wattage Operating Modes Estimate

Ceiling Fan Type	Blade Span Category	ENERGY STAR 4.0			Baseline		
		W_{HIGH}	W_{LOW}	W_{STBY}	W_{HIGH}	W_{LOW}	W_{STBY}
Standard	D ≤ 36”	37.10	4.10	1.00	48.77	5.39	1.31
	36” < D < 78”	34.20	4.69	1.06	104.01	14.28	3.22
	D ≥78”	49.72	4.81	1.33	169.38	16.38	4.54
Low Mount HSSD	D ≤ 36”	N/A	N/A	N/A	N/A	N/A	N/A
	36” < D < 78”	29.36	3.00	1.47	34.39	3.51	1.72
	D ≥78”	N/A	N/A	N/A	N/A	N/A	N/A
Hugger	D ≤ 36”	N/A	N/A	N/A	N/A	N/A	N/A
	36” < D < 78”	28.09	3.90	1.05	91.25	12.66	3.40
	D ≥78”	N/A	N/A	N/A	N/A	N/A	N/A

Table 11 shows the lumens of ENERGY STAR fans with ceiling light kits from the same ENERGY STAR analysis. Note that the weights below reflect the ENERGY STAR ceiling fans with light kits.

Table 11. ENERGY STAR Ceiling Fan Default Watts

Ceiling Fan Type	Blade Span Category	Lumens ENERGY STAR Ceiling Fan with Light Kit Based on ENERGY STAR Certified Products List	Watts ENERGY STAR Ceiling Fan with Light Kit Based on ENERGY STAR Certified Products List	Watts of Baseline Ceiling Fan with Light Kit	Weight in ENERGY STAR Certified Products List
Standard	D ≤ 36”	1,870.67	23.57	72.78	1%
	36” < D < 78”	1,447.69	18.50	71.49	82%
	D ≥78”	1,465.40	20.05	71.57	3%
Low Mount HSSD	D ≤ 36”	N/A	N/A	N/A	0%
	36” < D < 78”	1,633.00	22.67	72.17	2%
	D ≥78”	N/A	N/A	N/A	1%
Hugger	D ≤ 36”	N/A	N/A	N/A	0%
	36” < D < 78”	1,493.66	18.43	71.68	11%
	D ≥78”	N/A	N/A	N/A	0%
Weighted Average			**18.73**	**71.55**	

Ceiling fans that allow for lights but don’t come with lights will calculate savings based off Residential Lighting - Lighting End Use section.

References

1. Illinois Stakeholder Advisory Group. 2021 Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 9.0. Volume 3: Residential Measures. September 25, 2020. https://data.energystar.gov/Active-Specifications/ENERGY-STAR-Certified-Ceiling-Fans/2te3-nmxp/data
2. ENERGY STAR. Program Requirements for Residential Ceiling Fans and Ceiling Fan Light Kits. Version 4.0. https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Ceiling%20Fans%20and%20Ceiling%20Fan%20Light%20Kits%20Version%204.0_Program%20Requirements_0.pdf
3. Code of Federal Regulations. Title 10, Chapter II, Subchapter D, Part 430, Subpart C, §430.32. https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-430/subpart-C/section-430.32
4. Code of Federal Regulations. Title 10, Chapter II, Subchapter D, Part 430, Subpart B, Appendix U. https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-430/subpart-B
5. ENERGY STAR. Certified Product List for ENERGY STAR Ceiling Fans. Downloaded 9/2/2021. https://data.energystar.gov/Active-Specifications/ENERGY-STAR-Certified-Ceiling-Fans/2te3-nmxp/data
6. Value for room air conditioners used as an approximation of when ceiling fans are operated
7. Lighting hours and coincidence factor taken from residential Lighting End Use measure

Revision History

Version	Description	Author	Date
3.3	Updated to match current ENERGY STAR standards and federal standards	Cadmus	9/2021

Residential Lighting - ENERGY STAR CFL Fixtures

Measure Detail	Measure Value
Target Market Segments	Residential, Commercial
Target End Uses	Lighting
Applicable To	Single family, duplex, townhome, and multifamily (3+ units) customers
Actions	Replace on Failure, Replace Working, New Construction
Delivery Methods	Direct Install, Coupon, Giveaway, Upstream
Version No.	2.3
Unit kWh Savings per Year	Refer to the algorithm and tables provided in the Lighting End Use section
Unit Peak kW Savings	Refer to the algorithm and tables provided in the Lighting End Use section
Unit Dth Savings per Year	Refer to the algorithm and tables provided in the Lighting End Use section

Measure Description

ENERGY STAR CFL Fixtures replace less efficient incandescent fixtures in retrofits or new construction. Fixtures are hardwired and use pin-based lamps.

Algorithm

Refer to the algorithm and tables provided in the Lighting End Use section.

Deemed Input Tables

Table 1. Measure Life (Ref. 1), Fixture Wattage (Ref. 2 and 3) and Costs (Ref. 4)

Retrofit Category	Existing Device	Replacement Device	Measure Life	kW_base	kW_EE	Incremental Cost
Residential CFL Fixture	Average Incandescent fixture	Average ENERGY STAR replacement fixture	9.4	0.106	0.034	$40

Methodology and Assumptions

The baseline wattage is assumed to be approximately 4 times the efficient wattage of the fixture.

The option to collect the existing wattage and efficient wattage is available to input customer specific values in the algorithm. Use the average values provided if the existing and/or efficient wattages were not provided.

Requirements

Efficient fixtures should appear on the current ENERGY STAR Qualified Product List available at www.energystar.gov.

References

1. Measure life: 9.4 years (calculated), based on 10,000 hour average lamp life
2. ENERGY STAR Light Fixtures Product List - accessed 8/29/2012 and summarized in the Assumptions tab. http://downloads.energystar.gov/bi/qplist/Lamps_Qualified_Product_List.xls?1c46-c682
3. Study of costs for both incandescent and fluorescent fixture options determined an average incremental cost of $40 for ENERGY STAR fixtures.
4. CFL METERING STUDY FINAL REPORT, Prepared for: Pacific Gas & Electric Company, San Diego Gas & Electric Company, Southern California Edison Company, 2005

Revision History

Version	Description	Author	Date

Residential Lighting - ENERGY STAR LED Lamps and Fixtures

Measure Detail	Measure Value
Target Market Segments	Residential, Commercial
Target End Uses	Lighting
Applicable To	Single family, duplex, townhome, and multifamily (3+ units) customers
Actions	Replace on Failure, Replace Working, New Construction
Delivery Methods	Direct Install, Coupon, Giveaway, Upstream, Kits
Version No.	3.0
Unit kWh Savings per Year	Refer to the algorithm and tables provided in the Lighting End Use section
Unit Peak kW Savings	Refer to the algorithm and tables provided in the Lighting End Use section
Unit Dth Savings per Year	Refer to the algorithm and tables provided in the Lighting End Use section

Measure Description

ENERGY STAR LED lamps and fixtures provide an energy efficient alternative to traditional incandescent and halogen lamps. The ENERGY STAR program began labeling qualified LED products in the latter half of 2010. LED A-line lamps are used as efficient replacements of general service incandescent lamps and more efficient halogen lamps. LED Globes are commonly used in restroom vanity fixtures and offer an efficient alternative to incandescent lamps. LED PAR/Flood lamps are commonly used in downlights and track lighting and replace less efficient incandescent and halogen lamps. Recessed downlight fixtures are common in living rooms, bedrooms, and rec rooms and are typically incandescent lamps. LED recessed downlight fixtures offer an efficient alternative to the incandescent fixtures.

Algorithm

Refer to the algorithm and tables provided in the Lighting End Use section.

Deemed Input Tables

Table 1. Fixture Wattage (Ref. 2) and Costs (Ref. 3)

LED Lamp or Fixture	kW_base	kW_EE	Incremental Cost
17W LED A-Line Lamp	0.072	0.017	$11.50
13W LED A-Line Lamp	0.053	0.013	$8.15
10W LED A-Line Lamp	0.043	0.010	$11.25
7W LED A-Line Lamp	0.029	0.007	$6.50
3W LED Globe Lamp	0.025	0.003	$11.00
8W LED Globe Lamp	0.050	0.008	$13.00
14W LED PAR/Flood Lamp	0.078	0.014	$15.00
12W LED Downlight Fixture	0.065	0.012	$85.00

Table 2. Measure Life

Equipment Type	Measure Life (Years)				Ref.
	Screw or Pin Based Interior	Integrated Interior	Screw or Pin Based Exterior	Integrated Exterior	
LED Lamps - Single Family/Unit	16.0				1
LED Lamps - Multi-Family Common Area	2.5				5
LED Lamps - Exterior			8.2		6
LED Decorative or Directional Lamps - Single Family/Unit	20.0				7
LED Decorative or Directional Lamps - Multi-Family Common Area	4.2				8
LED Decorative or Directional Lamps - Exterior			13.7		9
LED Fixtures - Single Family/Unit	20.0	20.0			10
LED Fixtures - Multi-Family Common Area	4.2	8.4			11
LED Fixtures - Exterior			19.2	20.0	12

Methodology and Assumptions

The baseline wattages in Table 3 reflect the approved baseline wattages for Xcel Energy's Home Lighting program in a February 14, 2012 Order (Docket No. E,G002/CIP-09-198), shown below. The wattages reflect the gradual depletion of traditional incandescent lighting from the market and were derived from the following report: United States Environmental Protection Agency, October 2011. *Next Generation Lighting Programs: Opportunities to Advance Efficient Lighting for a Cleaner Environment.*

Table 3. Approved Baseline Wattages, Xcel Energy's Home Lighting Program

Lumen Bin	Typical Incandescent Wattage	EISA-Compliant Halogen Wattage	2016+
1490-2600	100W	72W	72.0 W
1050-1489	75W	53W	53.0 W
750-1049	60W	43W	43.0 W
310-749	40W	29W	29.0 W

Notes

The following tables indicate the effective phase out dates of incandescent lamps under the Energy Independence and Security Act of 2007 (EISA 2007) and technical information.

Table 4. Wattage and Lumen Ranges for General Service Incandescent Types

Incandescent Lamp Wattage	Rated Lumen Range	Replacement Maximum Rated Wattage	Minimum Rated Lamp Life	Effective Phase-Out Date Products Manufactured on or after:
100	1490-2600	72	1,000 hrs	1/1/2012
75	1050-1489	53	1,000 hrs	1/1/2013
60	750-1049	43	1,000 hrs	1/1/2014
40	310-749	29	1,000 hrs	1/1/2014

Incandescent reflector lamps (IRLs) are common cone-shaped light bulbs most typically used in track lighting and "recessed can" light fixtures. The table below shows lumen ranges and incandescent equivalents for LED reflector lamps based on EISA 2007 amendment for reflector lamps in residential settings.

Table 5. Equivalent Wattage vs. Lumens

Minimum Lumens	Maximum Lumens	Incandescent Equivalent Wattage
2340	3075	150
1682	2339	120
1204	1681	100
838	1203	75
561	837	60
420	560	45

Requirements and Qualifications

All LED lamps and fixtures must be ENERGY STAR qualified. Criteria for ENERGY STAR qualified LED products vary by product type and include specifications for: light output (lumens), efficacy (lumens per Watt), zonal lumen density, Correlated Color Temperature (CCT), lumen maintenance (lifetime), Color Rendering Index (CRI), and power factor, among others. LED bulbs also have three-year (or longer) warranties covering material repair or replacement from the date of purchase and must turn on instantly.

References

1. ENERGY STAR LED Lamp Version 2.0 has a rated minimum life of 15,000 hours for screw-based general lamps. 15,000 divided by 938 hours of operation = 16 years.
2. Baseline wattages are from EISA 2007 phase out table for general service incandescents. Baseline wattages for PAR/Floods were averaged based on available products. Baseline for downlights is based on the average downlight fixture. ENERGY STAR efficient wattages are from product information and available qualified products.
3. Costs are based on manufacturer product surveys and Midwest program data.

4. ENERGY STAR LED Lamp Version 2.0 has a rated minimum life of 15,000 hours for screw-based general lamps. 15,000 hours divided by 5,950 hours for multi-family common areas = 2.5 years.
5. ENERGY STAR LED Lamp Version 2.0 has a rated minimum life of 15,000 hours for screw-based general lamps. 15,000 hours divided by 1,825 hours for exterior lighting = 8.2 years.
6. ENERGY STAR LED Lamp Version 2.0 has a rated minimum life of 25,000 hours for screw-based Decorative or Directional Lamps. 25,000 divided by 938 hours for single family = 26.7 years. This is capped at 20 years as the maximum eligible lifetime for Minnesota.
7. ENERGY STAR LED Lamp Version 2.0 has a rated minimum life of 25,000 hours for screw-based Decorative or Directional Lamps. 25,000 divided by 5,950 hours for multi-family common area = 4.2 years.
8. ENERGY STAR LED Lamp Version 2.0 has a rated minimum life of 25,000 hours for screw-based Decorative or Directional Lamps. 25,000 divided by 1,825 hours for exterior = 13.7 years.
9. ENERGY STAR LED Fixture Version 2.0 has a rated minimum life of 25,000 hours for screw-based fixtures. 25,000 divided by 938 hours for single family = 26.7 years. This is capped at 20 years as the maximum eligible lifetime for Minnesota.
   ENERGY STAR LED Fixture Version 2.0 has a rated minimum life of 50,000 hours for integrated fixtures. 50,000 divided by 938 hours for single family = 53.3 years. This is capped at 20 years as the maximum eligible lifetime for Minnesota.
10. ENERGY STAR LED Fixture Version 2.0 has a rated minimum life of 25,000 hours for screw-based fixtures. 25,000 divided by 5,950 hours for multi-family common area = 4.2 years.
    ENERGY STAR LED Fixture Version 2.0 has a rated minimum life of 50,000 hours for integrated fixtures. 50,000 divided by 5,950 hours for multi-family common area = 8.4 years.
11. ENERGY STAR LED Fixture Version 2.0 has a rated minimum life of 35,000 hours for screw-based fixtures. 35,000 divided by 1,825 hours for exterior = 19.2 years.
    ENERGY STAR LED Fixture Version 2.0 has a rated minimum life of 50,000 hours for integrated fixtures. 50,000 divided by 1,825 hours for exterior = 27.4 years. This is capped at 20 years as the maximum eligible lifetime for Minnesota.

Revision History

Below is a summary of the revision history for the entire Residential lighting section.

Version	Description	Author	Date
2.0	Updated format, baseline and efficient wattages, costs, energy standards, and requirements where applicable through the lighting section. Added residential occupancy sensors and outdoor fixtures. Updated HVAC Heating Penalty Factor. Added default values where appropriate. Added In Service Rate. Added delivery methods.	Franklin Energy Services	11/13/2015
2.1	Added measure lives for LED lamps and fixtures based on ENERGY STAR Qualified Specifications for Lamps and Fixtures	Franklin Energy Services	9/30/2016

Residential Lighting - ENERGY STAR Outdoor Fixtures

Measure Detail	Measure Value
Target Market Segments	Residential, Commercial
Target End Uses	Lighting
Applicable To	Single family, duplex, townhome, and multifamily (3+ units) customers
Actions	Replace on Failure, Replace Working, New Construction
Delivery Methods	Direct Install, Coupon, Giveaway, Upstream
Version No.	1.0
Unit kWh Savings per Year	Refer to the algorithm and tables provided in the Lighting End Use section
Unit Peak kW Savings	Refer to the algorithm and tables provided in the Lighting End Use section
Unit Dth Savings per Year	Refer to the algorithm and tables provided in the Lighting End Use section

Measure Description

ENERGY STAR Outdoor Fixtures replace less efficient incandescent fixtures in retrofits or new construction. Fixtures are hardwired and use either pin based or screw in lamps.

Algorithm

Refer to the algorithm and tables provided in the Lighting End Use section.

Deemed Input Tables

Table 1. Measure Life (Ref. 1 and 5), Fixture Wattage (Ref. 2 and 3) and Costs (Ref. 4)

Retrofit Category	Existing Device	Replacement Device	Measure Life	kW_base	kW_EE	Incremental Cost
Residential Outdoor CFL Fixture	Average Incandescent fixture	Average ENERGY STAR replacement fixture	5.5	0.106	0.034	$40
Residential Outdoor LED Fixture	Average Incandescent fixture	Average ENERGY STAR replacement fixture	19	0.106	0.034	$40

Methodology and Assumptions

The baseline wattage is assumed to be approximately 4 times the efficient wattage of the fixture.

The option to collect the existing wattage and efficient wattage is available to input customer specific values in the algorithm. Use the average values provided if the existing and/or efficient wattages were not provided.

Requirements

Efficient fixtures should appear on the current ENERGY STAR Qualified Product List available at www.energystar.gov.

References

1. Measure life: 5.5 years (calculated), based on 10,000 hour average lamp life.
2. ENERGY STAR Light Fixtures Product List, outdoor category - accessed 11/3/2015 www.energystar.gov
3. Study of costs for both incandescent and fluorescent fixture options determined an average incremental cost of $40 for ENERGY STAR fixtures.
4. CFL METERING STUDY FINAL REPORT, Prepared for: Pacific Gas & Electric Company, San Diego
5. Gas & Electric Company, Southern California Edison Company, 2005
   Measure life: 15 years (capped for persistence), based on 35,000 hour average fixture life.

Revision History

Version	Description	Author	Date

Residential Lighting - Controls

Measure Detail	Measure Value
Target Market Segments	Residential, Multi-Family
Target End Uses	Lighting
Applicable To	Residential Single Family, Multi-Family
Actions	Modify
Delivery Methods	Direct Install, Coupon, Giveaway, Upstream, Kits
Required from Customer/Contractor	Control type/quantity, connected load (kW) to each control, building type, HVAC system (heating only, heating & cooling, exterior/unconditioned)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10 years (Ref. 1)
Unit Participant Incremental Cost	$40 for wall mounted, $100 for ceiling mounted

Measure Description

Occupancy sensors represent an energy-efficient way to control lighting use in low occupancy areas such as halls, storage rooms, and restrooms. Instead of relying on people to remember to switch lights off when they leave a space, occupancy sensors perform this task. They measure the movement of people within a space. When movement is detected, the lights turn on automatically; they then shut off when they no longer sense movement. Each unit's shut-off time can be preset, given the needs of the space being controlled.

Algorithms

Unit kWh Savings per Year = kW controlled x ESF x Hrs x HVAC_cooling_kWhsavings_factor

Unit Dth Savings per Year = kW_connected x ESF x Hrs x HVAC_heating_penalty_factor

Where:

kW_controlled = Total connected fixture load, determined as the sum of stipulated fixture wattages from Appendix B.

Hrs = Hours per day, See Table 2 in Lighting End Use

ESF = Energy savings factor – 40% (Ref 2)

HVAC_cooling_kWhsavings_factor = Cooling system energy savings factor resulting from lighting from Table 1 in Lighting End Use. Reduction in lighting energy results in a reduction in cooling energy, if the customer has air conditioning.

HVAC_cooling_kWsavings_factor = Cooling system demand savings factor resulting from lighting from Table 1 in Lighting End Use. Reduction in lighting demand results in a reduction in cooling demand, if the customer has air conditioning.

HVAC_heating_penalty_factor = Heating system penalty factor resulting from lighting control from Table 1 in Lighting End Use.

Example:

Install a wall mounted occupancy sensor with a connected load of 0.560 kW (10 - 2L 32W T8 fixtures) in a common area.

kWh = 0.560kW * 40% * 938 * 1.075 = 225.87 kWh

kW = There is no demand savings for occupancy controls

References

1. GDS Associates, Inc (2007). Measure Life Report: Residential and Commercial/Industrial Lighting and HVAC Measures. Prepared for The New England State Program Working Group.
2. "Residential Lighting Controls Market Characterization" Consortium for Energy Efficiency (CEE), January 9, 2014. Average of lighting on during unoccupied times across multiple room locations.
3. Calculated through energy modeling by FES in 2012
4. As above but using estimate of 64% of single family and multifamily in unit buildings in Minnesota having central cooling (based on data from "Table HC7.1 Air Conditioning in Homes in Midwest Region, Divisions, and States, 2009"
5. As above but using estimate of 45% of multifamily buildings in Minnesota having central cooling (based on data from "Table HC7. Air Conditioning in U.S. Homes, By Housing Unit Type, 2009" which is for the whole of the US, scaled to MN air conditioning prevalence compared to US average);
6. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 Section 7.5 based on lighting logger study conducted as part of the PY3 ComEd Residential Lighting Program evaluation.
7. Multifamily common area lighting assumption is 16.3 hours per day (5950 hours per year) based on Focus on Energy Evaluation, ACES Deemed Savings Desk Review, November 2010.
8. Based on lighting logger study conducted as part of the PY3 ComEd Residential Lighting Program evaluation. "ComEd Residential Energy Star Lighting Program Metering Study: Overview of Study Protocols" http://www.icc.illinois.gov/downloads/public/edocket/303835.pdf

9. "Memo RE: Lighting Logger Study Results – Version 2, Date: May 27, 2011, To: David Nichols and ComEd Residential Lighting Interested Parties, From: Amy Buege and Jeremy Eddy; Navigant Evaluation Team" http://www.icc.illinois.gov/downloads/public/edocket/303834.pdf

10. Coincidence factor is based on healthcare/clinic value (used as proxy for multifamily common area lighting with similar hours of use) developed using Equest models for various building types averaged across 5 climate zones for Illinois for the following building types.

Revision History

Version	Description	Author	Date

Residential Lighting - LED Holiday Lighting

Measure Detail	Measure Value
Target Market Segments	Residential, Commercial
Target End Uses	Lighting
Applicable To	Residential customers in single-family homes, duplexes, and townhomes. Also available to commercial customers
Actions	Replace on Fail, Replace Working, New Construction
Delivery Methods	Direct Install, Coupon, Giveaway, Upstream, Kits
Required from Customer/Contractor	Number of light strings, number of lights per string, type of each lighting string (C7, C9, mini)
Version No.	2.8
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	8 (Ref. 1)
Unit Participant Incremental Cost	$10 (Ref. 3)

Measure Description

This measure includes replacement of failed or working incandescent holiday light strings with new LED holiday light strings

Algorithms

Unit kWh Savings per Year = (kW_Base - kW_EE) x Q x N x Hrs

Unit Dth Savings per Year = (kW_Base - kW_EE) x Q x N x Hrs x HVAC_heating_penalty_factor

Where:

kW_EE = Stipulated wattage per light (kW per light) for efficient light string. See Table 1.

kW_Base = Stipulated wattage per light (kW per light) from baseline light string. See Table 1.

Q = Number of light strings

N = Number of lights in string

Hrs = Estimated annual operational hours per year of the fixture = 150 (Ref. 4);

HVAC_heating_penalty_factor = Heating system penalty factor resulting from efficient lighting

Example:

A customer bought (4) 70-light LED mini holiday light strings.

Unit kWh Savings per Year = (0.00045 - 0.000043) x 4 x 70 x 150 = 17.1 kWh

Unit Peak kW Savings per Year = 0 kW

Deemed Input Tables

Table 1. Post-and Pre-retrofit Wattages per Light (Ref. 2, 5)

Post-retrofit Fixture	kW_EE	Pre-retrofit Fixture	kW_Base
LED Mini Holiday Lights	0.000043	Incandescent Mini Holiday Lights	0.000450
LED C7 Holiday Lights	0.000480	Incandescent C7 Holiday Lights	0.006000
LED C9 Holiday Lights	0.002000	Incandescent C9 Holiday Lights	0.007000

Table 2. HVAC Interactive Factors by HVAC System

Space Type	HVAC Heating Penalty Factor (Dth/kWh)	Reference
	HVAC System: Heating Only or Heating & Cooling	
Interior Living Quarters	-0.0029	6
Multifamily Common Areas	-0.0029	6
Exterior/Uncond. Space	0	6
Interior Living Quarters - Cooling Unknown	-0.0029	7
Multifamily Common Areas - Cooling Unknown	-0.0029	8

Methodology and Assumptions

Light strings are assumed to be operating during winter (HVAC cooling factors and kW savings ignored)

Any potential gas savings is assumed to be negligible; due to a number of installations being in unheated space.

Hours are based on 5 hours per day, 30 days per year.

Light strings are assumed to be operating during non-peak hours; CF = 0

Notes

ENERGY STAR criteria for Decorative Light Strings is: "Products must meet stringent efficiency (under 0.2W per bulb) and quality (3-year warranty, protection against over-voltage, maintained light output) requirements.

If desired, the baseline and proposed wattages can be prorated for light strings of different lengths (i.e. 50-light and 100-light strings)

References

1. Engineering judgment based on 50% of DEER measure life value (16 years).
2. Based on a 70-light string; Pacific Gas & Electric document "Light up the holidays and save", November 2009.
3. State of Ohio Energy Efficiency Technical Reference Manual (TRM) for Ohio State Senate Bill 221, October 2009. Page 59.
4. Holiday Lights: LED and Fiber Optics, November 2007. Energy Ideas Clearinghouse.
5. Technical Reference Manual State of Pennsylvania Act 129 Energy Efficiency and Conservation Program & Act 213 Alternative Energy Portfolio Standards, June 2014 page 174.
6. Calculated through energy modeling by FES 2012
7. As above but using estimate of 64% of single family and multifamily in unit buildings in Minnesota having central cooling (based on data from “Table HC7.1 Air Conditioning in Homes in Midwest Region, Divisions, and States, 2009”
8. As above but using estimate of 45% of multifamily buildings in Minnesota having central cooling (based on data from “Table HC7. Air Conditioning in U.S. Homes, By Housing Unit Type, 2009” which is for the whole of the US, scaled to MN air conditioning prevalence compared to US average);

Revision History

Version	Description	Author	Date

HVAC

Residential HVAC - Central AC/ASHP Quality Install Additional Savings

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, multi-family homes (including 3- and 4-family homes), and townhomes
Actions	O&M
Required from Customer/Contractor	Equipment size (tons), SEER or EER of new equipment, HSPF of new equipment (ASHP only), existing or new construction, building type (single family or multifamily*), project location (county) * Multifamily includes duplexes, townhomes, and buildings with 3 or more units
Version No.	3.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	18 years (Ref. 1
Unit Participant Incremental Cost	$250/unit (Ref. 2)

Measure Description

This measure represents additional savings from installation of high efficiency AC systems or ASHP in existing or new homes through a "Quality Installation" program.

Intended for use with the Residential Central A/C-ASHP measure which represents the estimated savings that would be achieved without a Quality Installation program.

Algorithms

Unit kWh Savings per Year for AC system =

$$Size \times EFLH_{COOL} \times (12 / SEER_{EFF}) \times [1 / (1 - Loss_{NoQI,e}) - 1]$$

Unit kWh Savings per Year for ASHP =

$$Size \times EFLH_{COOL} \times (12 / SEER_{EFF}) \times [1 / (1 - Loss_{NoQI,e}) - 1] +$$
$$Size \times EFLH_{HEAT} \times (12 / (HSPF_{EFF} \times C_{IV-V})) \times [1 / (1 - Loss_{NoQI,e}) - 1]$$

Unit Peak kW Savings = $Size \times CF \times (12 / EER_{EFF}) \times [1 / (1 - Loss_{NoQI,d}) - 1]$

Where:

Size	=	Unit capacity in tons (1 ton = 12,000 btu/h)
$EFLH_{COOL}$	=	Effective Full Load Cooling Hours. See Table 1 (Ref. 3)

$SEER_{EFF}$	=	SEER of new high efficiency unit provided by customer/contractor, or use SEER = EER / 0.875 if EER is provided. (Ref. 4)
EER_{EFF}	=	EER of new high efficiency unit provided by customer/contractor, or use EER = SEER*0.875 if SEER is provided (Ref. 4)
$Loss_{NoQI,e}$	=	Efficiency loss of average unit due to improper installation for energy = 10%. (see Notes)
$Loss_{NoQI,d}$	=	Efficiency loss of average unit due to improper installation for demand = 8%. (see Notes)
CF	=	Coincidence factor = 0.75 for standard single-speed compressor equipment, 0.9 for variable-speed compressor equipment (see Notes)
$EFLH_{HEAT}$	=	Effective Full Load Heating Hours. See Table 2 (Ref. 7)
$HSPF_{EFF}$	=	Heating system performance factor of efficient ASHP, provided by customer/contractor.
C_{IV-V}	=	Conversion from rated HSPF to HSPF appropriate for AHRI climate zone V = 0.85 (Ref. 8, Ref. 9)

Example:

Retrofit AC System installed in single family home, 3-ton with SEER rating 14.5, Climate Zone 3 following quality installation procedures.

Additional kWh Savings per Year = 3 x 520 x (12 / 14.5) x [1 / (1 - 0.10) - 1] = 143

Additional Peak kW Savings = 3 x 0.75 x (12 / 12.7) x [1 / (1 – 0.08) - 1] = 0.18

Retrofit ASHP in single family home, 3-ton with SEER rating 15, HSPF rating 9, Climate Zone 2.

Additional kWh Savings per Year = 3 x 379 x (12 / 15) x [1 / (1 - 0.10) - 1] +
3 x 2099 x (12 / (9 * 0.85)) x [1 / (1 - 0.10) - 1] = 1,199

Additional Peak kW Savings = 3 x 0.75 x (12 / 13) x [1 / (1 - 0.08) - 1] = 0.18

Deemed Input Tables

Table 1. Effective Full Load Cooling Hours (EFLCH) by Climate Zone (Ref. 3)

Zone	Effective Full Load Cooling Hours	
	Single Family	Multifamily*
Zone 1 (Northern MN)	213	228
Zone 2 (Central MN)	379	473
Zone 3 (Southern MN/Twin Cities)	520	616

Table 2. Equivalent Full Load Heating Hours (EFLHH) by Climate Zone (Ref. 7)

Zone	Equivalent Full Load Heating Hours
Zone 1 (Northern MN)	2280
Zone 2 (Central MN)	2099
Zone 3 (Southern MN/Twin Cities)	1932

Methodology and Assumptions

Savings with QI consist of four measures: equipment sizing, air flow, refrigerant charge, and duct leakage. The savings for each of four measures are not additive as stated in (6), (7). Our review of the studies' shows the reasonable estimated savings would be 25%, approximately 75% of max savings in studies

To claim Quality Installation savings, a certified technician must sign off on the installation indicating that he or she has inspected the installation and reviewed the submitted data, and verifies that the installation meets proper refrigerant charging and indoor airflow specifications, is sized appropriately according to Manual J calculations, and that ducts have been sealed to the extent practical. In addition, the technician must verify that the indoor and outdoor units are part of a matched system according to the AHRI Certification Directory (www.ahridirectory.org) or other recognized source.

Certification implies that the technician has passed an HVAC certification test by NATE, HVACReducation.net, or a similar organization.

EFLH_Cool data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Notes

The prior national standards for central air conditioners and heat pumps, which raised the minimum Seasonal Energy Efficiency Ratio (SEER) requirement from 10 to 13, became effective in 2006. In January 2010, HVAC manufacturer representatives and efficiency advocates presented a negotiated consensus agreement to DOE to increase efficiency standards for central air conditioners and heat pumps. The consensus agreement included regional standards for three regions: the South, the Southwest, and the North, reflecting varying HVAC needs for each climate. DOE issued a direct final rule (DFR) in June 2011 based on the standard levels in the consensus agreement. These DFR became effective on October 25, 2011 . The new standards increase the minimum cooling efficiency requirement to SEER 14 for split system central air conditioners in the South and the Southwest while maintaining the SEER 13 standard for the North. The new standards also include EER (Energy Efficiency Ratio) requirements for the Southwest region to ensure efficient operation at high outdoor temperatures. For heat pumps, the standards raise the cooling efficiency requirement to SEER 14 for all three regions and also increase the heating efficiency requirements. The standards will become effective on January 1, 2015.

The requirement pertains to the manufacture of units with an 18 month grace period allowed for the sale AC units and a similar period expected for ASHP units.

The value for coincidence factor is derived from a 2016 CARD study (Ref. 5) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 6) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

The memo (Ref. 6) also recommends updating $Loss_{NoQI,e}$ to 10%, rather than the previous value of 25%. It also recommends using a separate demand loss factor, $Loss_{NoQI,d}$ of 8%, and eliminating assumed losses for units with a quality install.

References

1. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, Inc. June 2007 http://www.ctsavesenergy.org/files/Measure%20Life%20Report%202007.pdf
2. DEER 2008 Database Technology and Measure Cost Data (www.deeresources.com)
3. Calculated through energy modeling be FES 2012
4. ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment
5. Seventhwave. *Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps*. September 30, 2016. http://mn.gov/commerce-stat/pdfs/card-improving-insullation.pdf
6. Seventhwave. *TRM Implications from the CARD "Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps" study*. Memo from Seventhwave to MN DER. June 8, 2016.
7. FES scaled annual heating loads from those provided in the Illinois Technical Reference Manual based on Minnesota weather data.
8. P. Francisco et al. *Understanding Heating Seasonal Performance Factor for Heat Pumps*. 2004. https://aceee.org/files/proceedings/2004/data/papers/SS04_Panel1_Paper08.pdf. Comparing adjusted HSPF values in climate zone IV to zone V in Figures 3, 5, and 7 reveals a ratio of 85%.
9. C. K. Rice et al. *An Analysis of Representative Heating Load Lines for Residential HSPF Ratings*. July 2015. https://info.ornl.gov/sites/publications/files/Pub56184.pdf. Fig. B.4 shows an actual HSPF approximately 15% less than rated HSPF for zone V, using the standard AHRI 210/240 load line.

Revision History

Version	Description	Author	Date
2.9	Federal standard grace period note added	Franklin Energy Services	07/31/2014
3.0	Changed heating savings approach and changed from HDD to EFLH	Franklin Energy Services	1/13/2016
3.1	Updated CF and $Loss_{NoQI}$, set $Loss_{QI}$ to zero, adjusted HSPF for AHRI climate zone V	Cadmus	10/2019

Residential HVAC - Central AC/ASHP Tune-Up

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	This measure assumes that the existing unit has not been serviced for at least 2 years for residential customers in single-family homes, duplexes, multi-family homes (including 3- and 4-unit buildings), and townhomes
Actions	O&M
Required from Customer/Contractor	Project location (county), tons, SEER, actual cost of tune-up, procedures performed during tune-up, building type (single family or multifamily*) * Multifamily includes duplexes, townhomes, and buildings with 3 or more units
Version No.	4.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	Coil cleaning and filter change: 2 years (Ref. 4) Refrigerant charge and airflow adjustment: 10 years (Ref. 7)
Unit Participant Incremental Cost	$175 (default/planning figure; Use actual cost of tune-up) (Ref. 4)

Measure Description

A residential split-system air conditioning or air source heat pump tune-up can incorporate one or more of several actions:

- Condenser coil cleaning
- Air filter change
- Refrigerant charge measurement and correction
- Air flow measurement and correction

The first two actions, coil cleaning and an air filter change, are frequently needed and provide a modest boost to system performance. The last two actions, refrigerant charge and airflow correction (RCA), generally produce a larger boost in performance but must only be performed once over the life of the air conditioner or heat pump.

Algorithms

Unit kWh Savings per Year = (Cap * 12) * $EFLH_{COOL}$ / [SEER * (1 – SF_E)] * SF_E

Unit Peak kW Savings = (Cap * 12) * CF / [EER * (1 – SF_D)] * SF_D

Where:

Cap	=	Cooling capacity of AC system or ASHP, in Btu/h. Note 1 ton=12,000 Btu/h. For units with unknown capacity use 2.5 tons
12	=	Conversion from tons to MBtu
$EFLH_{COOL}$	=	Full load cooling hours (varies by location, see Table 1)
SEER	=	Nameplate SEER of equipment (kWh / MBtu). For units with unknown SEER use 11.5 (Ref. 2)
EER	=	Nameplate EER of equipment (kWh / MBtu). For units with unknown EER use EER = SEER * 0.875 = 10.1 (Ref. 5, Ref. 2)
CF	=	Coincidence factor = 0.75 for standard single-speed compressor equipment, 0.9 for variable-speed compressor equipment (see Notes)
SF_E	=	Energy savings factor (see Table 2)
SF_D	=	Demand savings factor (see Table 2)

Example:

Tune-up of a central AC unit in a single family house in Zone 3, consisting of coil cleaning and filter change only:

Unit kWh Savings per Year = (2.5 * 12) * 520 / [11.5 * (1 – 0.05)] * 0.05 = 71.4 kWh

Unit Peak kW Savings = (2.5 * 12) * 0.75 / [10.1 * (1 – 0.02)] * 0.02 = 0.046 kW

Deemed Input Tables

Table 1. Equivalent Full Load Cooling Hours ($EFLH_{Cool}$) by Climate Zone (Ref. 3)

Zone	Effective Full Load Cooling Hours	
	Single Family	Multifamily*
Zone 1 (Northern MN)	213	228
Zone 2 (Central MN)	379	473
Zone 3 (Southern MN/Twin Cities)	520	616

* Multifamily includes duplexes, townhomes, and buildings with 3 or more units

Table 2: Savings Factors for Tune-Up Actions

Actions	Energy Savings Factor (SF_E)	Demand Savings Factor (SF_D)	Source
Condenser coil cleaning, filter change	5%	2%	Ref. 2, Ref. 7
Refrigerant charge correction, air flow correcton	12.1%	12.1%	Ref. 7

Methodology and Assumptions

Measurements and corrections must be performed with standard industry tools and practices, and the results tracked by the efficiency program.

$EFLH_{Cool}$ data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

The EUL of 10 years for the refrigerant charge correction and airflow adjustment actions reflects the approximate remaining useful life of an air conditioner or heat pump. These actions may not be credited with savings more than once per system.

Notes

The value for coincidence factor is derived from a 2016 CARD study (Ref. 7) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 6) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

References

1. Based on Wassmer, M. (2003). A Component-Based Model for Residential Air Conditioner and Heat Pump Energy Calculations. Master's Thesis, University of Colorado at Boulder. Note this is appropriate for single speed units only.
2. Energy Center of Wisconsin. *Central Air Conditioning in Wisconsin, A Compilation of Recent Field Research*. May 2008. https://focusonenergy.com/sites/default/files/centralairconditioning_report.pdf
3. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012
4. DEER 2008 Database Technology and Measure Cost Data (www.deeresources.com)

5. ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment
6. Seventhwave. *TRM Implications from the CARD "Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps" study*. Memo from Seventhwave to MN DER. June 8, 2016.
7. Seventhwave. *Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners and Heat Pumps*. September 30, 2016. https://www.cards.commerce.state.mn.us/CARDS/security/search.do?documentId=%7B881DD1B7-1FE4-495A-9FC0-F74A54B99CB6%7D

Revision History

Version	Description	Author	Date
1.0	Initial version based on Nexant's original specification	Joe Plummer	
1.1	Increased default tune-up cost to $200	Joe Plummer	
2.1	Changed energy savings equations arrangement	Franklin Energy Services	7/25/2012
2.2	Changed measure life	Franklin Energy Services	7/25/2012
2.3	Changed incremental cost	Franklin Energy Services	7/25/2012
2.4	Changed references	Franklin Energy Services	7/25/2012
2.5	Changed assumption that unit has not been serviced for at least three years to two years to be consistent with measure life of two years	Joe Plummer	3/25/2013
2.6	Added explanation of multifamily buildings	Joe Plummer	3/12/14
3.0	Made EFLH terminology consistent with other measures, added to description of source	Franklin Energy Services	11/12/15
4.0	Adjusted equations, split measure into two tiers	Cadmus	10/2018
4.1	Updated CF	Cadmus	10/2019

Residential HVAC - Central AC/ASHP

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes) with residential type AC systems
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Equipment size (tons), SEER or EER of new equipment, SEER or EER of existing equipment (if program includes early replacements), HSPF of new equipment (ASHP only), HSPF of existing equipment (ASHP only, if program includes early replacements), existing equipment condition (working or failed, if program includes early replacements), building type (single family/multifamily*), project location (county) * Multifamily includes duplexes, townhomes, and multifamily buildings with 3 or more units
Version No.	3.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	18 years (Ref. 1)
Unit Participant Incremental Cost	See Table 4, 5. Incremental equipment cost only, labor is not included

Measure Description

This measure includes replacement of failed or working central AC system or ASHP in existing homes with high efficiency units, as well as installation of high efficiency AC systems in new homes. Savings for replacement of working units are in reference to existing unit.

Algorithms

Unit kWh Savings per Year for AC system = Size x $EFLH_{COOL}$ x (12 / $SEER_{BASE}$ - 12 / $SEER_{EFF}$)

Unit kWh Savings per Year for ASHP = Size x $EFLH_{COOL}$ x (12 / $SEER_{BASE}$ - 12 / $SEER_{EFF}$) + (Size x $EFLH_{HEAT}$) x [12 / ($HSPF_{BASE}$ x C_{IV-V}) - 12 / ($HSPF_{EFF}$ x C_{IV-V})]

Unit Peak kW Savings = Size x CF x (12/EER_{BASE} - 12/EER_{EFF})

Where:

Size	=	Unit capacity in tons (1 ton = 12,000 btu/h)
$EFLH_{COOL}$	=	Equivalent Full Load Cooling Hours. See Table 1.
$SEER_{BASE}$	=	SEER of baseline or existing unit provided by customer/contractor if Replace Working, or use SEER = EER / 0.875 if EER is provided (Ref. 4). If unknown, Replace on Fail or New Construction see Table 2.

EER_{BASE}	=	EER of baseline or existing unit provided by customer/contractor, or use EER = SEER x 0.875 if SEER is provided (Ref. 4). If unknown, Replace on Fail or New Construction see Table 2.
$SEER_{EFF}$	=	SEER of new high efficiency unit provided by customer/contractor, or use SEER = EER / 0.875 if EER is provided. (Ref. 4)
EER_{EFF}	=	EER of new high efficiency unit provided by customer/contractor, or use EER = SEER x 0.875 if SEER is provided (Ref. 4)
CF	=	Coincidence factor = 0.75 for standard single-speed compressor equipment, 0.9 for variable-speed compressor equipment (see Notes)
$HSPF_{BASE}$	=	Heating system performance factor of baseline or existing ASHP, provided by customer/contractor, or see Table 2 if unknown, Replace on Fail or New Construction
C_{IV-V}	=	Conversion from rated HSPF to HSPF appropriate for AHRI climate zone V = 0.85 (Ref. 9, Ref. 10)
$HSPF_{EFF}$	=	Heating system performance factor of efficient ASHP, provided by customer/contractor
$EFLH_{HEAT}$	=	Equivalent Full Load Hours Heating. See Table 3.

Example:

Retrofit AC System in single family home, 3-ton with SEER rating 14.5, Climate Zone 3.

Unit kWh Savings per Year = 3 x 520 x (12 / 13 - 12 / 14.5) = 149 kWh

EER_Eff = 14.5 x 0.875 = 12.7

Unit Peak kW Savings = 3 x 0.75 x (12 / 11.4 - 12 / 12.7) = 0.24 kW

Retrofit ASHP in single family home, 3-ton with SEER rating 15, HSPF rating 9, Climate Zone 2.

Unit kWh Savings per Year = 3 x 379 x (12 / 13 - 12 / 15) + 3 x 2099 x (12 / (7.7 x 0.85) - 12 / (9 * 0.85)) = 1,808 kWh

EER_Eff = 15 x 0.875 = 13.125

Unit Peak kW Savings = 0.75 x 3 x (12 / 11.4 - 12 / 13.125) = 0.311 kW

Deemed Input Tables

Table 1. Effective Full Load Cooling Hours ($EFLH_{Cool}$) by Climate Zone (Ref. 3)

Zone	Effective Full Load Cooling Hours	
	Single Family	Multifamily*
Zone 1 (Northern MN)	213	228
Zone 2 (Central MN)	379	473
Zone 3 (Southern MN/Twin Cities)	520	616

* Multifamily includes duplexes, townhomes, and buildings with 3 or more units

Table 2. Baseline SEER, EER, and HSPF Values (Ref. 6)

Product Type	$SEER_{BASE}$	EER_{BASE}*	$HSPF_{BASE}$
Split system air conditioner	13	11.4	
Split system heat pump	14	12.3	8.2
Single package air conditioner	14	12.3	
Single package heat pump	14	12.3	8.0

*EER = SEER * 0.875

Table 3. Equivalent Full Load Heating Hours ($EFLH_{Heat}$) by Climate Zone (Ref. 7)

Zone	Equivalent Full Load Heating Hours
Zone 1 (Northern MN)	2280
Zone 2 (Central MN)	2099
Zone 3 (Southern MN/Twin Cities)	1932

*Includes duplex, townhome, and multifamily buildings with 3 or more units

Table 4. AC Incremental cost (Ref. 2)

Efficiency Level	Cost per Ton
SEER 14	$119
SEER 14.5	$178
SEER 15	$238
SEER 16	$357
SEER 17	$476
SEER 18	$596
SEER 19	$715
SEER 20	$834
SEER 21	$908
Average	**$530**

Table 5. ASHP Incremental cost (Ref. 2)

Efficiency Level	Cost per Ton
SEER 14	$137
SEER 15	$274
SEER 16	$411
SEER 17	$548
SEER 18	$685

Methodology and Assumptions

$EFLH_{Cool}$ data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

$EFLH_{Heat}$ were determined from Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{65,MN} / HDD_{65,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 6. Heating Degree Days and Design Temperature Difference

Geography	HDD65	DTD
Chicago, IL	6,339	73.5
MN Zone 1	9,833	92
MN Zone 2	8,512	86.5
MN Zone 3	7,651	84.5

Notes

The prior national standards for central air conditioners and heat pumps, which raised the minimum Seasonal Energy Efficiency Ratio (SEER) requirement from 10 to 13, became effective in 2006. In January 2010, HVAC manufacturer representatives and efficiency advocates presented a negotiated consensus agreement to DOE to increase efficiency standards for central air conditioners and heat pumps. The consensus agreement included regional standards for three regions: the South, the Southwest, and the North, reflecting varying HVAC needs for each climate. DOE issued a direct final rule (DFR) in June 2011 based on the standard levels in the consensus agreement. These DFR became effective on October 25, 2011. The new standards increase the minimum cooling efficiency requirement to SEER 14 for split system central air conditioners in the South and the SW while maintaining the SEER 13 standard for the North. The new standards also include EER (Energy Efficiency Ratio) requirements for the SW region to ensure efficient operation at high outdoor temperatures. For heat pumps, the standards raise the cooling efficiency requirement to SEER 14 for all three regions and also increase the heating efficiency requirements. The standards became effective on January 1, 2015. The requirement pertains to the

manufacture of units with an 18 month grace period allowed for the sale AC units and a similar period expected for ASHP units.

The value for coincidence factor is derived from a 2016 CARD study (Ref. 5) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 8) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

References

1. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, Inc. June 2007 http://www.ctsavesenergy.org/files/Measure%20Life%20Report%202007.pdf
2. DEER 2008 Database Technology and Measure Cost Data (www.deeresources.com)
3. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012
4. ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment
5. Seventhwave. *Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners and Heat Pumps*. September 30, 2016. https://www.cards.commerce.state.mn.us/CARDS/security/search.do?documentId=%7B881DD1B7-1FE4-495A-9FC0-F74A54B99CB6%7D
6. Code of Federal Regulations. 10 CFR Ch. II, § 430.32. https://www.govinfo.gov/content/pkg/CFR-2017-title10-vol3/pdf/CFR-2017-title10-vol3-sec430-32.pdf
7. FES scaled annual heating loads from those provided in the Illinois Technical Reference Manual based on Minnesota weather data.
8. Seventhwave. *TRM Implications from the CARD "Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps" study*. Memo from Seventhwave to MN DER. June 8, 2016.
9. P. Francisco et al. *Understanding Heating Seasonal Performance Factor for Heat Pumps*. 2004. https://aceee.org/files/proceedings/2004/data/papers/SS04_Panel1_Paper08.pdf. Comparing adjusted HSPF values in climate zone IV to zone V in Figures 3, 5, and 7 reveals a ratio of 85%.
10. C.K. Rice et al. *An Analysis of Representative Heating Load Lines for Residential HSPF Ratings*. July 2015. https://info.ornl.gov/sites/publications/files/Pub56184.pdf. Fig. B.4 shows an actual

HSPF approximately 15% less than rated HSPF for zone V, using the standard AHRI 210/240 load line.

Revision History

Version	Description	Author	Date
1.0	New spec to reflect standalone QI measure in DER Smart Measure Library	Joe Plummer	
1.1	Added wording to clarify how EER and SEER are calculated	Joe Plummer	
2.1	Changed energy savings equations arrangement	Franklin Energy Services	7/25/2012
2.2	Changed measure life	Franklin Energy Services	7/25/2012
2.3	Changed incremental cost	Franklin Energy Services	7/25/2012
2.4	Changed references	Franklin Energy Services	7/25/2012
2.5	Added incremental cost table	Franklin Energy Services	7/25/2012
2.6	Added to description, added missing customer/contractor inputs	Joe Plummer	3/25/2013
2.7	Add explanation of multifamily buildings under required customer/contractor inputs, corrected ASHP example calculation, added existing HSPF to Required Inputs (if program includes early replacements of working units.)	Joe Plummer	3/12/2014
2.8	Federal standard grace period note added	Joe Plummer	07/31/2014
3.0	Changed to EFLHHeat algorithm	Franklin Energy Services	11/12/2015
3.1	Updated CF, adjusted HSPF for AHRI climate zone V	Cadmus	10/2019
3.2	Updated baseline SEER, EER, and HSPF	Cadmus	10/2020

Residential HVAC - Duct Sealing

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes) with residential type ducted heating or cooling systems
Actions	O&M
Required from Customer/Contractor	ΔCFM25 as measured in pressurized duct test, Cooling System SEER, Heating System HSPF, Duct Location, project location (county)
Version No.	1.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	$5 per CFM reduction (ΔCFM25DL) (Ref. 2)

Measure Description

Duct Sealing reduces the exfiltration of supply air and infiltration of return air. Sealing of duct work can be accomplished through application of mastic sealant or metal tape to or injection of fog sealant into the distribution system of homes with either central air conditioning or a ducted heating system. For application of mastic or tape the following minimum requirements should be completed.

- Plenum, main ducts, takeoffs and boots must be sealed.
- Post-project carbon monoxide tests must be taken and adjustments made to heating system, until test results are within standard industry acceptable limits.
- In areas where mastic is the main source of sealing, thickness of mastic must be a minimum of 1/16th inch and a good faith effort must be made to remove existing duct tape and cover with mastic.

Algorithms

Unit kWh Savings per Year = ΔkWh_cooling + ΔkWh_heating

Unit Peak kW Savings = ΔCFM25DL/ (Size x 400) x Size x 12,000 x TRF_{cool} / 1000 / (ηDuct x EER) x CF

Unit Dth Savings per Year = ΔCFM25DL / (Btuh_in x 0.017) x EFLH_heat x Btuh_in / ηDuct x TRF_{Heat} / 1,000,000

Where:

ΔkWh_cooling = ΔCFM25DL/ (Size x 400) x $EFLH_{Cool}$ x Size x 12,000 x TRF_{Cool} / (ηDuct x SEER) / 1000

ΔkWh_heating = For electrically heated homes: ΔkWh_heating = ΔCFM25DL/(Size x 400) x $EFLH_{Heat}$ x Size x 12000 x TRF_{Heat} / (ηDuct x (HSPF * C_{IV-V})) / 1000
For gas heated homes: ΔkWh_heating = (Unit Dth Savings per Year) x Fe x Conversion_Factor

ΔCFM25DL	=	Reduction in CFM25 as measured through blower testing of pressurized duct work.
12,000	=	Conversion factor for Btu/h to tons of refrigeration
400	=	nominal cfm per ton of refrigeration (Ref. 3)
$EFLH_{Cool}$	=	Equivalent Full Load Cooling Hours. See table 1.
TRF_{Cool}	=	Thermal Regain Factor for Cooling depending upon duct location. See Table 2.
SEER	=	Cooling efficiency of equipment. Assume 11.5 unless provided with other input from customer. (Ref. 6)
EER	=	SEER x 0.875 (Ref. 9)
Size	=	Capacity of AC, heat pump or electric resistance system in tons provided by the customer (1 ton = 12,000 Btu/h)
Btuh_in	=	rated input capacity of gas furnace in Btu/h provided by the customer
HSPF	=	the efficiency of the electric heating system provided by customer. See table 3 for default values depending upon heating system type. (Ref. 7)
C_{IV-V}	=	Conversion from rated HSPF to HSPF appropriate for AHRI climate zone V = 0.85 (Ref. 15, Ref. 16)
Fe	=	ratio of furnace electric usage to gas usage = 2.97% (Ref. 8)

Conversion_Factor = 293 kWh/Dth

0.017	=	Conversion of Heating Capacity to CFM (0.017 CFM / (Btu/hr)) (Ref. 10)
$EFLH_{Heat}$	=	Equivalent Full Load Heating Hours. See table 4. (Ref. 11)
TRF_{Heat}	=	Thermal Regain Factor for Heating depending upon duct location (see Table 2) (Ref. 5)
ηDuct	=	pre-duct sealing system distribution efficiency. Assume 89% if unknown. (Ref. 12)
CF	=	electric peak coincidence factor = 0.75 for cooling equipment with standard single-speed compressor, 0.9 for cooling equipment with variable-speed compressor (see Notes). If unknown use 0.75.

Example:

Duct sealing in single family home Climate Zone 3 crawl space with 2.5 ton SEER 14 AC and 60,000 btu/h input gas furnace with a reduction of 300 CFM25.

Unit kWH Savings per Year = 300 / (2.5 x 400) x 520 x 2.5 x 12,000 x 1.0 / (0.89 x 14) / 1000 + 38.3 x 0.0297 x 293 = 709 kWh

Unit kW Peak Savings = 300 / (2.5 x 400) x 2.5 x 12,000 x 1.0 / 1000 / (0.89 x 14 x 0.875) x 0.75 = 0.619 kW

Unit Dth Savings per Year = 300 / (60,000 x 0.017) x 1932 x 60,000 / 0.89 x 1.0 / 1,000,000 = 38.3 Dth

Deemed Input Tables

Table 1. Equivalent Full Load Cooling Hours ($EFLH_{Cool}$) by Climate Zone (Ref. 4)

Zone	Effective Full Load Cooling Hours	
	Single Family	Multifamily*
Zone 1 (Northern MN)	213	228
Zone 2 (Central MN)	379	473
Zone 3 (Southern MN/Twin Cities)	520	616

* Multifamily includes duplexes, townhomes, and buildings with 3 or more units

Table 2. Thermal Regain Factor (TRF) by Duct Location (Ref. 5)

Duct Location	TRF	
	Cooling, TRF_{cool}	Heating, TRF_{Heat}
Unfinished Basement (semi-conditioned)	0.0	0.40
Attic, Crawl Space, Outdoors (unconditioned)	1.0	1.0

Table 3. Electrical Heat System Efficiencies (Ref. 7)

Heat System Type	System HPSF
Heat Pump	7.3
Electric Resistance	1.0

Table 4. Equivalent Full Load Heating Hours ($EFLH_{Heat}$) by Climate Zone (Ref. 11)

Zone	Equivalent Full Load Heating Hours
Zone 1 (Northern MN)	2280
Zone 2 (Central MN)	2099
Zone 3 (Southern MN/Twin Cities)	1932

*Includes duplex, townhome, and multifamily buildings with 3 or more units for in unit furnaces.

Methodology and Assumptions

Measurements and corrections must be performed with standard industry tools and practices; it is recommended that the results be tracked by the efficiency program.

$EFLH_{Cool}$ data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

$EFLH_{Heat}$ were determined from Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{65,MN} / HDD_{65,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 5. Heating Degree Days and Design Temperature Difference

Geography	HDD65	DTD
Chicago, IL	6,339	73.5
MN Zone 1	9,833	92
MN Zone 2	8,512	86.5
MN Zone 3	7,651	84.5

Unknown efficiency determination for cooling is based upon the market dominant efficiency values over the measure life of the equipment.

Unknown efficiency determination for heating equipment is based upon recent federal standards and available equipment.

The percentage of fan energy consumption was determined using values for the North Region were applicable from: Table 5.5.1 Characteristics of Representative Residential Furnaces, Table 7.3.2 – Range of Adjusted Heating Loads for Each Furnace Product Class by Region, MMBtu/y; Table 7.3.3 – Range of Baseline Furnace Heating Hours Annual Burner Operating Hours for Each Furnace Product Class, hours; Table 7B.3.1 Furnace Fan Motor Power Consumption by Product Type and Furnace Fan Size, watts from the reference noted.

Pre-sealing duct efficiency assumes greater than 90% of duct work is contained within the building envelop and some observable leaks are present.

Notes

Duct sealing cost may vary depending on contractor's procedure.

The value for coincidence factor is derived from a 2016 CARD study (Ref. 13) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 14) that recommended coincidence factor be reduced from 90% to 75%. Because the

previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

References

1. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, June 2007.
2. FES calculated from nominal leakage rate of 30% ("New duct-sealing law could save homeowners big bucks this fall", News Release, California Energy Commission), average cost $1250 ("Duct Sealing", Maryland Home Performance with Energy Star) and nominal central air conditioning size of 2.5 tons ("Central Air Conditioning in Wisconsin", Scott Pigg, Focus on Energy & Energy Center of Wisconsin).
3. Rule of Thumb: http://www.hvacsalesandsupply.com/Linked%20Documents/Tech%20Tips/61-Why%20400%20CFM%20per%20ton.pdf
4. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012.
5. Home Energy Services Impact Evaluation, prepared for the Massachusetts Residential Retrofit and Low Income Program Area Evaluation, Cadmus Group, Inc., August 2012.
6. Energy Center of Wisconsin, May 2008; "Central Air Conditioning in Wisconsin, A Compilation of Recent Field Research."
7. Based average of split system efficiencies meeting the Minimum Federal Standards for 1994 & 2008.
8. Table 7.3.14, Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Furnaces, 2/10/2015, DOE. Ratio of electrical energy (converted to MMBtu) to gas energy in MMBtu, averaged across all efficiency levels, for North region.
9. ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment. This value is given as a SEER and is modified as EER = 0.875 x SEER
10. Determined from values in Table 5.5.1 Characteristics of Representative Residential Furnaces, Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Furnaces, 2/10/2015, DOE.
11. FES scaled annual heating loads from those provided in the Illinois Technical Reference Manual based on Minnesota weather data.

12. Building Performance Institute, Inc., 11/20/2007, Distribution Efficiency look- Up Table, Building Performance Institute Technical Standards for the Heating Professional.
13. Seventhwave. *Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners and Heat Pumps*. September 30, 2016. https://www.cards.commerce.state.mn.us/CARDS/security/search.do?documentId=%7B881DD1B7-1FE4-495A-9FC0-F74A54B99CB6%7D
14. Seventhwave. *TRM Implications from the CARD "Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps" study*. Memo from Seventhwave to MN DER. June 8, 2016.
15. P. Francisco et al. *Understanding Heating Seasonal Performance Factor for Heat Pumps*. 2004. https://aceee.org/files/proceedings/2004/data/papers/SS04_Panel1_Paper08.pdf. Comparing adjusted HSPF values in climate zone IV to zone V in Figures 3, 5, and 7 reveals a ratio of 85%.
16. C.K. Rice et al. *An Analysis of Representative Heating Load Lines for Residential HSPF Ratings*. July 2015. https://info.ornl.gov/sites/publications/files/Pub56184.pdf. Fig. B.4 shows an actual HSPF approximately 15% less than rated HSPF for zone V, using the standard AHRI 210/240 load line.

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	11/12/2015
1.1	Updated CF, adjusted HSPF for AHRI climate zone V	Cadmus	10/2019

Residential HVAC - ECM Blower Motors

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family/multi-family homes, duplexes, and townhomes
Actions	Replace Working, Modify
Required from Customer/Contractor	Central AC present (yes/no, furnace AFUE)
Version No.	2.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	9 years (Ref. 6)
Unit Participant Incremental Cost	$475 (Ref. 3)

Measure Description

This measure is the retrofit of a less efficient (PCS) motor to a 2 stage BPM or ECM motor in an existing furnace. The target age range for existing furnaces is 10-12 years. This measure characterizes only the electric savings associated with the fan.

Savings improve when the blower is used for cooling as well and when it is used for continuous ventilation, but only if the non-ECM motor would have been used for continuous ventilation too.

New standards for residential furnace blower motor fans (Ref. 8) require the incorporation of ECMs, thereby making ECMs the baseline. Accordingly, this measure does not apply to new construction or replace on fail actions.

Algorithms

Unit kWh Savings per Year = Heating Savings + Cooling Savings + Shoulder Season Savings

Unit Peak kW Savings = Cooling Watts Savings * CF/1000

Unit Dth Savings per Year = -Heating Savings * 0.003412 / AFUE

Where:

Heating Savings = 126 kWh (Ref. 4)

Cooling Savings = 68 kWh if AC is present (Ref. 5) , = 0 if no AC is present

Shoulder Season Savings = 54 kWh (Ref. 7)

Cooling Watts Savings = Cooling Watts Saved = 220 if retrofit of single speed PSC motor and AC is present (Ref. 3) , = 0 if no AC is present

CF	=	Coincidence factor = 0.75 for cooling equipment with standard single-speed compressor, 0.9 for cooling equipment with variable-speed compressor (see Notes). If unknown use 0.75.
0.003412	=	Converts kWh to Dth
AFUE	=	Efficiency of Furnace provided by customer. If unknown assume 80%

Example:

An ECM blower is installed in place of an existing single speed PSC motor in a home where central AC is present and AFUE of furnace is unknown.

Unit kWh Savings per Year = 126 + 68 + 54 = 248 kWh

Unit Peak kW Savings = 220 * 0.75/1000 = 0.165 kW

Unit Dth Savings = -126 * 0.003412 / 0.8 = -0.54 Dth

Methodology and Assumptions

All the assumptions were made based on furnaces analysis in Wisconsin described in study "PA Consulting Group/Patrick Engineering Residential Deemed Savings Review for Focus on Energy, 2009" (Ref. 1) and the values were adapted for Minnesota.

Notes

The value for coincidence factor is derived from a 2016 CARD study (Ref. 2) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 9) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

References

1. PA Consulting Group/Patrick Engineering Residential Deemed Savings Review for Focus on Energy, 2009
2. Seventhwave. *Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners and Heat Pumps*. September 30, 2016. https://www.cards.commerce.state.mn.us/CARDS/security/search.do?documentId=%7B881DD1B7-1FE4-495A-9FC0-F74A54B99CB6%7D
3. “Evaluation of Retrofit Variable-Speed Furnace Fan Motors”, R. Aldrich and J. Williamson, Consortium for Advanced Residential Buildings, January 2014
4. Ibid. The Evaluation referenced noted a difference of 126 Watts. Over the course of 1000 hour heating system, “Electricity Savings from Variable-Speed Furnaces in Cold Climates”, Scott Pigg,

Energy Center of Wisconsin and Tom Talerico, Glacier Consulting Group, the kWH savings = 126 Watts* 1000 hrs / 1000 W/KW = 126 KWh.

5. Ibid. The Evaluation referenced noted a difference of 220 Watts. Over the course of 310 hour cooling system, "State of Wisconsin Public Service Commission, Focus on Energy Evaluation, Residential Programs: CY09 Deemed Savings Review", March 26, 2010, the kWH savings = 220 Watts* 310 hrs / 1000 W/KW = 68 KWh.
6. Massachusetts Common Assumption: The early replacement measure life of 9 years was determined by subtracting the estimated target age range of existing equipment between 10 and 12 years old from the 20 year measure life for new equipment.
7. Modified by the ratio of Watt savings 422 watts (Ref. 4) / 400 watts (Ref. 1) x 51 KWh = 54 KWh.
8. Electronic Code of Federal Regulations. Title 10, Chapter II, Subchapter D, Part 430, Subpart C, §430.32. https://www.ecfr.gov/cgi-bin/text-idx?SID=a9921a66f2b4f66a32ec851916b7b9d9&mc=true&node=se10.3.430_132&rgn=div8
9. Seventhwave. *TRM Implications from the CARD "Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps" study*. Memo from Seventhwave to MN DER. June 8, 2016.

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	7/31/2012
1.1	Added additional output to Cooling Savings input that cooling savings = 0 if central AC installed as part of project.	Joe Plummer	4/1/2013
1.2	Removed project location and AFUE from required inputs from customer/contractor, removed Table 1 (EFLH by zone- not needed)	Joe Plummer	3/2/2014
1.3	Added retrofit option. Corrected cooling watt savings and calculations.	Franklin Energy Services	12/23/2014
1.4	Moved seasonal savings into a deemed input table, updated example description	Joe Plummer	2/2/2015
2.0	Included interactive effect of negative Dth gas savings and aligned % of homes with CAC with lighting measure assumptions	Franklin Energy Services	11/12/2015
2.1	Removed replace on fail and new construction actions consistent with new federal standards	Cadmus	10/2018
2.2	Updated CF	Cadmus	10/2019

Residential HVAC - ECM Circulators

Measure Detail	Measure Value
Target Market Segments	Residential and Multi-family
Target End Uses	Pumps
Applicable To	Residential and multi-family customers
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Motor wattage, motor application
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$6 per Watt (Ref. 2)

Measure Description

Electronically commutated (EC) circulators (pumps) are high-efficiency brushless DC motors. They are typically fractional horsepower motors that enjoy several benefits over the more common permanent split capacitor (PSC) fractional horsepower motor.

Algorithms

Unit kWh Savings per Year = kWbase x tbase - kWECM x tproposed

Unit Peak kW Savings = (kWbase - kWECM) x CF

Where:

kWbase = kWECM / 18% (Ref. 3)

kWECM = 0.050 kW, 0.250 kW, 0.700 kW (Ref. 4)

tbase = See Table 1

tproposed = See Table 1

CF_DHW = 1.0 (Ref. 5)

CF_CW = 0.299 (Ref. 6)

CF_HW = 0

Example:

A customer installed a new 250W ECM pump on their domestic hot water heater.

Unit kWh Savings per Year = 0.250 kW / 18% x 4,000 hours - 0.250 kW x 2,190 hours = 5,008 kWh

Unit Peak kW Savings = (0.250 kW / 18% - 0.250 kW) x 1.0 = 1.140 kW

Deemed Input Tables

Table 1. Annual Operating Hours

Annual Hours	DHW Circulator (Ref. 7, 8)	Heating Water Circulator (Ref. 9)	Cooling Water Circulator (Ref. 10)
Baseline	4,000	2,582	1,191
Proposed	2,190	2,582	1,191

Table 2. Coincident Peak Impact

EC Motor Size	DHW Circulator	Heating Water Circulator	Cooling Water Circulator
< 100 W	0.228 kW	0.000 kW	0.068 kW
100 - 500 W	1.139 kW	0.000 kW	0.341 kW
500 - 750 W	3.189 kW	0.000 kW	0.953 kW

Table 3. Estimated Energy Savings

EC Motor Size	DHW Circulator	Heating Water Circulator	Cooling Water Circulator
< 100 W	1,002 kWh	588 kWh	271 kWh
100 - 500 W	5,008 kWh	2,941 kWh	1,356 kWh
500 - 750 W	14,023 kWh	8,234 kWh	3,798 kWh

Methodology and Assumptions

Pump motor must be EC, DC brushless, or permanent magnet style

Pump motor must be capable of variable speed operation

Motor must include integrated “smart” controls that will modulate flow based on demand

Motor must be < 1 hp

References

1. Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems. January 2001. Page 4. Accessed 6/11/14. https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/pumplcc_1001.pdf.
2. These values are based on $29/gpm for ECM pumps and $12/gpm for PSC pumps. Costs are found in Wilo's Price Book - Pumps and systems for Building Services and Groundwater. Accessed 6/10/2014. http://www.wilo-usa.com/fileadmin/us/Price_Pages/2014_Wilo_Price_Book_BS.GW_20-44-004-0614.pdf.
3. The Cadmus Group, Inc. Impact Evaluation of the 2011–2012 ECM Circulator Pump Pilot Program. October 18, 2012. Table 2. Pump Spot Measurements.
4. General sizes chosen to represent given size ranges.

5. Assumes baseline pump would be operating during the peak period. Franklin Energy Services.
6. Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 2.0, June 7, 2013, page 235.
7. Estimate based on EPRI Report Assessment of New Energy Efficient Circulator Pump Technology (40%*8,760 hr = 3,504 hr) and recommendation by Grundfos representatives (60%*8,760 hr = 5,256 hr).
8. Hours of use for pumps with an aqua-stat control in multi-family applications (6 hr/d * 365 d = 2,190 hr). DHW Recirculation System Control Strategies, Final Report 99-1. NYSERDA, January 1999. Page 3-30. http://www.emra.com/NYSERDA%20DHW%20Report%2099-1%20(Recirc%20Control)%20(a5-0).pdf.
9. Estimated based on an average of HDD65. Hours = HDD65*24/(70°F-Design Temps).
10. Estimated based on an average of CDD65. Hours = CDD65*24/(Design Temps-70°F).

Revision History

Version	Description	Author	Date
1.0	Measure created	Franklin Energy Services	11/10/2015

Residential HVAC - Electronic Ignition Hearth

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes) with residential type heating equipment
Actions	Replace on Failure, Replace Working
Required from Customer/Contractor	None
Version No.	1.2
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$193 (Ref. 1)

Measure Description

This measure includes replacement of existing hearth/artificial fireplace using a standing pilot with a unit using electronic ignition.

Algorithms

Unit Dth Savings per Year = P/CF x t

Where:

P = Pilot rate in Btu/h, assumed to be 1,000 Btu/h (Ref. 2,3)

CF = Conversion factor, CF=1,000,000 Btu/Dth

T = Unit usage, in hrs/year, assumed to be 24 hours x 182.5 days/year = 4,380

Example:

An electronic ignition for fireplace installation. Fireplace is used 24 hrs/day, 182.5 days/year.

Unit Dth Savings per Year = 1000/1000000*24*182.5 = 4.38

Notes

Electronic ignition is difficult to install on existing systems and should be undertaken only by someone who is very experienced in this type of work.

References

1. Online survey and discussion with suppliers and manufacturers
2. Pilot lights add small increase to gas bill, Clark County Public Utilities, March 26, 2006
3. Canadian study Home Energy Magazine, January/February 1997

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	8/14/2012
1.1	Changed name to Electronic Ignition Hearth	Joe Plummer	4/3/2013
1.2	Made P and t deemed values	Joe Plummer	4/3/2013

Residential HVAC - ENERGY STAR Dehumidifiers

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Unit capacity (pints per day)
Version No.	4.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$50 for units < 75 pints/day, $35 for units 75-185 pints/day (Ref. 1)

Measure Description

This measure includes installation of a new ENERGY STAR Dehumidifier or replacement of an old dehumidifier with an ENERGY STAR unit.

Algorithms

Unit kWh Savings per Year = CAP * 0.473 / 24 * HOU * (1 / EF_{BASE} - 1 / EF_{EFF})

Unit Peak kW Savings = Unit kWh Savings per Year / HOU * CF

Where:

CAP	=	Capacity of the unit in pints/day. CAP = 50 pints/day if unknown
0.473	=	Liters/pint conversion factor
HOU	=	1,933 hours/year, run hours per year (Ref. 2, see Notes)
EF_{BASE}	=	Energy factor (liters of water removed per kWh) of baseline standard efficiency unit, as provided in Table 1 below
EF_{EFF}	=	Energy factor (liters of water removed per kWh) of new ENERGY STAR unit, as provided in Table 2 below
CF	=	0.6, Coincidence Factor (Ref. 2, see Notes)

Example:

Install an ENERGY STAR dehumidifier with a capacity of 50 pints/day.

Unit kWh Savings per Year = 50 * 0.473 / 24 * 1,933 * (1 / 1.6 - 1 / 1.8) = 132.3

Unit Peak kW Savings = 132.3 / 1,933 * 0.6 = 0.041

Deemed Input Tables

Table 1. Federal Standard and ENERGY STAR Criteria (Ref. 3, Ref. 4)

Capacity (Pints/Day)	Federal Standard Criteria (L/kWh)	ENERGY STAR Criteria (L/kWh)
≤ 25	≥ 1.30	≥ 1.57
> 25 to ≤50	≥ 1.60	≥ 1.80
> 50	≥ 2.80	≥ 3.30

Notes

To qualify for this measure, the new dehumidifier must meet the ENERGY STAR standards.

Qualifying units shall be equipped with an adjustable humidistat control or shall require a remote humidistat control to operate.

For its study of dehumidifier use in Minnesota (Ref. 2), Center for Energy and Environment metered energy use, run time, and condensate production of 23 dehumidifiers at 20 sites. These sites were selected based on criteria developed from a statewide phone survey, including HVAC system characteristics, dehumidifier equipment details, and behavioral and operational details specified by occupants. Though not called out in the study text, the metering showed average HOU of 1,933 hours across the sites. The metering also showed coincidence factors varying by month, measured as the average hourly power divided by the sum of maximum power across the fleet of dehumidifiers. These coincidence factors were 0.29, 0.54, 0.66, 0.59, and 0.42 for May, June, July, August, and September respectively. A value of 0.6 is used here. While the metering also showed considerably poorer performance than ratings would indicate, this poorer performance translated largely to lower condensate production and not to increased total energy use.

References

1. Savings Calculator for ENERGY STAR Qualified Appliances. https://www.energystar.gov/ia/partners/promotions/cool_change/downloads/CalculatorConsumerDehumidifier.xls. Accessed 09/20/16.
2. Center for Energy and Environment. *Portable Dehumidification in Minnesota Single-Family Homes*. September 23, 2020. https://mn.gov/commerce-stat/pdfs/20210421_cee_dehumidification.pdf
3. Electronic Code of Federal Regulations. Title 10, Part 430, Subpart C, §430.32. https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-430/subpart-C/section-430.32
4. ENERGY STAR Program Requirements for Dehumidifiers. Version 5.0. https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Dehumidifiers%20Version%205.0%20Program%20Requirements.pdf

Revision History

Version	Description	Author	Date
3.0	Removed old federal efficiency criteria tables.	Franklin Energy Services	1/16/2016
3.1	Updated ES values, notes, and example. Updated incremental cost. Added future energy standard information.	Franklin Energy Services	8/19/2016
4.0	Updated federal and ENERGY STAR criteria, and HOU and CF	Cadmus	9/2021

Residential HVAC - ENERGY STAR Room A/C

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes and multi-family homes (including 3- and 4-unit buildings), including duplexes and townhomes
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	New unit rated Btuh or tons, new unit EER, new unit type (side louvers or no side louvers), building type (single family/multifamily*), project location (county) * Multifamily includes duplexes, townhomes, and 3 or more unit buildings
Version No.	2.7
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	9 (Ref. 1)
Unit Participant Incremental Cost	See Table 5

Measure Description

This measure includes the replacement of failed or working room air conditioners in residential homes, as well as installation of high efficiency room air conditioners in new homes.

Algorithms

Unit kWh Savings per Year = ΔkW x Hrs

Unit Peak kW Savings = CF x ΔkW

Where:

ΔkW	=	Btuh x (1/CEER_base - 1/CEER_eff) / 1000
Btuh	=	Cooling capacity of air-conditioner in Btu/h, provided by customer. If given in tons, 1 cooling ton = 12,000 Btuh.
CEER_base	=	Federal minimum standard combined energy efficiency ratio (CEER) of air-conditioner. Refer to Table 1.
CEER_eff	=	Combined energy efficiency ratio (CEER) of new ENERGY STAR room A/C. Refer to Table 1.
Hrs	=	Equivalent full load cooling hours. Refer to Table 4.
CF	=	Peak coincidence factor = 0.75 (see Notes)

Example:

A 1-ton (12,000 Btuh), 12.0 CEER ENERGY STAR-rated window air conditioner without reverse cycle is installed in a Climate Zone 1 Single-Family home.

CEER_Base = 10.9

ΔkW = 12,000 x (1/10.9 - 1/12.0) / 1000 = 0.101 kW

Electric Energy Savings (kWh/yr) = 0.101 x 213 = 21.495 kWh

Electric Peak Demand Savings (kW) = 0.101 x 0.75 = 0.076 kW

Deemed Input Tables

Table 1. Baseline and high efficiency CEER ratings for units without reverse cycle. (Ref. 3, 6)

Capacity (Btu/h)	Window Units (w/ louvered sides)		Sleeve Units (w/o louvered sides)	
	Federal Minimum Efficiency, CEER	ENERGY STAR Efficiency, CEER	Federal Minimum Efficiency, CEER	ENERGY STAR Efficiency, CEER
< 6,000	11.0	12.1	10.0	11.0
6,000 to 7,999	11.0	12.1	10.0	11.0
8,000 to 10,999	10.9	12.0	9.6	10.6
11,000 to 13,999	10.9	12.0	9.5	10.5
14,000 to 19,999	10.7	11.8	9.3	10.2
20,000 to 27,999	9.4	10.3	9.4	10.3
≥ 28,000	9.0	9.9	9.4	10.3

Table 2. Baseline and high efficiency CEER ratings for units with reverse cycle. (Ref. 3, 6)

Capacity (Btu/h)	Window Units (w/ louvered sides)		Sleeve Units (w/o louvered sides)	
	Federal Minimum Efficiency, CEER	ENERGY STAR Efficiency, CEER	Federal Minimum Efficiency, CEER	ENERGY STAR Efficiency, CEER
< 14,000	NA	NA	9.3	10.2
≥ 14,000	NA	NA	8.7	9.6
< 20,000	9.8	10.8	NA	NA
≥ 20,000	9.3	10.2	NA	NA

Table 3. Baseline and high efficiency CEER ratings for casement units. (Ref. 3)

Capacity (Btu/h)	Window Units	
	Federal Minimum Efficiency, CEER	ENERGY STAR Efficiency, CEER
Casement-Only	9.5	10.5
Casement-Slider	10.4	11.4

Table 4. Effective full load cooling hours (Ref. 4)

Building Type	Zone 1	Zone 2	Zone 3
Single Family	213	379	520
Multi Family*	228	473	616

* Multifamily includes duplexes, townhomes, and 3 or more unit buildings

Table 5. Incremental Cost by Capacity (Ref. 5)

Capacity (Btu/h)	Incremental Cost
< 6,000	$19.00
6,000 to 7,999	$27.00
8,000 to 13,999	$43.00
14,000 to 19,999	$66.00
>= 20,000	$85.00

Methodology and Assumptions

EFLH_Cool data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Notes

There are currently federal efficiency standards in place for room air conditioners. See Table 1 above for details.

ENERGY STAR Room Air Conditioners are required to be at least 10% more energy efficient than the minimum federal government standards.

The value for coincidence factor is derived from a 2016 CARD study (Ref. 2) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 7) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

References

1. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values, October 10, 2008
2. Seventhwave. *Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners and Heat Pumps*. September 30, 2016.

https://www.cards.commerce.state.mn.us/CARDS/security/search.do?documentId=%7B881DD1B7-1FE4-495A-9FC0-F74A54B99CB6%7D

3. ENERGY STAR® Program Requirements, Product Specification for Room Air Conditioners. https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Draft%20Version%204.1%20Room%20Air%20Conditioners%20Specification.pdf.
4. Calculated through energy modeling by FES 2012
5. Costs are averaged from vendor pricing for typical models meeting these criteria.
6. Title 10, Code of Federal Regulations, Part 430 - Energy Conservation Program For Consumer Products. https://www.ecfr.gov/cgi-bin/text-idx?rgn=div8&node=10:3.0.1.4.18.3.9.2
7. Seventhwave. *TRM Implications from the CARD "Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps" study*. Memo from Seventhwave to MN DER. June 8, 2016.

Revision History

Version	Description	Author	Date
2.3	Updated to new Federal and ENERGY STAR standards, updated incremental costs	Franklin Energy Services	7/31/2014
2.4	Removed mention of existing unit in example, adding EER_Eff to Required Inputs	Joe Plummer	7/31/2014
2.5	Updated ENERGY STAR standards, example, and notes	Franklin Energy Services	8/25/2016
2.6	Corrected CEER ratings table, added CEER ratings tables for units with reverse cycle and casement units	Cadmus	10/2018
2.7	Updated CF	Cadmus	10/2019

Residential HVAC - Furnace Quality Installation/Maintenance

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes) with residential type furnaces
Actions	O&M, Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Input Btu/h for existing and new furnace, nameplate AFUE of existing and new furnaces, test-in conversion efficiency, test-out conversion efficiency, project location (county)
Version No.	1.1
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 years if Replace on Fail, New Construction, or Replace Working; 10 years if O&M (Ref. 3)
Unit Participant Incremental Cost	Field Testing/Verification Labor + Incremental Equipment/Installation Cost if new furnace installed. See Table 2a and 2b.

Measure Description

This measure characterizes the impact of quality maintenance (QM) and quality installation (QI) practices performed by a qualified HVAC professional on gas forced-air furnace energy consumption. The measure is based on the HVAC SAVE® program (System Adjustment and Verified Efficiency).

1. For each tune-up or new installation, a contractor must perform the following actions in addition to a standard "clean and check":
2. Determine manufacturer's expected capacity based on current conditions. This includes determining the gas flow rate by clocking the gas meter.
3. With equipment running, measure the temperature difference across the heat exchanger. Adjust airflow to manufacturer's rated temperature range.
4. Measure dry bulb temperature at the equipment.
5. Measure dry bulb temperature at three grilles and registers.
6. Enter measurements in steps 2, 3, and 4, plus outdoor temperature and elevation into M&V software to determine score (conversion efficiency).

Electrical energy impacts may result from airflow adjustments or duct sealing but are not included in this characterization.

Algorithms

Unit Dth Savings per Year = Btuh_EE x LF x EFLH x AFUE_EE x (1/(AFUE_base x CE_base) - 1/(AFUE_prop x CE_EE)) / C

Where:

Btuh_EE	=	the nominal rating of the input capacity of the proposed furnace in Btu/h. If equipment is not being replaced, then use input capacity of the existing equipment.
LF	=	the load factor, assumed to be 0.77 (implies 30% oversizing) (Ref. 2) AFUE_base = Nameplate efficiency of the existing furnace. If Replace on Fail = 80%. If New Construction baseline efficiency = 90% (Ref. 4).
AFUE_EE	=	Nameplate efficiency of the proposed furnace. If furnace is not being replaced, then AFUE_EE = AFUE_base.
CE_base	=	Test-in conversion efficiency of existing furnace. A formula for conversion efficiency is provided in Methodology and Assumptions.
CE_EE	=	Test-out conversion efficiency of proposed furnace. A formula for conversion efficiency is provided in Methodology and Assumptions.
EFLH	=	Effective full load heating hours. See Table 1.
C	=	conversion factor from Btu to Dth, 1,000,000 Btu/Dth.

Examples:

Example 1: Quality maintenance is performed on a 60,000 Btu/h, 80% AFUE furnace in single-family home located in Climate Zone 3. The test-in conversion efficiency is calculated as 70%. The test-out conversion efficiency is calculated as 90%.

Unit Dth Savings per Year = (60000 x 0.77 x 1956 x 0.80 x (1/(0.80 x 0.70) - 1/(0.80 x 0.90)))/1000000 = 28.7

Example 2: Install a 60,000 Btu/h, 95% AFUE furnace in a single-family home located in Climate Zone 1. The existing furnace is a working 80,000 Btu/h, 80% AFUE furnace. The test-in conversion efficiency of the existing furnace is calculated as 75%. The test-out conversion efficiency is calculated as 88%.

Unit Dth Savings per Year = 60000 x 0.77 x 2245 x 0.95 x (1/(0.80 x 0.75) - 1/(0.95 x 0.88))/1e6 = 46.4

Example 3: Install a 60,000 Btu/h, 97% AFUE furnace in a new single-family home located in Climate Zone 2. The test-out conversion efficiency is calculated as 98%.

Unit Dth Savings per Year = 60000 x 0.77 x 2099 x 0.97 x (1/(0.90 x 0.72) - 1/(0.97 x 0.98))/1000000 = 46.2

Deemed Input Tables

Table 1. Effective Full Load Heating Hours by Climate Zone (Ref. 7)

Zone	Equivalent Full Load Heating Hours
Zone 1 (Northern MN)	2280
Zone 2 (Central MN)	2099
Zone 3 (Southern MN/Twin Cities)	1932

Table 2a. Estimated field testing and verification labor costs (Ref. 6)

Job Type	Labor
Tune-up (O&M)	$170
Replace Working	$170
Replace on Fail or New Construction	$78

Table 2b. Incremental Equipment and Installation Costs (Ref. 5)

New Furnace Efficiency	Existing Home	New Construction
AFUE ≥ 90% and < 92%	$630	$0
AFUE ≥ 92% and < 94%	$802	$172
AFUE ≥ 94%	$1,438	$636

Methodology and Assumptions

The savings algorithm is based on measurement of conversion efficiency at "test in" and "test out". Conversion efficiency is defined as:

Actual Btuh output / Theoretical Btuh output = (1.08 x CFM x ΔT) / (Installed Input Btu/h x AFUE)

Where:

CFM = airflow across the heat exchanger in cubic feet per minute

ΔT = temperature rise across the heat exchanger in ˚F

Installed Btu/h = Btu/h measured by clocking the gas flow rate

AFUE = nameplate annual fuel utilization efficiency

Baseline or "test in" conversion efficiency (CE_base) is a measured parameter using the formula above for early replacements (Replace Working) or tune-ups of existing equipment (O&M). In the case of replacement of failed equipment (Replace on Fail) or New Construction, a deemed value for CE_base is provided under Algorithms. This value is based on a field testing results for over 500 homes in Iowa (see Ref. 1).

An assumed value for proposed or "test out" conversion efficiency (CE_prop) is provided based on a different sample of Iowa HVAC SAVE homes (see Ref. 1) for planning purposes. However, it is strongly recommended that a measured CE_prop be used for each installation for calculating actual savings.

Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{65,MN} / HDD_{65,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 3. Heating Degree Days and Design Temperature Difference

Geography	HDD65	DTD
Chicago, IL	6,339	73.5
MN Zone 1	9,833	92
MN Zone 2	8,512	86.5
MN Zone 3	7,651	84.5

References

1. Assumed baseline conversion efficiency is drawn from a sample of 507 homes in Iowa field tested in 2011 and 2012. Assumed proposed conversion efficiency is drawn from a sample of 588 homes that participated in the HVAC SAVE program in Iowa in 2014 and 2015 and based on in-field verification and testing. Conversion efficiencies higher than 100 were excluded from the calculation.
2. PA Consulting, KEMA, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that boilers are 30% oversized on average.
3. A measure life of 20 years for Replace on Fail, Replace Working, and New Construction is based on: Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, Inc. June 2007
4. A measure life of 9 years for O&M assumes that on average, tune-ups are performed at the midpoint of the equipment's lifespan (18 years).
5. The US Code of Federal Regulations, 10 CFR 430.32(e)(1)(i) defines a minimum AFUE of 78% for residential non-weatherized gas furnaces manufactured before November 19, 2015. On this date, the minimum AFUE changes to 80%. A baseline of 80% is used for Replace Working because there are very few models available below this efficiency; a review of AHRI shows that most low efficiency units are 80%.
6. A 90% AFUE baseline for new construction is based on a Minnesota Department of Commerce analysis from 2006 showing that the vast majority of furnaces installed in hew homes were 90% or higher.
7. Xcel Energy 2010-2012 CIP Triennial (Docket No. E,G002/CIP-09-198)
8. Incremental labor costs for QI/QM were derived from the following labor estimates.

Table 4. Field Time Estimates (Replace on Fail, New Construction)

	Required By Program	Required by OEM	Required SAVE Verification
Complete Rebate Form	Required		Required
M&V Software			15
Equipment Pressures (2)		5	5
Other Pressures (2)			5
Equipment Temps (2)		5	5
Duct Temperatures (7)			10
Clock Gas Meter		10	10
Verify CFM		5	5
Time Required (minutes)		25	55
Contractor Billable Rate		**$85.00**	**$85.00**
Measure Cost		**$35.42**	**$77.92**

Table 5. Field Time Estimates (Replace Working, O&M)

	Required By Program	Required SAVE Verification
Complete Rebate Form	Required	Required
M&V Software		25
Test-In (no room temps)		30
Reset Furnace by setting optimum air flow and tuning combusion		25
Test-Out (with room temps		40
		120
Contractor Billable Rate		**$85.00**
Measure Cost		**$170.00**

9. Calculated through energy modeling by FES

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	9/14/2015
2.0	Modified lifetime methodology	Franklin Energy Services	10/30/2015

Residential HVAC - Furnaces & Boiler Tune-Up

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes) with residential type furnace
Actions	O&M
Required from Customer/Contractor	Input Btu/h, project location (county), heating equipment type, building type
Version No.	3.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	2 (Ref. 1)
Unit Participant Incremental Cost	Unit Participant Incremental Cost = $175 (default/planning figure; OK to use actual cost of tune- up) (Ref. 2 TBD)

Measure Description

A furnace tune-up includes inspection/adjustment of the following components as performed by a qualified service technician:

- Burner(s) – clean per manufacturer's recommendations
- Pilot and Pilot Tube – clean per manufacturer's recommendations
- Flame Baffle – clean and adjust per manufacturer's recommendations
- Gas Pressure – adjust per manufacturer's recommendations
- Burner Air – adjust and set per manufacturer's recommendations
- Fan Control – verify operation per manufacturer's recommendations (furnace only)
- Heat Exchanger – clean and verify condition is per manufacturer's recommendations
- Gas piping and valves – verify configuration and condition are per manufacturer's recommendations
- Ignition System - verify operation per manufacturer's recommendations
- Combustion Chamber – verify condition is per manufacturer's recommendations
- Temperature Rise - verify operation per manufacturer's recommendations
- Blower system - verify condition and operation are per manufacturer's recommendations
- Wiring – replace/repair loose connections and verify conditions are per manufacturer's recommendations
- Air filtration system – clean per manufacturer's recommendations

- Flue & Venting - verify configurations and conditions are per manufacturer's recommendations
- Thermostat - verify operation per manufacturer's recommendations
- Safety Locks - verify operation per manufacturer's recommendations
- Final Operation - verify operation per manufacturer's recommendations

A boiler tune-up includes inspection/adjustment of the following components as performed by a qualified service technician:

- Burner(s) – clean per manufacturer's recommendations
- Pilot and Pilot Tube – clean per manufacturer's recommendations
- Flame Baffle – clean and adjust per manufacturer's recommendations
- Gas Pressure – adjust per manufacturer's recommendations
- Burner Air – adjust and set per manufacturer's recommendations
- Heat Exchanger – clean and verify condition is per manufacturer's recommendations
- Gas piping and valves – verify configuration and condition are per manufacturer's recommendations
- Ignition System - verify operation per manufacturer's recommendations
- Combustion Chamber – verify condition is per manufacturer's recommendations
- Temperature Rise - verify operation per manufacturer's recommendations
- Blower system - verify condition and operation are per manufacturer's recommendations (if applicable)
- Wiring – replace/repair loose connections and verify conditions are per manufacturer's recommendations
- Pumping system – verify correct operation
- Flue & Venting - verify configurations and conditions are per manufacturer's recommendations
- Thermostat - verify operation per manufacturer's recommendations
- Safety Locks - verify operation per manufacturer's recommendations
- Final Operation - verify operation per manufacturer's recommendations

Algorithms

Unit Dth Savings per Year = Btuh_input x Load_Factor x $EFLH_{Heat}$ / Conversion_Factor x MF

Where:

Btuh_in = the nominal rating of the input capacity of the furnace in Btu/h

Load_Factor = the load factor, assumed to be 0.77 (implies 30% oversizing) (Ref. 3)

$EFLH_{Heat}$ = Equivalent Full Load Hours of Heating. (Ref. 4)

Conversion_Factor = 1,000,000 Btu/Dth

MF = Maintenance saving factor. MF=2%. (Ref. 5)

Example:

Furnace Tune-up in single family home, 60,000 btu/h input, Climate Zone 3.

Unit Dth Savings per Year = 60000 x 0.77 x 1932 / 1000000 * 0.02= 1.79 Dth

Deemed Input Tables

Table 1. Equivalent Full Load Heating Hours ($EFLH_{Heat}$) by Climate Zone (Ref. 4)

Zone	Equivalent Full Load Heating Hours
Zone 1 (Northern MN)	2280
Zone 2 (Central MN)	2099
Zone 3 (Southern MN/Twin Cities)	1932

*Includes duplex, townhome, and multifamily buildings with 3 or more units

Methodology and Assumptions

Measurements and corrections must be performed with standard industry tools and practices; it is recommended that the results be tracked by the efficiency program.

$EFLH_{Heat}$ were determined from Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{65,MN} / HDD_{65,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 2. Heating Degree Days and Design Temperature Difference

Geography	HDD65	DTD
Chicago, IL	6,339	73.5
MN Zone 1	9,833	92
MN Zone 2	8,512	86.5
MN Zone 3	7,651	84.5

Notes

Actual tune-up cost may vary depending on contractor's tune-up procedure.

References

1. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, Inc. June 2007 http://www.ctsavesenergy.org/files/Measure%20Life%20Report%202007.pdf
2. TBD
3. PA Consulting, KEMA, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that boilers are 30% oversized on average.

4. FES scaled annual heating loads from those provided in the Illinois Technical Reference Manual based on Minnesota weather data.
5. FES determined by collection of results from over 125 projects completed through a Midwest energy project.

Revision History

Version	Description	Author	Date
1.0	Replaces furnace tune-up measure in ResidentialFurnaceMeasures_v01; changed algorithm to match commercial boiler tune-up	Joe Plummer	
1.1	Specified action, removed modification type from list of inputs from customer/vendor	Joe Plummer	
1.2	Corrected error so that cost of tune-up is an optional input, increased cost of tune-up to $200	Joe Plummer	
2.1	Changed savings equation	Franklin Energy Services	8/14/2012
2.2	Added Multi-family buildings to the measure	Franklin Energy Services	8/14/2012
2.3	Added efficiency standards	Franklin Energy Services	8/14/2012
2.4	Added references	Franklin Energy Services	8/14/2012
2.5	Changed wording of Btuh_input description	Joe Plummer	4/3/2013
3.0	Added Service Recommendations and changed algorithm format to EFLH and Boilers	Franklin Energy Services	11/12/2015

Residential HVAC - Furnaces and Boilers

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes) with residential type heating equipment
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Equipment type (furnace w/o ECM or boiler), Input Btu/h of new unit, project location (county), AFUE of the new equipment, Action Type (Replace on Fail, Replace Working, or New Construction), building type (single-family or duplex, multifamily*or townhome) * Multifamily includes buildings with 3 or more units.
Version No.	3.4
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	See Table 3

Measure Description

This measure includes replacement of failed or working furnaces and boilers in existing homes with high efficiency units, as well as installation of high efficiency furnaces and boilers in new residences. Electric kWh and kW savings are included only for furnaces with ECM blowers replacing a working unit—i.e. no electric savings for replace on failure or new construction (Ref. 10)

Algorithms

Unit kWh Savings per Year = Heating Savings + Cooling Savings + Shoulder Season Savings (for replaced working furnaces incorporating a Blower ECM motor)
= 0 (for boilers, furnaces not incorporating a Blower ECM motor, or for replace on failure or new construction furnaces)

Unit Peak kW Savings = Cooling Watts Savings x CF/1000 (for furnaces incorporating a Blower ECM motor)
= 0 (for boilers, furnaces not incorporating a Blower ECM motor, or for replace on failure or new construction furnaces)

Unit Dth Savings per Year = Btuh_in x Load_Factor x $EFLH_{Heat}$ x Eff_High x (1/Eff_Base - 1/Eff_high) / Conversion_Factor - Heating Savings x 0.003412 / Eff_High

Where:

Heating Savings = Blower ECM motor savings during heating season = 418 kWh (Ref 6.)

Cooling Savings = Blower ECM motor savings during cooling season. If central AC = 263 kWh. If no central AC = 175 kWh. If unknown = 251 kWh (Ref 7.) If new central AC installed as part of the project, cooling savings equal 0 (Ref. 8).

Shoulder Season Savings = Blower ECM motor savings during shoulder season = 51 kWh (Ref 6.)

Cooling Watts Savings = ECM motor Cooling Watts Saved = 73 (Ref. 6)

CF = Coincidence factor = 0.75 for cooling equipment with standard single-speed compressor, 0.9 for cooling equipment with variable-speed compressor (see Notes). If unknown use 0.75.

Btuh_in = the nominal rating of the input capacity of the new furnace or boiler in Btu/h

Load_Factor = the load factor, assumed to be 0.77 (implies 30% oversizing) (Ref. 2)

$EFLH_{Heat}$ = Effective Full Load Hours of Heating (Ref.3)

Eff_base = Efficiency of the baseline, i.e., standard replacement, equipment. Refer to Table 2. (Ref. 4)

Eff_high = Efficiency (AFUE) of the new furnace or boiler, supplied by customer/contractor.

Conversion_Factor = 1,000,000 Btu/Dth

0.003412 = Converts kWh to Dth

Example:

Retrofit replacing a working furnace installed in single family home, 97% AFUE furnace with a Blower ECM motor, 60,000 btu/h input, Climate Zone 3.

Unit kWh Savings per Year = 418 + 251 + 51 = 720

Unit Peak kW Savings = 73 * 0.75/1000 = 0.056

Unit Dth Savings per Year = 60,000 x 0.77 x 1,932 x 0.97 x (1/0.80 - 1/0.97) / 1,000,000 - 418 kWh x 0.003412 / 0.97 = 17.5Dth

Deemed Input Tables

Table 1. Equivalent Full Load Heating Hours ($EFLH_{Heat}$) by Climate Zone (Ref. 3)

Zone	Equivalent Full Load Heating Hours
Zone 1 (Northern MN)	2280
Zone 2 (Central MN)	2099
Zone 3 (Southern MN/Twin Cities)	1932

*Includes duplex, townhome, and multifamily buildings with 3 or more units

Table 2. Deemed baseline efficiency (Ref. 4)

Equipment Type	Baseline Efficiency	
	New Construction	Existing
Furnace	90%	80%
Boiler	82%	

Table 3. Incremental Costs (Ref. 5)

Equipment Type	Incremental Cost ($/unit)	
	New Construction	Existing
New furnace, AFUE = 91%	$33	$604
New furnace, AFUE = 92%	$66	$637
New furnace, AFUE = 94%	$132	$703
New furnace, AFUE = 95%	$165	$736
New furnace, AFUE = 96%	$379	$950
New furnace, AFUE ≥ 97%	$477	$1048
New boiler, AFUE ≥ 84% and < 90%	$1,446	
New boiler, AFUE ≥ 90% and <95%	$2,379	
New boiler, AFUE ≥ 95%	$3,001	

Methodology and Assumptions

A baseline AFUE of 90% is assumed for new construction furnaces. This follows from air tightness requirements forcing furnaces in new homes to have direct venting capability, and a survey of builders indicating that new homes and townhomes would have 90% AFUE furnaces installed without incentive (Ref. 11).

Assumes dedicated exhaust installation for furnaces and chimney liner for water heaters.

Notes

On May 1, 2013, federal standards prohibiting the sale or import of non-weatherized furnaces with AFUEs of less than 90% were set to take effect in the Northern Region (including MN). This standard has been postponed.

$EFLH_{Heat}$ were determined from Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{65,MN} / HDD_{65,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 4. Heating Degree Days and Design Temperature Differences

Geography	HDD65	DTD
Chicago, IL	6,339	73.5
MN Zone 1	9,833	92
MN Zone 2	8,512	86.5
MN Zone 3	7,651	84.5

AFUE does not include any electrical power savings.

Furnace costs are derived from data in the Itron report (Ref. 5) They assume an average size of 70,500 Btu/h, a 10% markup for ≥ 95 AFUE furnaces, and $300 additional installation costs for existing construction, due to the installation of venting.

The value for coincidence factor is derived from a 2016 CARD study (Ref. 9) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 12) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

Residential boilers have an AFUE requirement of 84% as of January 15, 2021. This will be applied as the baseline for the TRM version 3.3, along with an updated incremental cost.

References

1. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, Inc. June 2007. http://www.ctsavesenergy.org/files/Measure%20Life%20Report%202007.pdf
2. PA Consulting, KEMA, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that boilers are 30% oversized on average.
3. FES scaled annual heating loads from those provided in the Illinois Technical Reference Manual based on Minnesota weather data.
4. US Department of Energy federal minimum efficiency (https://www.ecfr.gov/cgi-bin/text-idx?SID=a9921a66f2b4f66a32ec851916b7b9d9&mc=true&node=se10.3.430_132&rgn=div8).
5. Itron. *2010-2012 WO017 Ex Ante Measure Cost Study Final Report*. May 27, 2014. Appendix F-1, page 3. http://www.calmac.org/publications/2010-2012_WO017_Ex_Ante_Measure_Cost_Study_-_Final_Report.pdf
6. PA Consulting Group/Patrick Engineering Residential Deemed Savings Review for Focus on Energy, 2009

7. The weighted average value is based on assumption that 75% of homes installing BPM furnace blower motors have central AC.
8. Energy use of blower motor during cooling season is reflected in the SEER of the new central AC.
9. Seventhwave. *Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners and Heat Pumps*. September 30, 2016. https://www.cards.commerce.state.mn.us/CARDS/security/search.do?documentId=%7B881DD1B7-1FE4-495A-9FC0-F74A54B99CB6%7D
10. US Department of Energy standard for residential furnace fans https://www.regulations.gov/document?D=EERE-2010-BT-STD-0011-0117
11. Minnesota Office of Energy Security. *Analysis, Recommendations, and Proposed Decision of the Staff of the Office of Energy Security*. Docket G008/CIP 09-644. https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId={13E7C0EF-4534-449F-AD49-8DAB9AFF01DF}&documentTi
12. Seventhwave. TRM Implications from the CARD "Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps" study. Memo from Seventhwave to MN DER. June 8, 2016.

Revision History

Version	Description	Author	Date
1.0	Replaces ResidentialFurnaceMeasures_v01, moved furnace tune-ups to a separate measure, updated baseline efficiencies to reflect decisions in 2010-2012 gas utility triennials	Joe Plummer, DER	
1.1	Added specifications for actions and needed from customer/vendor	Joe Plummer, DER	
1.2	Added missing incremental cost categories	Joe Plummer, DER	
2.1	Changed savings equation	Franklin Energy Services	7/25/2012
2.2	Added Multi-family buildings to the measure	Franklin Energy Services	7/25/2012
2.3	Added efficiency standards	Franklin Energy Services	7/25/2012
2.4	Added references	Franklin Energy Services	7/25/2012
2.5	Updated equipment costs	Franklin Energy Services	8/1/2013
2.6	Updated baselines and Federal standard comments due to the postponing of the furnace efficiency standard	Franklin Energy Services	8/1/2013
2.7	Updated baselines from 78% to 80%	Franklin Energy Services	8/1/2013
2.8	Added Action Type as Required Input from Customer/Contractor (determines existing or new construction which is needed to determine baseline efficiency)	JP	1/13/14

Version	Description	Author	Date
2.9	Added equipment type to required inputs from customer/contractor. Corrected example to use baseline efficiency of 0.80 instead of 0.78.	JP	3/4/14
3.0	Changed to $EFLH_{Heat}$ algorithm and added kWh and kW savings and heating penalty factors.	Franklin Energy Services	11/12/2015
3.1	Indicated fan savings are for furnaces with ECM motors only.	Franklin Energy Services	1/15/2016
3.2	Updated incremental costs. Removed ECM savings for replace on failure and new construction	Cadmus	10/2018
3.3	Updated CF	Cadmus	10/2019
3.4	Noted upcoming boiler baseline AFUE change	Cadmus	10/2020

Residential HVAC - Ground Source Heat Pump Systems

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes and multi-family homes consisting of 2 units or more where ground source heat pump equipment can be installed
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	1. Existing HVAC system type (ground source heat pump, electric heat with split system A/C) 2. Existing system size 3. Proposed system size 4. Proposed system heating COP 5. Proposed system cooling EER
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 years (Ref. 1)
Unit Participant Incremental Cost	See Measure Costs section

Measure Description

This measure includes replacement of non-working and working ground source heat pump (GSHP) equipment and replacement of non-working and working electric resistance and air conditioner equipment with ground source heat pump systems (GSHP).

Algorithms

Unit kWh Savings per Year = (Unit Heating kWh Baseline per Year + Unit Cooling kWh Baseline per Year) - (Unit Heating Proposed kWh per Year + Unit Cooling Proposed kWh per Year)

Unit Peak kW Savings = (Unit Cooling kWh Baseline per Year - Unit Cooling Proposed kWh per Year) / $EFLH_{cool}$ x CF

Proposed

Unit Heating Proposed kWh per Year = Size x (3.52 / Rated_COP_EE) x COP_Adjust x $EFLH_{HEAT}$

Unit Cooling Proposed kWh per Year = Size x (12 / Rated_EER_EE) x EER_Adjust x $EFLH_{COOL}$

Existing GSHP Baseline (Replace on Fail, Replace Working)

Unit Heating kWh Baseline per Year = Size x (3.52 / Rated_COP_Base) x COP_Adjust x $EFLH_{HEAT}$

Unit Cooling kWh Baseline per Year = Size x (12 / Rated_EER_Base) x EER_Adjust x $EFLH_{COOL}$

Electric Heat with Split System A/C Baseline (Replace on Fail, Replace Working)

Unit Heating kWh Baseline per Year = Size x 3.52 x $EFLH_{HEAT}$

Unit Cooling kWh Baseline per Year = Size x (12 / SEER_Base) x $EFLH_{COOL}$

New Construction Baseline

Unit Heating kWh Baseline per Year = HP% x [Size x (3.52 / Rated_COP_Base) x COP_Adjust x $EFLH_{HEAT}$] + ERH% x [Size x 3.52 x $EFLH_{HEAT}$]

Unit Cooling kWh Baseline per Year = Size x (12 / SEER_Base) x $EFLH_{COOL}$

Where:

Size = Heat pump or split system A/C capacity in tons (1 ton = 12,000 btu/h)

3.52 = unit conversion, tons to kW

1,000,000 = unit conversion, BTU per Dtherm

Rated_COP_Base = 3.1, rated COP in heating mode for the baseline ground source heat pump (Ref. 5)

Rated_COP_EE = actual rated COP in heating mode for the proposed ground source heat pump

Rated_EER_Base = 13.4, rated EER in cooling mode for the baseline ground source heat pump (Ref. 5)

Rated_EER_EE = actual rated EER in cooling mode for the proposed ground source heat pump

SEER_Base = 13.0, baseline split system A/C SEER (Ref. 6)

COP_Adjust = 81.6%, adjustment factor from rated COP to average COP (Ref. 3)

EER_Adjust = 89.1%, adjustment factor from rated EER to average EER (Ref. 3)

CF = Coincidence factor = 0.90, deemed coincidence factor (Ref. 10)

HP% = 22%, fraction of electrically-heated MN homes with heat pumps (Ref 11)

ERH% = 78%, fraction of electrically-heated MN homes with electric resistance heat (Ref 11)

Table 1. Equivalent Full Load Heating Hours ($EFLH_{Heat}$) by Climate Zone (Ref. 8)

Zone	Equivalent Full Load Heating Hours
Zone 1 (Northern MN)	2,280
Zone 2 (Central MN)	2,099
Zone 3 (Southern MN/Twin Cities)	1,932

*Includes duplex, townhome, and multifamily buildings with 3 or more units

Table 2. Equivalent Full Load Cooling Hours ($EFLH_{Cool}$) by Climate Zone (Ref. 9)

Zone	Equivalent Full Load Cooling Hours	
	Single Family	Multifamily*
Zone 1 (Northern MN)	213	228
Zone 2 (Central MN)	379	473
Zone 3 (Southern MN/Twin Cities)	520	616

*Includes duplex, townhome, and multifamily buildings with 3 or more units

Example:

A low efficiency ground source heat pump is being replaced by a high efficiency 2.5 ton model with COP of 4.2 and EER of 18 in a single family residential home in zone 2:

Heating savings = 2.5 tons x 2099 hours x 3.52 x (1 / 3.1 – 1 / 4.2) x 81.6% = 1273 kWh

Cooling savings = 2.5 tons x 379 hours x 12 x (1 / 13.4 - 1 / 18) x 89.1% = 193 kWh

Demand savings = 193 kWh / 379 hours x 0.9 = 0.459 kW

Notes

Proposed heat pump should meet Energy Star minimum requirements.

For multi-stage ground source heat pumps, average the highest and lowest EER and COP, per Energy Star guidelines (www.energystar.gov/index.cfm?c=geo_heat.pr_crit_geo_heat_pumps).

$EFLH_{Cool}$ data based on DOE2/eQUEST building simulation. The prototype building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

$EFLH_{Heat}$ were determined from Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{65,MN} / HDD_{65,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

HDD and DTD for MN Climate Zones

Geography	HDD65	DTD
Chicago, IL	6,339	73.5
MN Zone 1	9,833	92
MN Zone 2	8,512	86.5
MN Zone 3	7,651	84.5

Measure Costs

For Time of Sale, the incremental cost is $2,576 per ton for a ground source heat pump baseline, $1,946 per ton for a gas furnace baseline, and $414 per ton for a boiler baseline (Ref. 2). For New Construction,

the incremental cost is assumed to be an average of these costs, or $1,645. For Replace Working, incremental cost is the full cost of ground source heat pump, or $3,957 per ton (Ref. 2).

References

1. U.S. Department of Energy. Geothermal Heat Pumps. https://www.energy.gov/energysaver/heat-and-cool/heat-pump-systems/geothermal-heat-pumps. Measure life is up to 50 years for ground loop, 12 – 15 years for indoor components. EUL is deemed 25 years.
2. Illinois Stakeholder Advisory Group. Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 6.0, Volume 3. February 8, 2017. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf
3. Performance, Emissions, Economic Analysis of Minnesota Geothermal Heat Pumps, Michaels Energy for Minnesota Department of Commerce, April 2008. http://www.michaelsenergy.com/PDFs/Minnesota%20GHP.pdf
4. Personal communication with Eric O'Neil of Michaels Energy, 7/30/15. Eric provided HVAC capacity for the building types modeled in Ref. 3.
5. ASHRAE Standard 90.1-2010, Energy Standard for Buildings Except Low-Rise Residential Buildings, Table 6.8.1B, Ground Source Heat Pump 32°F entering water for heating, 77°F entering water for cooling.
6. Title 10, Code of Federal Regulations, Part 430 - Energy Conservation Program for Consumer Products, Subpart C, Section 430.32. January 1, 2013. http://www.gpo.gov/fdsys/pkg/CFR-2013-title10-vol3/pdf/CFR-2013-title10-vol3-sec430-32.pdf
7. US Department of Energy. Though the federal minimum efficiency is 78% there are very few models available at this efficient; a review of AHRI shows that most low efficiency units are 80%. http://buildingsdatabook.eere.energy.gov/ChapterIntro7.aspx
8. FES scaled annual heating loads from those provided in the Illinois Technical Reference Manual based on Minnesota weather data.
9. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012
10. 0.9 is a typical value used for central HVAC equipment in many programs. The range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.
11. Center for Energy and Environment. Data obtained for the 2020–2029 Minnesota Energy Efficiency Study show that 78% of Minnesota single-family homes with electric heat have electric resistance heating, and 22% have heat pump heating (approximately 8% air-source and 14% ground-source).

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	7/31/2015
2.0	Removed gas heating baseline, clarified electric heat with split A/C baseline, updated incremental costs	Cadmus	10/2018

Residential HVAC - Mini Split Ductless Systems A/C Only and Heat Pump

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers with < 65,000 Btu/hr cooling systems where mini-split ductless equipment (both cooling-only and heat pump versions) can be installed
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Existing HVAC system type (furnace with a split system air conditioner, air-source heat pump, electric heat with split system, or other thru-the-wall air condioner), mini-split system size, furnace system size (if applicable), proposed system heating HSPF, proposed system cooling SEER
Version No.	2.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	18 (Ref. 1)
Unit Participant Incremental Cost	Actual costs should be used. For planning purposes an averaged full installed cost was determined to be $2,500 per ton (Ref. 2)

Measure Description

This measure includes replacing non-working and working air-source heat pump equipment, electric resistance heating systems with split-system air conditioning systems, and electric mini-split ductless air conditioning or heat pump systems. Natural gas furnaces and delivered fuel are allowed as baseline conditions under specific circumstances. Electric utilities may provide direct space heating and domestic hot water energy savings measures to low-income delivered fuel customers and low-income small gas utility customers (non-CIP) offered in conjunction with the Weatherization Assistance Program (Ref 10).

Systems functioning as the primary heating and cooling system are applicable for savings and rebates. Back-up heating systems are not applicable. In circumstances where the mini-split heating system is installed in conjunction with an existing heating or cooling systems, the existing system must be controlled as the back-up heating or cooling.

Algorithms

Air-source heat pump baseline (not New Construction)

Unit kWh Savings per Year = Cap_{COOL} x 12 x $EFLH_{COOL}$ x (1 / $SEER_{BASE}$ - 1 / $SEER_{EE}$) + Cap_{HEAT} x 12 x $EFLH_{HEAT}$ x (1 / ($HSPF_{BASE}$ * C_{IV-V}) - 1 / ($HSPF_{EE}$ * C_{IV-V}))

Unit Peak kW Savings = Cap_{COOL} x 12 x (1 / EER_{BASE} - 1 / EER_{EE}) x CF

Electric resistance heat with air conditioner baseline (not New Construction)

Unit kWh Savings per Year = Cap_{COOL} x 12 x $EFLH_{COOL}$ x (1 / $SEER_{BASE}$ - 1 / $SEER_{EE}$) + Cap_{HEAT} x 12 x $EFLH_{HEAT}$ x (1 / $HSPF_{BASE,ERH}$ - 1 / ($HSPF_{EE}$ * C_{IV-V}))

Unit Peak kW Savings = Cap_{COOL} x 12 x (1 / EER_{BASE} - 1 / EER_{EE}) x CF

Electric resistance heat only baseline (not New Construction)

Unit kWh Savings per Year = Cap_{HEAT} x 12 x $EFLH_{HEAT}$ x (1 / $HSPF_{BASE,ERH}$ - 1 / ($HSPF_{EE}$ * C_{IV-V})) - Cap_{COOL} x 12 x $EFLH_{COOL}$ / $SEER_{EE}$

Unit Peak kW Savings = -Cap_{COOL} x 12 / EER_{EE} x CF

Natural gas furnace only baseline (not New Construction)

Unit kWh Savings per Year = -(Cap_{COOL} x 12 x $EFLH_{COOL}$ / $SEER_{EE}$ + Cap_{HEAT} x 12 x $EFLH_{HEAT}$ / ($HSPF_{EE}$ * C_{IV-V}))

Unit Peak kW Savings = -Cap_{COOL} x 12 / EER_{EE} x CF

Unit Dth Savings per Year = $Btuh_{IN}$ x $EFLH_{HEAT}$ / ($AFUE_{BASE}$ x 1,000,000)

Natural gas furnace and air conditioner baseline (not New Construction)

Unit kWh Savings per Year = Cap_{COOL} x 12 x $EFLH_{COOL}$ x (1 / $SEER_{BASE}$ - 1 / $SEER_{EE}$) - Cap_{HEAT} x 12 x $EFLH_{HEAT}$ / ($HSPF_{EE}$ * C_{IV-V})

Unit Peak kW Savings = Cap_{COOL} x 12 x (1 / EER_{BASE} - 1 / EER_{EE}) x CF

Unit Dth Savings per Year = $Btuh_{IN}$ x $EFLH_{HEAT}$ / ($AFUE_{BASE}$ x 1,000,000)

New Construction

Unit kWh Savings per Year = Cap_{COOL} x 12 x $EFLH_{COOL}$ x (1 / $SEER_{BASE}$ - 1 / $SEER_{EE}$) + HP% x [Cap_{HEAT} x 12 x $EFLH_{HEAT}$ x (1 / ($HSPF_{BASE,HP}$ * C_{IV-V}) - 1 / ($HSPF_{EE}$ * C_{IV-V}))] + ERH% x [Cap_{HEAT} x 12 x $EFLH_{HEAT}$ x (1 / $HSPF_{BASE,ERH}$ - 1 / ($HSPF_{EE}$ * C_{IV-V}))]

Unit Peak kW Savings = Cap_{COOL} x 12 x (1 / EER_{BASE} - 1 / EER_{EE}) x CF

Where:

Cap_{COOL}	=	Mini-split ductless cooling capacity in tons (1 ton = 12,000 Btu/h)
Cap_{HEAT}	=	Mini-split ductless heating capacity in tons (1 ton = 12,000 Btu/h)
12	=	Unit conversion, EER to kW/ton
$EFLH_{COOL}$	=	Equivalent full-load cooling hours, see Table 1 (Ref. 5)
$SEER_{BASE}$	=	SEER in cooling mode for the baseline HVAC system, see Table 2
$SEER_{EE}$	=	Actual SEER of the mini-split ductless system, from the AHRI database (Ref. 8)
$EFLH_{HEAT}$	=	Equivalent full-load heating hours, see Table 3

$HSPF_{BASE}$	=	HSPF for the baseline heat pump, see Table 4
C_{IV-V}	=	Conversion from rated HSPF to HSPF appropriate for AHRI climate zone V = 0.85 (Ref. 13, Ref. 14)$HSPF_{EE}$ = Actual HSPF in heating mode for the proposed heat pump, from the AHRI database (Ref. 8)
EER_{BASE}	=	EER of baseline system (= $SEER_{BASE}$ x 0.875)
EER_{EE}	=	EER of proposed system (= actual, or $SEER_{EE}$ x 0.875)
CF	=	Coincidence factor = 0.75 for single-speed compressor equipment, 0.9 for variable-speed compressor equipment (see Notes)
$Btuh_{IN}$	=	Furnace capacity in Btu/hr
$AFUE_{BASE}$	=	AFUE rating of baseline furnace (= actual, or 80%)
1,000,000	=	Unit conversion, Btu per Dtherm
HP%	=	22%, fraction of electrically-heated MN homes with heat pumps (Ref 11)
$HSPF_{BASE,HP}$	=	$HSPF_{BASE}$ value for heat pumps (Table 4)
ERH%	=	78%, fraction of electrically-heated MN homes with electric resistance heat (Ref 11)
$HSPF_{BASE,ERH}$	=	$HSPF_{BASE}$ value for electric resistance heat (Table 4)

Example:

Assume a 2.5-ton air-source heat pump is being replaced by a mini-split system in a single-family home in climate zone 1. Assume that two 1-ton mini-splits and one 1/2-ton mini-split will be installed.

Unit kWh Savings per Year = 2.5 x 12 x [213 x (1 / 14 - 1 / 20) + 2,280 x (1 / (8.2 x 0.85) - 1 / (11 x 0.85))] = 2,635 kWh

Unit Peak kW Savings = 2.5 x 12 x (1 / (14 x 0.875) - 1 / (20 x 0.875)) x 0.75 = 0.55 kW

Deemed Input Tables

Table 1. Equivalent Full-Load Cooling Hours ($EFLH_{COOL}$) by Climate Zone (Ref. 5)

Zone	Equivalent Full-Load Cooling Hours	
	Single Family	Multifamily*
Zone 1 (Northern MN)	213	228
Zone 2 (Central MN)	379	473
Zone 3 (Southern MN/Twin Cities)	520	616

* Multifamily includes duplexes, townhomes, and buildings with three or more units.

Table 2. Baseline SEER

Baseline Cooling System	$SEER_{BASE}$	Reference
Existing Residential Air-Source Heat Pump	14.0	Ref. 3
Existing Residential Split-System Air Conditioner	13.0	Ref. 3
Thru-the-Wall Air Conditioner or Heat Pump	10.6	Ref. 3

Table 3. Equivalent Full-Load Heating Hours ($EFLH_{HEAT}$) by Climate Zone

Zone	Equivalent Full-Load Heating Hours	
	Single Family (Ref. 6)	Multifamily* (Ref. 9)
Zone 1 (Northern MN)	2,280	1,761
Zone 2 (Central MN)	2,099	1,621
Zone 3 (Southern MN/Twin Cities)	1,932	1,492

* Multifamily includes duplex, townhome, and multifamily buildings with three or more units.

Table 4. Baseline HSPF

Baseline Heating System	$HSPF_{BASE}$	Reference
Existing Residential Air-Source Heat Pump	7.7	Ref. 3
Existing Electric Resistance	3.412	Assumed (= 100% efficient)
Thru-the-Wall Air Conditioner or Heat Pump	7.0	Ref. 3

Notes

Proposed mini-split ductless should meet ENERGY STAR minimum requirements (14.5 SEER, 8.2 HSPF).

Multi-head system capacity is the minimum of the total indoor unit capacity and outdoor unit capacity.

$EFLH_{COOL}$ data based on DOE2/eQUEST building simulation. The prototypes building models are based on the California DEER study prototypes, and were modified for local construction practices and code. Simulations were run using TMY3 weather data for Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis–St. Paul (Zone 3). $EFLH_{HEAT}$ for single-family sites was determined from Illinois field data and scaled with Minnesota weather data for Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis–St. Paul (Zone 3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{65,MN} / HDD_{65,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference. $EFLH_{HEAT}$ for multifamily sites was based on metering of multifamily units (Ref. 9) that were used as the primary heating source to the whole home, and in buildings that had received weatherization improvements. These are exclusive to mini-split ductless equipment.

Table 5. Heating Degree Days and Design Temperature Difference

Geography	HDD65	DTD
Chicago, IL	6,339	73.5
MN Zone 1	9,833	92
MN Zone 2	8,512	86.5
MN Zone 3	7,651	84.5

The value for coincidence factor is derived from a 2016 CARD study (Ref. 7) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced

(Ref. 12) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

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electric resistance heating, and 22% have heat pump heating (approximately 8% air-source and 14% ground-source).

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Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	7/31/2015
2.0	Streamlined equations, clarified requirements for furnace baseline, clarified requirements for back-up systems, added multifamily hours, updated and clarified baselines	Cadmus	11/2018
2.1	Updated CF, adjusted HSPF for AHRI climate zone V	Cadmus	10/2019

Residential HVAC - Thermostats

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes)
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Confirmation of heating type, existing or new home
Version No.	2.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0 unless Tier III device with demand response program. See Notes.
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10 (Ref. 1, Ref. 2)
Unit Participant Incremental Cost	Unit Participant Cost = See Table 2 or use actual device costs plus installation cost if available

Measure Description

This measure includes installation of a programmable (Tier I), communicating (Tier II), analytics capable (Tier III), or ENERGY STAR thermostat in existing or new homes.

Each tier is defined by the following characteristics:

Tier I: Programmable

- Customer programmed set points schedule

Tier II: Communicating

- Customer access to set points and schedule from anywhere using a smart device (phone, tablet or computer)

Tier III: Analytics Capable

- Additional energy savings features, including coaching, HVAC diagnostics, geofencing, comparative information, etc.
- Demand response capabilities
- Customer engagement features including customer-specific data and recommendations

ENERGY STAR Certified Smart Thermostat (Ref. 10)

- Static temperature accuracy ≤ 2.0 °F, average network standby power ≤ 3.0 W, ≤ 5 minutes to enter standby
- Customer engagement features
- Open access demand response capabilities
- Capable of collecting data including thermostat ID, HVAC equipment type (if possible), cooling and heating run time, auxiliary heat run time, space temperature, setpoints

- Demonstrated field savings calculated via collected usage data used with ENERGY STAR software

Note: There is a great deal of model overlap between Tier III and ENERGY STAR Certified Smart Thermostats, and this savings algorithm assumes no difference in measured savings performance.

Caution is advised in using this measure as few large-scale pilots have been completed to date and results have varied significantly. One or more large-scale whole-home consumption analyses are recommended in order to refine savings for these measures in Minnesota.

Algorithms

Unit kWh Savings per Year = (CSF x Cooling kWh) + (HSF x Heating kWh)

Unit Dth Savings per Year = (HSF x Heating Dth)

Where:

Heating Dth	=	Baseline heating energy for natural gas-heated residences in pilot area. Default = 69 Dth/yr (Ref. 9) for homes with gas heat, = 0 for homes with electric heat
Cooling kWh	=	Baseline cooling energy for residences in pilot area. Default = 760 kWh/yr. (Ref. 9)
Heating kWh	=	Baseline heating energy for primary electric-heated homes. Default = 16,200 kWh/yr for electric resistance, 7,200 kWh for air source heat pump, 4,900 kWh for ground source heat pump, and 0 for gas heat (Ref. 9)
HSF	=	Heating savings factor, assumed fraction of heating energy saved by thermostat, see Table 1.
CSF	=	Cooling savings factor, assumed fraction of cooling energy saved by thermostat, see Table 1.

Example:

150 Tier III thermostats are installed in 148 natural gas-heated homes with air-conditioning as part of a pilot program. The pilot does not include demand response.

kWh Savings per Year = 148 x 0.084 x 760 = 9,448.32

Dth Savings = 148 x 0.055 x 69 = 561.66

Deemed Input Tables

Table 1. Heating and cooling savings factors

Thermostat Type	Baseline Thermostat	Heating (HSF)		Cooling (HSF)	
		Value	Source	Value	Source
Tier I	Manual	3.6% / 0%[1]	Ref. 6	0.0%	Ref. 6
Tier II	Unknown	5.4%	Ref. 2	5.4%	Ref. 2
Tier III / ENERGY STAR		5.5%	Average of Ref. 3 (4.9%), Ref. 4 (4.8%), Ref. 5 (6.7%)	8.4%	Average of Ref. 3 (0%), Ref. 4 (20.5%), Ref. 7 (4.8%)
	Manual	10.9%	Average of Ref. 5 (8.8%), Ref. 11 (13.0%)	15.0%	Ref. 11 (15.0%)

[1]No savings may be claimed for Tier I thermostats in new homes with gas furnaces because they are required by MN Residential Energy Code.

Table 2. Incremental costs

Thermostat Type	Baseline Thermostat	Baseline Cost	Efficient Cost	Incremental Cost	Source
Tier I	Manual	$24	$54	$30	Ref. 8 for efficient cost. Assumed $24 baseline cost.
Tier II	Unknown	$39	$130	$91	Ref. 4 for efficient cost. $39 base cost reflects 50/50 average of manual and programmable.
Tier III / ENERGY STAR			$213	$174	
	Manual	$24		$189	Ref. 4 for efficient cost. Assumed $24 baseline cost.

Methodology and Assumptions

A Tier I (programmable) thermostat is assumed to replace a manual thermostat. Programmable thermostats are required by the 2015 Minnesota Residential Energy Code for new homes with gas furnaces.

As savings is dependent on household consumption, households with multiple thermostats shall not attain savings beyond that of the installation of one thermostat.

The references used to derive savings factors were large billing analyses, conducted with stock programmable and manual thermostat baselines, published from 2013 to 2018, in colder regions in the US (IL, WI, MI). While there is large variability in cooling savings factors found in these studies, the average value is in line with that found in other regions.

There are few studies available examining electric heat (resistance and heat pump) savings for thermostats. Sites with electric heat are assumed to have the same heating savings fractions as those with gas heat.

Notes

Few large-scale pilot programs have been completed as of the drafting of this measure and results vary significantly. As a result, the savings factors may require adjustment as more pilot programs are completed. One or more large-scale whole-home consumption analyses are recommended in order to refine savings for these measures in Minnesota. The reference for the 5.4% communicating thermostat savings fractions (Ref. 2) does not list root references for that value, and it should be used with additional caution.

The ENERGY STAR qualification tests assume baseline setpoints that may not reflect actual practice, and do not necessarily reflect actual HVAC savings fractions—using secondary billing analysis is used instead here.

There is little information on demand response impacts from smart thermostat programs at this time. kW savings could be updated as more pilot programs are completed.

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Revision History

Version	Description	Author	Date
1.0	Measure Created	Franklin Energy Services	2/28/2014
1.1	Added duplex to multifamily category	Joe Plummer	3/11/2014
1.2	Added IECC 2012 note	Franklin Energy Services	7/31/2014
1.3	In Methodology and Assumption, changed "solely" to "primarily" regarding gas heating for consistency with Description	Joe Plummer	7/31/2014
2.0	Expanded measure to three Tiers of Thermostats	Franklin Energy Services	11/12/2015
2.1	Expanded measures to include ENERGY STAR Thermostats	Franklin Energy Services	09/01/2017
2.2	Adjusted savings factors and costs, merged measures for gas and electric heating	Cadmus	10/2019

Residential HVAC - Line Voltage Thermostats

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes)
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Confirmation of heating type, existing or new home
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$115 per smart thermostat (Ref. 2) $37 per programmable thermostat (Ref. 2)

Measure Description

Thermostats for typical central HVAC systems get power and send signals via low voltage wires running to the furnace, boiler, AC, or heat pump control panel. But the controls for baseboard electric heaters are installed as part of the full-voltage circuit powering the heater, typically 120 or 240 volt. Therefore these are often referred to as line voltage thermostats. These are often bimetallic-controlled manual thermostats, although electronic-controlled manual and programmable varieties have been widely available for some time.

Recently, line voltage smart thermostats have become available which offer features similar to standard smart thermostats, including:

- Easier use and programming
- Occupancy sensing, via sensors on the thermostat or location tracking via a smartphone app
- Learning capability and / or automatic schedule generation or modification
- Encouraging the use of more energy-efficient set temperatures by users

This measure represents the installation of a line voltage thermostat in place of a manual or programmable thermostat.

Caution is advised in using this measure as few large-scale pilots have been completed to date and results have varied significantly. One or more large-scale whole-home consumption analyses are recommended in order to refine savings for these measures in Minnesota.

Algorithms

Unit kWh Savings per Year per thermostat = Heating kWh x SizeFactor x HSF / N

Where:

Heating kWh = Estimated average annual heating kilowatt-hours consumed by whole homes with baseboard electric heat, see Table 1.

SizeFactor = Adjustment factor for heated area of residence, = 1 if heated square footage is unknown, = home heated square footage divided by 1,889 for single family or 834 for multifamily (see Notes)

HSF = Heating savings factor, = 10% for smart thermostats, = 7% for programmable thermostats, see Savings Fraction section.

N = Deemed number of thermostats per home, = 6 for single family homes, = 4 for multifamily homes (Ref. 3)***Example:***

A single family home heated completely by baseboard heat, of unknown size and unknown base thermostat is outfitted with two line voltage smart thermostats, MN climate zone 3.

kWh Savings per Year = 2 x 1 x 11,527 x 0.08 / 6 = 307 kWh

Cost = $115 x 2 = $230

Deemed Input Tables

Table 1. Baseline Heating kWh for baseboard heaters (Ref. 4, Ref. 5, Ref. 6, see Notes)

Zone	Baseline Baseboard Heater Household kWh	
	Single family	Multifamily
Zone 1 (Northern MN)	14,184	3,357
Zone 2 (Central MN)	12,824	2,906
Zone 3 (Southern MN/Twin Cities)	11,527	2,612

Table 2. Savings Fractions

Baseline Thermostat	New Thermostat	Heating Savings Fraction	Formula (see Notes)
Manual	Programmable	6.0%	3.6% x (1 - 30%) + 3.5%
Manual	Smart	11.1%	10.9% x (1 - 30%) + 3.5%
Unknown	Smart	8.0%	5.5% x (1 - 30% + 30%) + 3.5% x (1 - 30%)
Programmable	Smart	5.1%	11.1% - 6.0%

Notes

Savings Fraction

Baseboard heaters are often controlled by bimetallic manual thermostats. Such thermostats for line voltage use may be less efficient than manual thermostats are for central systems because of droop and increased deadband (Ref. 3), and upgrading to electronic control relying on thermistors may produce savings, even if these thermostats are not programmable or smart. However there is mixed evidence for this, as seen in the studies in Table 2. The Regional Technical Forum (Ref. 7) currently uses a 5% savings factor for electronic manual line voltage thermostats, a value based on Ref. 8 and other earlier small studies. Here, a conservative estimate of 3.5% is used for this part of the upgrade.

Table 2. Line voltage thermostat studies

State	Ref	Equipment	Participant Count	Baseline	Efficient	Findings
OR	8	Baseboard	98	Bimetallic manual	Electronic programmable	1,475 kWh (Table 6) vs. 380 kWh for comparison group, vs. 11,548 kWh baseline so 9.4%
			65		Electronic manual	250 vs. 380 kWh for comparison group, no observed savings
CT, MA, NH	9	Baseboard	56	Bimetallic manual	Electronic manual	7.1% of heating load

Line voltage programmable and smart thermostats have electronic control and also likely provide additional savings from programmable and smart functionality. A study in Table 2 measured line voltage programmable thermostat savings, but it was relatively small and in a climate different from Minnesota. Additionally, no studies have been completed examining line voltage smart thermostat performance, and very few recent studies have been conducted examining low-voltage smart thermostat performance with electric heat (heat pump, baseboard, or resistance heat with forced air). Those and other recent studies examining gas savings are presented in Table 2 below. It should also be noted that the Regional Technical Forum only adds 1% to its 5% electronic manual savings fraction if the line voltage thermostat is smart (Ref. 7).

Table 3. Recent low-voltage smart thermostat studies

State	Ref	Equipment	Participant Count	Baseline	Efficient	Findings
FL	10	Mixed heat pump and resistance	30	Mixed	Smart	9.6% of heating load
OR	11	Heat pumps	176			12% of HVAC load
OR	12		113 treatment 211 control			12% of heating load
MI	13	Gas heating	6,479	Mixed	Smart	28 therms savings
WI	14		2,427			4.8% of heating load
IL	15		2,118 treatment 2,058 control			6.7% of heating load
				Manual	Smart	8.8% of heating load
IN	16		381 treatment, 3,845 control			12.5% of heating load
IN	17		455 treatment, 469 control			13.4% of heating load
IL	18		76	Programmable	Smart	3% of heating load

To sum these measured findings:

- Mixed to smart, electric, coastal: 10% to 12% savings
- Mixed to smart, gas, upper Midwest: 5% to 7% savings
- Manual to smart, gas, upper Midwest: 9% to 13% savings
- Programmable to smart, gas, upper Midwest: 3% savings (1 study)
- Manual to programmable, baseboard, coastal: 9.4% (1 study, includes bimetallic to electronic sensor upgrade)

For sites with an unknown baseline thermostat, the thermostat mix is likely a majority of bimetallic manual, some electronic manual, and a minority of electronic programmable. Upgrading from this baseline to a smart thermostat should produce savings that are a combination of savings from a bimetallic to electronic upgrade (deemed 3.5% above) and a manual or mixed to programmable or smart upgrade (Table 3). But the correct value to use for each of those is uncertain, and this combination may not be a linear one.

Reflecting the above notes, the savings estimates employ the savings fractions from the standard thermostat measure writeup, which are largely based on references cited here, and modify them:

- Standard thermostat savings fractions are 3.6% for manual to programmable, 10.9% for manual to smart, and 5.5% for unknown to smart.
- These savings fractions are each reduced by 30% as a conservative measure because they reflect gas central heating values but are being applied to electric space heating here.
- However for an unknown baseline, the 5.5% standard value reflects a low-voltage thermostat mix of manual and programmable. Because baseboard heaters likely have a higher proportion of manual baselines, 30% is added back.

- Then a full 3.5% is added for manual baselines, reflecting an upgrade from bimetallic to electronic sensing.
- For an unknown baseline, that additional 3.5% is reduced by 30% because some of this baseline likely already has electronic sensing.
- Programmable to smart upgrades reflect the difference between manual to programmable and manual to smart.

Base Consumption

To estimate base consumption for homes with baseboard heat, data from the 2015 Residential Energy Consumption Survey (RECS, Ref. 4) was used. The following filters were applied and a weighted average was obtained:

- Census division 4 (IA, KA, MN, MO, NE, ND, SD)
- Type of housing = single family detached and attached for single family, = apartment in a building 2 to 4 units, and with more than 5 units, for multifamily
- Equipment type = built-in electric units installed in walls, ceilings, basements, or floors
- Heating fuel = electricity

This produced values of 10,220 kWh for single family and 2,316 kWh for multifamily. This value was then adjusted to represent Minnesota specifically. Population-average heating degree days (HDDs) were obtained for the seven states in RECS census division 4 (Ref. 6). These were then used with the state populations (Ref. 5) to calculate an average HDD value for RECS census division 4 of 6,784. This is then combined with Minnesota climate zone heating degree days to produce normalized SF and MF consumption for each MN climate zone. For instance, Zone 3 has 7,651 heating degree days, so it has a single family consumption of 10,220 x 7,651 / 6,784 = 11,527.

The average heated square footage observed by RECS for these residences are 1,889 square feet for single family and 834 square feet for multifamily. Base consumption may be adjusted based on this, if heated square footage is known.

General Notes

Few large-scale pilot programs have been completed as of the drafting of this measure and results vary significantly. As a result, the savings factors may require adjustment as more pilot programs are completed. One or more large-scale whole-home consumption analyses are recommended in order to refine savings for these measures in Minnesota.

There is little information on demand response impacts from smart thermostat programs at this time. kW savings could be updated as more pilot programs are completed.

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Revision History

Version	Description	Author	Date
1.0	Measure Created	Cadmus	9/2020

Envelope

Residential Insulation and Air Sealing

Measure Detail	Measure Value
Target Market Segments	Residential, Commercial
Target End Uses	Envelope
Applicable To	Residential and small commercial customers. For existing buildings only
Actions	Modify
Required from Customer/Contractor	Pre and post R-values of attic insulation (if applicable); pre and post R-values of wall insulation (if applicable); confirmation of gas, electric resistance, or heat pump heating, confirmation of air conditioning, relative exposure of building (well-shielded, normal, or exposed, if air sealing), no. of stories (if air sealing), project location (county) Optional: Efficiency of heating and cooling systems, Infiltration before and after sealing as measured by blower door testing at 50 Pascals (if applicable).
Version No.	1.6
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 2)
Unit Participant Incremental Cost	See Table 4

Measure Description

This measure characterizes increased attic and/or wall insulation and air sealing for reduction of thermal losses through the building envelope.

The Minnesota Residential Energy Code requires that accessible attic bypasses be sealed prior to installing attic insulation (Ref. 8). Neglecting to seal bypasses can drastically reduce the effectiveness of insulation and lead to ice dams on the roof of the building during the winter. Ice dams can damage the roof and lead to water infiltration.

It is recommended that programs include pre- and post- blower door testing to measure the effectiveness of air sealing. Over-sealing a building can reduce natural ventilation to unsafe levels. The Minnesota Residential Energy Code specifies requirements for natural and mechanical ventilation to maintain acceptable air quality (Ref. 9). Programs should also include worst case draft testing of atmospherically-vented gas heating equipment following comprehensive air sealing and recommend installation of carbon monoxide detectors if not present.

Algorithms

For homes with gas heat

Unit Dth Savings per Year = $Savings_{WALL,DTH}$ + $Savings_{ATTIC,DTH}$ + $Savings_{AIRSEALING,DTH}$

$Savings_{WALL,DTH}$ (Dth) = [1/($R1_{INS,WALL}$ + R_{WALL}) - 1/($R2_{INS,WALL}$ + R_{WALL})] x A_{WALL} x (1 - FF) x 24 x HDD65 x CorrF / (AFUE x 1,000,000)

$Savings_{ATTIC,DTH}$ (Dth) = [1/($R1_{INS,ATT}$ + R_{ATT}) – 1/($R2_{INS,ATT}$ + R_{ATT})] x A_{ATT} x (1 - FF/2) x 24 x HDD65 x CorrF / (AFUE x 1,000,000)

$Savings_{AIRSEALING,DTH}$ (Dth) = 1.08 x 24 x HDD65 x CorrF x (CFM50 / N_{HEAT}) / (AFUE x 1,000,000)

Where:

$R1_{INS,WALL}$	=	Initial R-value of wall insulation
$R2_{INS,WALL}$	=	Final R-value of wall insulation
R_{WALL}	=	R-value of uninsulated wall assembly including air films = 2.73. See Methodology and Assumptions for derivation.
$R1_{INS,ATT}$	=	Initial R-value of attic insulation
$R2_{INS,ATT}$	=	Final R-value of attic insulation
R_{ATT}	=	R-value of uninsulated attic assembly including air films = 2.37. See Methodology and Assumptions for derivation.
A_{WALL}	=	Total area of insulated wall (square feet)
A_{ATT}	=	Total area of insulated ceiling/attic (square feet)
FF	=	Adjustment factor to account for the area of framing materials = 15%
HDD65	=	the heating degree days of the climate zone with a 65 degree base. See Table 1.
AFUE	=	Efficiency of gas heating system. Assume 80% if unknown.
CFM50	=	Total reduction in Infiltration at 50 Pascals as measured by blower door.
CorrF	=	Correction factor. Assumed to be 0.7 (Ref. 7)
N_{HEAT}	=	Conversion factor from leakage at 50 Pascal to leakage at natural conditions, based on climate, building height and exposure level (see Table 2)
1,000,000	=	Conversion factor from Btu to Dth

For homes with gas heat and air conditioning

Unit Dth Savings per Year = see above

Unit kWh Savings per Year = $Savings_{WALL,KWH,COOL}$ + $Savings_{ATTIC,KWH,COOL}$ + $Savings_{AIRSEALING,KWH,COOL}$

$Savings_{WALL,kWH,COOL}$ (kWh) = $[1/(R1_{INS,WALL} + R_{WALL}) – 1/(R2_{INS,WALL} + R_{WALL})] \times A_{WALL} \times (1 – FF) \times 24 \times CDD65 \times DUA / (SEER \times 1,000)$

$Savings_{ATTIC,kWH,COOL}$ (kWh) = $[1/(R1_{INS,ATT} + R_{ATT}) – 1/(R2_{INS,ATT} + R_{ATT})] \times A_{ATT} \times (1 – FF/2) \times 24 \times CDD65 \times DUA / (SEER \times 1,000)$

$Savings_{AIRSEALING,kWH,COOL}$ (kWh) = $1.08 \times 24 \times CDD65 \times DUA \times (CFM50 / N_{COOL}) / (SEER \times 1,000) \times LM$

Unit Peak kW Savings = $kWh_{COOL} / EFLH_{COOL} \times CF$

Where:

CDD65	=	The heating degree days of the climate zone with a 65 degree base. See Table 1.
DUA	=	Discretionary Use Adjustment to account for the fact that people do not always operate their air conditioning system when the outside temperature is greater than 75°F = 0.75 (Ref. 15)
N_{COOL}	=	Conversion factor from leakage at 50 Pascal to leakage at natural conditions, based on climate, building height and exposure level (see Table 2)
LM	=	Latent multiplier to convert the calculated sensible cooling savings to a value representing sensible and latent cooling loads = 6.2 (Ref. 12)
SEER	=	Nameplate efficiency of equipment, default = 11.5 (for units with unknown efficiency) (Ref. 14)
$EFLH_{Cool}$	=	Equivalent Full Load Cooling Hours. See Table 3
CF	=	Coincidence factor = 0.75 for cooling equipment with standard single-speed compressor, 0.9 for cooling equipment with variable-speed compressor (see Notes). If unknown use 0.75.
1000	=	Conversion factor from kW to kWh

For homes with electric resistance heat or heat pumps

Unit Dth Savings per Year = 0

Unit kWh Savings per Year = $Savings_{WALL,KWH,COOL} + Savings_{WALL,KWH,HEAT} + Savings_{ATTIC,KWH,COOL} + Savings_{ATTIC,KWH,HEAT} + Savings_{AIRSEALING,KWH,COOL} + Savings_{AIRSEALING,KWH,HEAT}$

$Savings_{WALL,KWH,COOL}$ = see above

$Savings_{ATTIC,KWH,COOL}$ = see above

$Savings_{AIRSEALING,KWH,COOL}$ = see above

$Savings_{WALL,kWH,HEAT}$ (kWh) = $[1/(R1_{INS,WALL} + R_{WALL}) – 1/(R2_{INS,WALL} + R_{WALL})] \times A_{WALL} \times (1 – FF) \times 24 \times HDD65 \times CorrF / (HSPF \times 1,000)$

$Savings_{ATTIC,kWH,HEAT}$ (kWh) = [1/($R1_{INS,ATT}$ + R_{ATT}) – 1/($R2_{INS,ATT}$ + R_{ATT})] x A_{ATT} x (1 – FF/2) x 24 x HDD65 x CorrF / (HSPF x 1,000)

$Savings_{AIRSEALING,kWH,HEAT}$ (kWh) = 1.08 x 24 x HDD65 x CorrF x (CFM50 / N_{HEAT}) / (HSPF x 1,000)

Unit Peak kW Savings = see above

Where:

HSPF = Electric heating system efficiency = 3.412 for electric resistance heat, the number of Btu in a watt-hour; = 7.7 x 0.85 = 6.55 for air source heat pump (Ref. 10, Ref. 18, Ref. 19)

Example:

A two-story single-family house with with gas heat, air conditioning, and normal exposure in Zone 1 receives attic insulation and air sealing. The existing insulation had an R-value of R-11. Cellulose insulation is blown into the 1,000 square foot attic to increase the R-value from 11 to 50. Pre- and post-blower door testing shows a decrease in CFM50 of 500. No wall insulation work is performed.

$Savings_{WALL,DTH}$ = 0

$Savings_{ATTIC,DTH}$ = [(1 / (11 + 2.37) - 1/(50 + 2.37)] x 1,000 x (1 - 0.15 / 2) x 24 x 9,833 x 0.7 / (0.80 x 1,000,000) = 10.6 Dth

$Savings_{AIRSEALING,DTH}$ = 1.08 x 24 x 9,833 x 0.7 x (500 / 15.5) / (0.8 x 1,000,000) = 7.2 Dth

Unit Dth Savings per Year = 0 + 10.6 + 9.0 = 17.8 Dth

$Savings_{WALL,kWH,COOL}$ (kWh) = 0

$Savings_{ATTIC,kWH,COOL}$ (kWh) = [1 / (11 + 2.37) – 1 / (50 + 2.37)] x 1000 x (1 - 0.15 / 2) x 24 x 140 x 0.75 / (11.5 x 1,000) = 43.6 kWh

$Savings_{AIRSEALING,kWH,COOL}$ (kWh) = 1.08 x 24 x 140 x 0.75 x (500 / 12.4) / (11.5 x 1,000) x 6.2 = 59.2 kWh

Unit kWh Savings per Year = 0 + 43.6 + 59.2 = 96.7 kWh

Unit Peak kW Savings = 96.7 / 213 x 0.75 = 0.34 kW

Deemed Input Tables

Table 1. Heating and Cooling Degrees Days (HDD / CDD) per zone in Minnesota

	Zone 1 (Northern MN)	Zone 2 (Central MN)	Zone 3 (Southern MN / Twin Cities)
HDD65 (Ref. 5)	9,833	8,512	7,651
CDD65 (Ref. 11)	140	414	634

Table 2. N_{HEAT} (Ref. 3) and N_{COOL} (see Notes) for Minnesota

Variable	Relative Exposure	Building Height (Stories)		
		1	2	3
N_{HEAT}	Well Shielded	18.6	14.9	13.0
	Normal	15.5	12.4	10.9
	Exposed	14.0	11.2	9.8
N_{COOL}	Well Shielded	29.8	23.8	20.8
	Normal	24.8	19.8	17.4
	Exposed	22.4	17.9	15.7

Well shielded: urban areas with buildings or sheltered areas. Buildings surrounded by trees, bermed earth, or higher terrain.
Normal: buildings in a residential neighborhood or subdivision setting, with yard space between buildings.
Exposed: buildings in an open setting with few buildings or trees around; buildings on top of a high hill, exposed to winds.

Table 3. Equivalent Full Load Cooling Hours ($EFLH_{Cool}$) by Climate Zone (Ref. 16)

Zone	Effective Full Load Cooling Hours	
	Single Family	Multifamily*
Zone 1 (Northern MN)	213	228
Zone 2 (Central MN)	379	473
Zone 3 (Southern MN/Twin Cities)	520	616

* Multifamily includes duplexes, townhomes, and buildings with 3 or more units

Table 4. Incremental Costs of Insulation (Ref. 6)

Insulation Type	Incremental Cost ($ / Square Foot)	
	Attic Insulation	Wall Insulaton
R-12	$0.62	$1.77
R-19	$0.81	$1.96
R-22	$0.96	$2.11
R-26	$1.16	$2.31
R-30	$1.29	$2.44
R-38	$1.61	$2.76
R-49	$2.05	$3.20

Methodology and Assumptions

The assumed R-value of an uninsulated wall assembly was derived from the following inputs:

Table 5. Component R-values for typical wall assembly

Component	R-value
Wall - Outside Air Film	0.17
Siding - Wood Bevel	0.8
Plywood Sheathing - 1/2"	0.63
Insulation	0
1/2" Drywall	0.45
Inside Air Film	0.68
Total Wall Component R-Values	2.73

The assumed R-value of an uninsulated attic assembly was derived from the following inputs:

Table 6. Component R-values for typical attic assembly

Component	R-value
Roof - Outside Air Film	0.17
Asphalt Shingles	0.44
Plywood Sheathing - 1/2"	0.63
Insulation	0
1/2" Drywall	0.45
Inside Air Film	0.68
Total Attic Component R-Values	2.37

$EFLH_{Cool}$ data based on DOE2/eQUEST building simulation. The prototype building models are based on California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Notes

Values for N_{COOL} were derived by examining the Illinois and Iowa TRMs (Ref. 1, Ref. 4). Their air sealing measures calculate various values for N_{HEAT} and N_{COOL}, for various cities in these regions. The ratio of N_{COOL} / N_{HEAT} is consistently between 1.5 and 1.7, with an average value of 1.6. That ratio is applied to the previously-derived values for N_{HEAT} in Minnesota to produce values for N_{COOL}.

There are statewide energy codes related to minimum insulation values of newly constructed and renovated commercial and residential buildings. There may also local building codes in place. Energy codes pertaining to insulation, air sealing, and ventilation should be verified for each utility or location.

The value for coincidence factor is derived from a 2016 CARD study (Ref. 13) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 17) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed

compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

References

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18. P. Francisco et al. *Understanding Heating Seasonal Performance Factor for Heat Pumps*. 2004. https://aceee.org/files/proceedings/2004/data/papers/SS04_Panel1_Paper08.pdf. Comparing adjusted HSPF values in climate zone IV to zone V in Figures 3, 5, and 7 reveals a ratio of 85%.
19. C. K. Rice et al. *An Analysis of Representative Heating Load Lines for Residential HSPF Ratings*. July 2015. https://info.ornl.gov/sites/publications/files/Pub56184.pdf. Fig. B.4 shows an actual HSPF approximately 15% less than rated HSPF for zone V, using the standard AHRI 210/240 load line.

Revision History

Version	Description	Author	Date
1.0	Original Document	Franklin Energy Services	7/31/2012
1.1	Changed Action to Modify	Joe Plummer	11/24/13
1.2	Added "confirmation of gas heating system" to Required Inputs	Joe Plummer	11/25/2013
1.3	Corrected required and optional inputs from customer/contractor, changed example to include air sealing, reformatted algorithm for clarity, modified description, added Commercial to market segment since also applicable to small commercial customers. Added definitions of shielding categories from FES.	Joe Plummer	2/14/2014
1.4	Changed algorithm to accept R-value of insulation as inputs rather than R-value of assembly for useability; added correction factor to ceiling and wall insulation algorithms	Franklin Energy Services	12/18/15
1.5	Added energy savings algorithms for cooling and electric heat	Cadmus	11/2018

Version	Description	Author	Date
1.6	Updated CF, adjusted HSPF for AHRI climate zone V	Cadmus	10/2019

Multifamily Aerosol Air Sealing

Measure Detail	Measure Value
Target Market Segments	Multi-Family
Target End Uses	Envelope
Applicable To	Residential customers in multi-family homes (including 3- and 4-family homes)
Actions	Modify, New Construction
Required from Customer/Contractor	Building type (existing or new construction), building ventilation type (exhaust only, exhaust and half supply, balanced, no ventilation)
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	$0.50 / SqFt of home size (Ref. 1)

Measure Description

This measure is the application of an aerosol sealant to a new or existing multifamily building (Ref. 1). The aerosol envelope sealing technology developed by the Western Cooling Efficiency Center at UC Davis uses an automated approach to produce extremely tight envelopes. Air is blown into a unit while an aerosol sealant "fog" is released in the interior. As air escapes the building through leaks in the envelope, the sealant particles are carried to the leaks where they impact and stick to the edges of the leaks, eventually sealing them. A standard house or duct air leakage test fan is used to pressurize the building and provide real-time feedback and a permanent record of the sealing. A recent CARD study, *Demonstrating the Effectiveness of an Aerosol Sealant to Reduce Multi-Unit Dwelling Envelope Air Leakage,* (Ref. 1) measured and modeled savings for new and existing multifamily buildings recieving this treatment.

When possible, custom modeling is recommended to address site specific characteristics. The CARD makes several recommendations to apply to custom modeling approaches.

Algorithms

Unit Dth Savings per Year = varies, see Table 1 and Table 2

Unit kWh Savings per Year = varies, see Table 1 and Table 2

Unit Peak kW Savings = (Unit kWh Savings per Year) / $EFLH_{COOL}$ x CF

Where:

$EFLH_{COOL}$ = Full load cooling hours, in hr (Table 3)

CF = 0.9; coincidence factor (Ref. 2)

Deemed Input Tables

Table 1. Dth and kWh Savings per Unit, New Construction

Ventilation Type	Space Heating Savings (Dth / unit)	Space Cooling Savings (kWh / unit)
Exhaust only	1.2	4
Exhaust and half supply	1.7	-5
Balanced	2.7	-19
No ventilation	2.6	-29

Table 2. Dth and kWh Savings per Unit, Existing

Ventilation Type	Space Heating Savings (Dth / unit)	Space Cooling Savings (kWh / unit)
Exhaust only	4.1	-8
Exhaust and half supply	5.6	-26
Balanced	6.7	-38
No ventilation	6.8	-47

Table 3. Effective Full Load Cooling Hours ($EFLH_C$) by Climate Zone (Ref. 3)

Zone	Multifamily*
Zone 1 (Northern MN)	228
Zone 2 (Central MN)	473
Zone 3 (Southern MN/Twin Cities)	616

Methodology and Assumptions

The CARD study (Ref. 1) examined 18 units receiving aerosol envelope sealing in three new construction multifamily buildings, and nine units in three existing multifamily buildings. The study measured envelope leakage reductions from 67% to 94% for new construction buildngs, and 39% to 89% for existing buildings. EnergyPlus models for four different ventilation strategies in new buildings used these reductions as inputs, and showed space heating energy savings of 4% to 25%, and similar models for existing buildings showed greater reductions. These savings are reflected in Table 1 and Table 2 above.

The study also showed that there is a small impact on the cooling energy required. This is due to the increased cooling energy needed after sealing (less infiltration to offset internal loads) The Card study concluded this is a relatively small impact and is not considered to be significant. Deemed savings here reflect this, with space cooling kWh penalties ranging from 0.7% to 3.8% of Dth savings (in absolute energy terms).

In 2015, Minnesota adopted the 2012 Residential International Energy Conservation Code with state amendments that requires multifamily buildings with one, two and three stories should meet envelope

tightness of 3.0 ACH50. Whereas, multifamily buildings with four stories and above, are required to meet the 2012 Commercial International Energy Conservation Code with state amendments by using continuous air barriers, tight materials, tight assemblies, or an envelope air leakage test.

References

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3. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012.

Revision History

Version	Description	Author	Date
1.0	Original document	Cadmus	11/2018

Low-E storm windows

Measure Detail	Measure Value
Target Market Segments	Residential, Multifamily
Target End Uses	Envelope
Applicable To	Residential and small commercial customers. For existing buildings only
Actions	Modify
Required from Customer/Contractor	Single family: Number of low-E windows sold, site HVAC system type, climate zone Multifamily: Square footage of low-E windows installed, number of windows installed, existing window type (single or double pane), site HVAC system type, climate zone
Version No.	1.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	Single family = $126 per window (see Notes) MultiFamily = $160 per window (see Notes)

Measure Description

Modern low emissivity (low-E) storm windows are a glazing attachment added to single-pane or double-pane windows. Low-E metal oxide coating (low-E storm windows/panels) decreases the winter heat loss and summer heat gain of an existing window by reducing thermal transmission. A low-E storm window may be installed on the interior or exterior of the existing window assembly. They are typically permanently mounted and operable. The products reduce thermal transmission in three ways:

- The low-E metal oxide coating acts as a selective heat mirror that reflects infrared light back into the home during the winter and back outside during the summer.
- The marine-quality glazing and caulked or compression-sealed interface reduces air leakage and infiltration.
- The dead air space created between the existing window and new storm window frame further reduces thermal transmission during both the winter and summer.

Algorithms

Unit Dth Savings per Year = $SF_{GASHEAT}$ * Area / 1,000

Unit kWh Savings per Year = kWh_{COOL} + kWh_{HEAT}

kWh_{COOL} = SF_{COOL} * Area

kWh_{HEAT} = $SF_{ELECHEAT}$ * Area

Unit Peak kW Savings = kWh_{COOL} / $EFLH_{COOL}$ x CF

Where:

$SF_{GASHEAT}$	=	See table 1; Average MBtu gas heating savings per square foot (= 0 for homes without a gas furnace)
Area	=	10.7 sq ft; size of average low-E storm window (Ref. 8)
1,000,000	=	Conversion from MBtu to Dth
SF_{COOL}	=	See table 2; Average kWh cooling savings per square foot (= 0 for homes without an air conditioner or heat pump)
$SF_{ELECHEAT}$	=	See table 3; Average kWh electric heating savings per square foot (= 0 for homes without a heat pump or electric resistance heat)
$EFLH_{COOL}$	=	Equivalent full load cooling hours. See Table 2 (Ref. 2)
CF	=	Coincidence factor = 0.75 for cooling equipment with standard single-speed compressor, 0.9 for cooling equipment with variable-speed compressor (see Notes). If unknown use 0.75.

Deemed Input Tables

Table 1. Gas Heating Savings per zone in Minnesota, MBtu/Sqft (see Notes)

Zone	Single Pane Baseline	Double Pane Baseline	Weighted Baseline
Zone 1 (Northern MN)	103	45	59.5
Zone 2 (Central MN)	82	37	48.3
Zone 3 (Southern MN/Twin Cities)	80	35	46.3

Table 2. Cooling Savings per zone in Minnesota, kWh/Sqft (see Notes)

Zone	Single Pane Baseline	Double Pane Baseline	Weighted Baseline
Zone 1 (Northern MN)	0.182	0.178	0.179
Zone 2 (Central MN)	0.325	0.318	0.320
Zone 3 (Southern MN/Twin Cities)	0.483	0.451	0.459

Table 3. Electric Heating Savings per zone in Minnesota kWh/Sqft (see Notes)

Zone	Electric Resistance Heat			Air Source Heat Pump		
	Single Pane Baseline	Double Pane Baseline	Weighted Baseline	Single Pane Baseline	Double Pane Baseline	Weighted Baseline
Zone 1 (Northern MN)	25.42	11.09	14.67	11.26	4.91	6.5
Zone 2 (Central MN)	20.28	9.05	11.86	8.99	4.01	5.26
Zone 3 (Southern MN/Twin Cities)	19.73	8.68	11.44	8.74	3.85	5.07

Table 4. Effective Full Load Cooling Hours ($EFLH_{COOL}$) by Climate Zone (Ref. 2)

Zone	Effective Full Load Cooling Hours	
	Single Family	Multifamily*
Zone 1 (Northern MN)	213	228
Zone 2 (Central MN)	379	473
Zone 3 (Southern MN/Twin Cities)	520	616

Methodology and Assumptions

Savings per square foot are based on RESFEN 5 models produced by D+R in October of 2018. These models closely mimic those used for ENERGY STAR Low-E window savings calculations (Ref. 4, Ref. 5), but were conducted specifically for the three Minnesota TRM climate zones, and additionally model savings for a double pane window baseline.

Window Characteristics

The EPA analysis shows U-factor and solar heat gain coefficient (SHGC) values for a variety of low-E storm window assemblies, as compared to single-pane wood frame primary windows. The properties of the low-E storm window used in the building models are shown in the table below. This measure assumes equal weighting between the three low-E storm window glass options.

Table 5. Properties of Modeled Window Glasses

Window Type	Glass Options (3 mm)	Emissivity	Solar Transmission	U-factor	SHGC
Standard	Clear	0.84	0.86	0.466	0.537
Low-E	AGC Comfort Select 73	0.15	0.69	0.356	0.458
	Guardian IS20	0.20	0.77	0.364	0.502
	PPG Sungate 500	0.22	0.69	0.367	0.468

Building Characteristics

The savings calculations are based on modeling two types of prototypical residential homes: one-story (1,700 sq ft) existing construction and two-story (2,800 sq ft) new construction. Both modeled homes have a 15% window-to-floor-area ratio. This workpaper assumes equal weighting between the two building types. The model building assumptions are shown in the table below.

Table 6. RESFEN Model Assumptions

Characteristic	Existing Construction	New Construction
Area	1,700 sq ft	2,800 sq ft
Window Area	255 sq ft (15 % of floor area)	420 sq ft (15 % of floor area)
Foundation	Basement	Basement
Insulation	RESFEN 5	2006 IECC
HVAC System	Natural gas furnace and A/C	Natural gas furnace and A/C
HVAC Efficiency	Natural gas furnace AFUE = 0.78 Air conditioner SEER = 10	Natural gas furnace AFUE = 0.90 Air conditioner SEER = 13

Conversion to Electric Heat

As noted, the RESFEN models simulated homes with a gas furnace and air conditioner. Heating kWh savings are calculated for homes with electric resistance and heat pump heat via a two-step process. First, the MBtu/Sqft savings for furnaces (Table 1) are converted to actual heat loss prevention by multiplying them by an AFUE of 84%, which reflects the average AFUE of the two modeled homes. Then, for electric resistance heat, this number is divided by 3.412 MBh per kWh. For heat pump heat, this number is divided by an assumed HSPF of 7.7 Btu/(watt-hour).

Window Baseline

Data obtained for the 2020–2029 Minnesota Energy Efficiency Study show that 25% of single family homes have single-pane windows and 75% have double pane windows. This weighting is used to produce the weighted savings per square foot in Table 1, Table 2, and Table 3.

Incremental Cost

The incremental cost for a low-E storm window includes the product cost and the installation cost. Because the baseline condition is an existing single-pane or double-pane window assembly, the incremental product cost is the full cost of the low-E storm window and its installation. A low-E window is assumed to cost $115, which is the average of the $80 to $150 range provided in a recent paper (Ref. 6). The installation cost of a self-install is assumed to be $2, while the cost of a professional installation is $45 (Ref. 2). It is assumed that single family residence low-E storm windows are installed by homeowners 80% of the time, and that multifamily residence low-E storm windows are always installed by contractors (Ref. 7). Therefore the average installation cost for single family sites is $2 * 80% + $45 * 20% = $11, the average total cost per window for single family sites is $115 + $11 = $126, and the total cost for multifamily sites is assumed to be $115 + $45 = $160.

Notes

The value for coincidence factor is derived from a 2016 CARD study (Ref. 3) that examined quality install and maintenance practices for residential furnaces, air conditioners and heat pumps, in part by metering the behavior and performance of 58 cooling systems and 55 furnaces. A follow-on memo was produced (Ref. 9) that recommended coincidence factor be reduced from 90% to 75%. Because the previous 90% value was simply deemed as a typical value worth updating when primary data was available, that update is applied here. However, because the metered systems had single-speed compressors, 90% may still be used for equipment with variable-speed compressors. The memo also recommended reducing residential EFLH by 25% – 40%, based on statistically significant data. That update should be strongly considered for the TRM version 4.0.

References

1. U.S. Department of Energy. Database of Low-e E Storm Window Energy Performance across U.S. Climate Zones. September 2013. Available online: https://basc.pnnl.gov/sites/default/files/resource/Culp%20ET%20Task%205_3_PNNL-22865_Final2.pdf
2. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012
3. Seventhwave. *Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners and Heat Pumps*. September 30, 2016. https://www.cards.commerce.state.mn.us/CARDS/security/search.do?documentId=%7B881DD1B7-1FE4-495A-9FC0-F74A54B99CB6%7D
4. Environmental Protection Agency and D+R International. *ENERGY STAR for Exterior and Interior Storm Windows. Analysis of Additional Low-e Glass Options*. April 4, 2018. https://www.energystar.gov/sites/default/files/ES%20Storm%20Windows%20Additional%20Analysis.pdf
5. ENERGY STAR Storm Windows RESFEN Data and Calculations. https://www.energystar.gov/sites/default/files/ES%20Storm%20Windows%20RESFEN%20Data%20and%20Calculations.xlsx
6. Pacific Northwest National Laboratory (Cort, K.A.). Low-E Storm Windows: Market Assessment and Pathways to Market Transformation. Table 2.1. (Cort, KA. 2013. PNNL-22565. Pacific Northwest National Laboratory, Richland, Washington. Table 2.1. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22565.pdf
7. Drumheller, S. Craig, C. Kohler, S. Minen. "Field Evaluation of Low-E Storm Windows." Paper presented at the Thermal Performance of the Exterior Envelopes of Whole Buildings X International Conference, Clearwater Beach, Fl, December 2–7, 2007. Page 8. https://eetd.lbl.gov/sites/all/files/publications/1940e.pdf
8. D+R International. Historical sales data of low-E windows.
9. Seventhwave. TRM Implications from the CARD "Improving Installation and Maintenance Practices for Minnesota Residential Furnaces, Air Conditioners, and Heat Pumps" study. Memo from Seventhwave to MN DER. June 8, 2016.

Revision History

Version	Description	Author	Date
1.0	New workpaper	Cadmus	10/2018
1.1	Updated CF	Cadmus	10/2019

Hot Water

Residential Hot Water - Drainpipe Heat Exchanger with Electric Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single-family homes and multi-family homes consisting of 2 units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size electric water heaters
Actions	Modify
Required from Customer/Contractor	Confirmation of electric water heater, building type (single family or multi family*), project location (county). * Includes buildings with 2+ units and townhomes
Version No.	2.5
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	$742 (Ref. 1)

Measure Description

This measure includes installing a drainpipe heat exchanger to a residential or multi-family building to recover heat from heated water going down the building's drain. The savings for this measure is “per living unit affected.”

Algorithms

Unit kWh Savings per Year = EnergyToHeatWater / Eff x SavingsFactor / ConversionFactor

Unit Peak kW Savings = Unit kWh Savings per Year / 8,760

Where:

EnergyToHeatWater = SpecificHeat x Density x Gal/Day x 365 Days/Year x (Tset - Tcold)

SpecificHeat = 1.0 Btu/(lb x °F)

Density = 8.34 lbs/gal

Gal/Day = See Table 2; Average gallons per day of hot water usage (gal/day)

Tset = 120 °F (Ref. 4)

Tcold = Average groundwater temperature per Table 1 (Ref. 3)

Eff = Recovery efficiency of electric water heater, 0.98.

SavingsFactor = 0.25 (Ref. 2)

ConversionFactor = 3,412 Btu/kWh

Example:

A single-family customer in Zone 1 has installed a drain pipe heat exchanger to recover wasted energy from the house's drain line.

EnergyToHeatWater = (1 Btu/lb°F) x (8.34 lbs/gal) x (52.7 gal/day) x (365 days/yr) x (120°F - 46.5°F) = 11,799,245 Btu/yr

Unit kWh Savings per Year = (11,799,245 Btu/yr) / (0.98) x (25%) / (3,412 Btu/kWh) = 882 kWh

Unit Peak kW Savings = 882 kWh / 8,760 h = 0.101 kW

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 3)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Daily Hot Water Usage by Building Type

Building Type	Daily Gal/person (Ref. 5)	Num_People (Ref. 6)	Total Daily Hot Water Use (gal/day)
Single-family	20.4	2.59	52.7
Multi-family	18.7	2.17	40.5

Notes

There are no current efficiency standards for this technology.

References

1. State of Ohio Energy Efficiency Technical Reference Manual, 2010. Prepared by Vermont Energy Investment Corporation. Page 78.
2. Drain pipe heat exchange savings estimates are based on study findings reported in a communication from J. J. Tomlinson, Oak Ridge Buildings Technology Center, to Marc LaFrance, DOE Appliance and Emerging Technology Center, DOE, August 24, 2000, suggesting 25 to 30% of water heating consumption savings potential. The lower end of the savings scale was chosen for this report, assuming ideal installation for the study.

3. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
4. "Lower Water Heating Temperature for Energy Savings," Department of Energy website, http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090. Accessed 7/26/12. The webpage referenced by the link has since changed and is no longer relevant.
5. Interpolated values from Table 38, Ohio Technical Reference Manual. October 15, 2009. Page 52.
6. U.S. Census Bureau, *Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates)* for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=tabl

Revision History

Version	Description	Author	Date
1.0	Derived from ResidentialElectricDHW_v03.2 and ResidentialGasDHW_v03.2 which were based on Nexant's original spec.	Joe Plummer	
2.0	Updated the groundwater temperatures, see "Water Temps" tab	Franklin Energy Services	7/23/2012
2.1	Added example	Franklin Energy Services	7/23/2012
2.2	Updated the measure cost	Franklin Energy Services	7/23/2012
2.3	Changed action to Modify, changed “electric or gas water heater” to “confirmation of electric water heater” under required inputs, changed annual hours from 8,760 to 8,760, updated example for electric instead of gas	Joe Plummer	11/24/2013
2.4	Added building type to required inputs, added definition of multifamily	Joe Plummer	3/18/2014
2.5	Added unknown location and removed gas information.	Frankin Energy Services	12/18/2015

Residential Hot Water - Drainpipe Heat Exchanger with Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size gas water heaters
Actions	Modify
Required from Customer/Contractor	Confirmation of gas water heater, building type (single family or multi-family*), project location (county) * Includes buildings with 2+ units and townhomes
Version No.	4.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	$742 (Ref. 1)

Measure Description

This measure includes installing a drainpipe heat exchanger to a residential or multi-family building to recover heat from heated water going down the building's drain.

Algorithms

Unit Dth Savings per Year = EnergyToHeatWater / Eff x SavingsFactor / ConversionFactor

Where:

EnergyToHeatWater = SpecificHeat x Density x Gal/Day x 365 Days/Year x (Tset - Tcold)

SpecificHeat = 1.0 Btu/(lb x °F)

Density = 8.34 lbs/gal

Gal/Day = See Table 2; Average gallons per day of hot water usage (gal/day)

Tset = 120 °F (Ref. 4)

Tcold = Average groundwater temperature per Table 1 (Ref. 3)

Eff = Recover efficiency of gas water heater, 0.75.

SavingsFactor = 0.25 (Ref. 2)

ConversionFactor = 1,000,000 Btu/Dth

Example:

A single-family customer in Zone 1 has installed a drain pipe heat exchanger to recover wasted energy from the house's drain line.

EnergyToHeatWater = (1 Btu/lb°F) x (8.34 lbs/gal) x (52.7 gal/day) x (365 days/yr) x (120°F - 46.5°F) = 11,791,169 Btu/yr

Unit Dth Savings per Year = (11,791,169 Btu/yr) / (0.75) x (25%) / (1,000,000 Btu/Dth) = 3.9 Dth

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 3)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Daily Hot Water Usage by Building Type

Building Type	Daily Gal/person (Ref. 5)	Num_People (Ref. 6)	Total Daily Hot Water Use (gal/day)
Single-family	20.4	2.59	52.7
Multi-family*	18.7	2.17	40.5

* Includes buildings with 2+ units and townhomes

Notes

There are no current efficiency standards for this technology.

References

1. State of Ohio Energy Efficiency Technical Reference Manual, 2010. Prepared by Vermont Energy Investment Corporation. Page 78.
2. Drain pipe heat exchange savings estimates are based on study findings reported in a communication from J. J. Tomlinson, Oak Ridge Buildings Technology Center, to Marc LaFrance, DOE Appliance and Emerging Technology Center, DOE, August 24, 2000, suggesting 25 to 30% of water heating consumption savings potential. The lower end of the savings scale was chosen for this report, assuming ideal installation for the study.
3. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
4. "Lower Water Heating Temperature for Energy Savings," Department of Energy website, http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090. Accessed 7/26/12. The webpage referenced by the link has since changed and is no longer relevant.

5. Interpolated values from Table 38, Ohio Technical Reference Manual. October 15, 2009. Page 52.
6. U.S. Census Bureau, *Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates)* for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=tabl

Revision History

Version	Description	Author	Date
1.0	Derived from ResidentialElectricDHW_v03.2 and ResidentialGasDHW_v03.2 which were based on Nexant's original spec.	Joe Plummer	
2.0	Updated the groundwater temperatures, see "Water Temps" tab	Franklin Energy Services	7/23/2012
2.1	Added example	Franklin Energy Services	7/23/2012
2.2	Updated the measure cost	Franklin Energy Services	7/23/2012
2.3	Changed action type to Modify, changed "electric or gas water heater" to "confirmation of gas water heater" in Required Inputs	Joe Plummer	11/25/2013
2.4	Added building type to required inputs, added footnotes clarifying multifamily definition	Joe Plummer	3/18/2014
2.5	Added unknown location and removed electric information	Franklin Energy Services	12/18/2015

Residential Hot Water - Water Heater Jacket Insulation

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single-family, duplexes and townhomes with storage water heaters
Actions	Retrofit
Required from Customer/Contractor	Project location (county), water heater size in gal, water heater fuel type
Version No.	4.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	7 (Ref. 4)
Unit Participant Incremental Cost	$30 (Ref. 5)

Measure Description

This measure includes installing a water heater blanket on an electric or gas water storage water heater.

Algorithms

Unit kWh Savings per Year = (A_base / R_base - A_insul / R_insul) x (T_hot - T_ambient) x Hours / (ElecEff * 3,412)
Electric-fueled storage water heater only

Unit Peak kW Savings = Unit kWh Savings per Year / Hours
Electric-fueled storage water heater only

Unit Dth Savings per Year = (A_base / R_base - A_insul / R_insul) x (T_hot - T_ambient) x Hours / (GasEff * 1,000,000)
Gas-fueled storage water heater only

Where:

R_base = R-value of existing water heater tank insulation = Actual or if unknown assume R-12 (Ref. 1)

R_insul = R-value of total water heater insulation after insulation addition = Actual or if unknown assume R-18 (Ref. 5)

A_base = Surface area of uninsulated water heater (Table 1)

A_insul = Surface area of insulated water heater (Table 1)

T_hot = 120°F (Ref. 3)

T_ambient = 60°F (Ref. 6)

ElecEff	=	Recovery efficiency of electric water heater = 98% (Ref. 2)
GasEff	=	Recovery efficiency of gas water heater = 78% (Ref. 2)
Hours	=	8,760 hours
3,412	=	Conversion from Btu to kWh
1,000,000	=	Conversion from Btu to Dth

Example:

A customer in Zone 2 installed an insulation jacket on their 50-gallon water heater.

Unit kWh Savings per Year = (24.99 / 12 - 27.06 / 18) x (120 - 60) x 8,760 / (0.98 x 3,412) = 91.0 kWh

Unit Peak kW Savings = 91.0 kWh / 8,760 hours = 0.010 kW

Dth Savings per Year = 0

Deemed Input Tables

Table 1. Surface Areas, ft^2 (Ref. 1)

Water Heater Size	A_base	A_insul
30-gallon tank	19.16	20.94
40-gallon tank	23.18	25.31
50-gallon tank	24.99	27.06
80-gallon tank	31.84	34.14

Notes

If assuming 46 gal/day hot water usage, the savings in the example comes out to about 4% of the overall DHW energy.

There is no current standard for level of insulation necessary for new or existing water heaters.

References

1. Pennsylvania Public Utility Commission. *Technical Reference Manual. Volume 2: Residential Measures*. August 2019. http://www.puc.pa.gov/pcdocs/1630968.docx
2. Electric water heaters generally have recovery efficiency of 98%, and gas water heaters generally have a recovery efficiency of 78%: http://www.ahridirectory.org/ahridirectory/pages/home.aspx
3. Recommended value on DOE website, http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090. Consistent with other DHW measures.
4. California Energy Commission and California Public Utilities Commission. Database for Energy Efficient Resources. EUL Table. 2014.

http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EUL-table-update_2014-02-05.xlsx

5. Online research at Amazon, Lowes, and Home Depot conducted by Cadmus, September 2020. Costs for 15 models ranged from $22 to $44, no trends observed with respect to area or R-value. Average $31. Average R-value of 7; 6 is a conservative default.
6. The ambient temperature is based on the water heaters being located in the basement.

Revision History

Version	Description	Author	Date
1.0	Based on original from Nexant, cleaned up and reformatted	Joe Plummer	
2.0	Added algorithms based on IL TRM	Franklin Energy Services	7/31/2012
3.0	Updated hours from 8,760 to 8,766.	Franklin Energy Services	1/11/2016
4.0	Updated recovery efficiency, added gas measure, reverted hours to 8,760 to be consistent with other measures.	Cadmus	9/2020

Residential Hot Water - Electric Water Heater Setback

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single-family homes and multi-family homes consisting of 2 units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size electric water heaters
Actions	Operations and Maintenance
Required from Customer/Contractor	Confirmation of electric water heater, project location (county), single-family or multi-family* * Includes buildings with 2+ units and townhomes
Version No.	3.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	2 (Ref. 2)
Unit Participant Incremental Cost	$0

Measure Description

This measure involves turning the water heater set point temperature to 120°F on residential storage-type water heaters, both gas and electric. The action must be performed by a utility representative on site during a home energy audit or other home visit.

The existing temperature set point is assumed to be 130°F.

Algorithms

Unit kWh Savings per Year = SpecificHeat x Density x Gal_Person x People x 365 x (Tset - Tin) x Savings_Factor/ Eff / ConversionFactor

Unit Peak kW Savings = Unit kWh Savings per Year / 8,760 hours

Where:

SpecificHeat = 1.0 btu / (lb x °F)

Density = 8.34 lbs / gal

Gal_Person = See Table 2; Daily hot water usage per person

People = See Table 3; Number of people per household

Tset1 = 130 °F (assumed average starting temperature)

Tin = Average groundwater temperature per Table 1

Eff = 0.92 (2004 Federal minimum Energy Factor for 40 gal tank = 0.97 - 0.00132 x 40)

ConversionFactor = 3,412 Btu/kWh (electric water heater) or 1,000,000 Btu/MMBtu (gas water heater)

Savings_Factor = 4% (Ref. 3)

Example:

A direct install team reduces the set point of an electric water heater in a single-family home in Zone 1.

kWh savings = (1.0 Btu/lb°F) x (8.34 lb/gal) x (20.4 gal/day/person) x (2.59 people) x (365 day/yr) x (130°F - 46.5°F) x 4% / (0.92) / (3,412 Btu/kWh) = 171 kWh

kW savings = (171 kWh) / 8,760 hours = 0.020 kW

Deemed Input Tables:

Table 1. Average groundwater temperatures (Ref. 4)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3

Table 2. Daily Hot Water Usage per Person (Ref. 6)

Location	Gal/day/person
Single-Family	20.4
Multi-Family*	18.7

* Includes buildings with 2+ units and townhomes

Table 3. People per Household (Ref. 7)

Application	Num_People
Single-Family	2.59
Multi-Family*	2.17

* Includes buildings with 2+ units and townhomes

Methodology and Assumptions

The savings from lowering the temperature setpoint 10°F is 3% to 5% of the overall domestic hot water energy. (Ref. 3)

The existing temperature is assumed to be 130°F (Ref. 5)

Notes

There are no current energy standards for this measure.

The previous algorithm assumed that all hot water uses are done at max temperature, when in reality only a few are (i.e. clothes washer, dishwasher, misc. cleaning, etc.). The result of this was that the savings was being overestimated (i.e. 446 kWh, resulting in ~13% overall DHW savings). The IL TRM

however, only accounts for the aforementioned uses and ignores the reduction in standby losses by lowering the delta T. The result of this is that the savings is underestimated (i.e. 49 kWh). The DOE estimates a savings that is between these two values. The savings value given by DOE estimates are supported by Ref. 2 (Efficiency Vermont TRM).

The excel algorithms yield a savings of 158 kWh and 0.84 Dth, which is within 4% of the values for Zone 1-single-family applications. The difference in savings will increase in zones 2 and 3 and in multi-family applications.

References

1. Daily hot water usage is based on CEE's tankless water heater field study in Mpls/St. Paul (2008-2010); Supported by Focus on Energy's Residential Deemed Savings Review, page 4.
2. Efficiency Vermont Technical Reference User Manual (TRM), 2/19/2010. Page 409. This value is supported by the Illinois Technical Reference User Manual, 2012.
3. Average of 3-5% savings values on DOE website. Accessed 7/2. http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090
4. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
5. Franklin Energy Services internal value.
6. Interpolated values from Table 38, Ohio Technical Reference Manual. October 15, 2009. p. 52.
7. U.S. Census Bureau, Selected Housing Characteristics 2010 American Commnity Survey 1-Year Estimates) for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table

Revision History

Version	Description	Author	Date
1.0	Originally part of ResidentialGasDHW_v03.2 which was derived from Nexant spec; changed algorithm to assume an average starting and final temperature rather than using an unsupported savings factor	Joe Plummer	
2.0	Updated algorithm to use Savings_Factor of 4%	Franklin Energy Services	7/26/2012
2.1	Updated measure lifetime per Ref. 2	Franklin Energy Services	7/27/2012
3.0	3.0 Updated the hot water usage to be consistent with the hot water heater measure algorithm	Franklin Energy Services	8/6/2012
3.1	Changed “electric or gas water heater” to “confirmation of electric water heater” under required inputs, changed annual hours from 8760 to 8766	Joe Plummer	11/25/2013
3.2	Added footnotes clarifying multifamily definition. In kWh algorithm, replaced Gal/Day with Gal_Person x People. Corrected example calculation.	Joe Plummer	3/18/2014

Residential Hot Water - Faucet Aerator with Electric Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single-family homes and multi-family homes consisting of 2 units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size electric water heaters
Actions	Replace Working
Required from Customer/Contractor	Confirmation of electric water heater, building type (single family or multi-family*), project location (county) * Includes buildings with 2+ units and townhomes
Version No.	5.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$6.70 (Ref. 6)

Measure Description

This measure includes replacing an existing faucet aerator with low-flow aerator.

Algorithms

Unit kWh Savings per Year = $(GPM_{BASE} \times TF_{BASE} - GPM_{LOW} \times TF_{LOW}) \times (PH \times FLU / FH) \times DF \times 365 \times Density \times C_P \times (T_{OUT} - T_{IN}) / (ReEff \times 3{,}412)$

Unit Peak kW Savings = Unit kWh Savings per Year x CF / Hours

Where:

GPM_{BASE}	=	Actual or 2.2 gallons per minute (Ref. 5)
TF_{BASE}	=	Throttling factor for base use, 0.83 (Ref. 8)
GPM_{LOW}	=	Actual
TF_{LOW}	=	Throttling factor for installed use, 0.95 (Ref. 8)
PH	=	Number of people per household, per Table 1 (Ref. 3)
FLU	=	Fixture length of use in minutes / person per day, per Table 2 (Ref. 2)
FH	=	Fixtures per home per Table 2 (Ref. 2)
DF	=	Drain factor per Table 2 (Ref. 7). Drain factor accounts for the fact that a portion of faucet use is dictated by volume, not time (generally filling vessels, as opposed to washing items).
365	=	Days per year
Density	=	8.34 lb / gal

C_P	=	1.0 Btu / (lb x °F)
T_{OUT}	=	Temperature of faucet usage per Table 2 (Ref. 2)
T_{IN}	=	Average groundwater temperature per Table 3 (Ref. 4)
ReEff	=	Recovery Efficiency = 98% (electric water heater) (Ref. 7)
3,412	=	Conversion from Btu to kWh
CF	=	Coincidence factor per Table 2 (Ref. 9)
Hours	=	Hours of use per year = (PH x FLU / FH) x 365 / 60

Example:

Direct install of a 1.5 GPM faucet aerator in an apartment with electric water heat, located in Zone 1, room type unknown.

Unit kWh Savings per Year = (2.2 x 0.83 – 1.5 x 0.95) x (2.17 x 3.1 / 1.22) x 0.83 x 365 x 8.34 x 1 x (90 – 46.5) / (0.98 x 3,412) = 72.7 kWh

Hours = (2.17 * 3.1 / 1.22) x 365 / 60 = 33.5 hours

Unit Peak kW Savings = 72.7 x 0.0023 / 33.5 = 0.005 kW

Deemed Input Tables

Table 1. People per Household (Ref. 3)

Application	PH
Single-Family	2.59
Multi-Family*	2.17
If unknown	2.38

* Includes buildings with 2+ units and townhomes

Table 2. Fixture Length of Use and T_{OUT} (Ref. 2), Drain Factor (Ref. 7), and Coincidence Factor (Ref. 9)

Location	FLU	T_{OUT}	DF	CF
Kitchen	4.5	93°F	0.75	0.0033
Bathroom	1.6	86°F	0.90	0.0012
Unknown	3.1	90°F	0.83	0.0023

Table 3. Fixtures Per Home (Ref. 2)

Application	Location	FH
Single-Family	Kitchen	1
	Bathroom	2.04
	Unknown	1.52
Multi-Family*	Kitchen	1
	Bathroom	1.43
	Unknown	1.22
Unknown	Unknown	1.37

Table 4. Average groundwater temperatures (Ref. 4)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

References

1. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values. http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf. Accessed on 7/31/12.
2. Cadmus and Opinion Dynamics. Showerhead and Faucet Aerator Meter Study. Memo to Michigan Evaluation Working Group. June 2013.
3. U.S. Census Bureau, *Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates)* for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table
4. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
5. Title 10, Code of Federal Regulations, Part 430 – Energy Conservation Program for Consumer Products, Subpart C – Energy and Water Conservation Standards and Their Effective Dates. https://www.ecfr.gov/cgi-bin/text-idx?SID=45151ba12ebfbba8afbf95d31bcd2ace&mc=true&node=pt10.3.430&rgn=div5#sp10.3.430.c

6. 2008 Database for Energy-Efficient Resources, Cost Values and Summary Documentation http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf
7. Illinois Stakeholder Advisory Group. State of Illinois Energy Efficiency Technical Reference Manual, Version 6.0, Volume 3: Residential Measures. February 8th, 2017. Page 179. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf
8. M. Schuldt and D. Tachibana. *Energy-Related Water Fixture Measurements: Securing the Baseline for Northwest Single Family Homes*. August 2008. Page 1-265. http://www.seattle.gov/light/Conserve/Reports/paper_10.pdf
9. Public Service Commision of Wisconsin. Wisconsin Focus on Energy 2017 Technical Reference Manual. Spring 2017. Page 642. https://focusonenergy.com/sites/default/files/Focus%20TRM-%20Spring%202017-%20Final%20for%20Posting%20May%202017_0.pdf

Revision History

Version	Description	Author	Date
1.0	Created standalone spec from ResidentialElectricDHW_v03.2	Joe Plummer	
2.0	Revised formatting and algorithms	Franklin Energy Services	7/27/2012
2.1	Update the measure life and measure cost	Franklin Energy Services	7/27/2012
3.0	Corrected Energy Factor equations	Franklin Energy Services	3/20/2013
3.1	Changed action from Direct Install to Replace Working	Joe Plummer	4/5/2013
3.2	Removed extra multiplication sign following Eff in savings algorithms	Joe Plummer	8/28/2013
3.3	Changed “electric or gas water heater” to “confirmation of electric water heater” under required inputs, changed efficiency (0.92) to recovery efficiency (0.98) and updated example accordingly, changed annual hours from 8,760 to 8,760	Joe Plummer	11/25/13
3.4	Added residence type (single family or multi-family) to required inputs	Joe Plummer	1/3/14
3.5	Removed “owner-occupied” from single-family and “renter-occupied” from multi-family categories in Tables 2 and 3, added footnotes clarifying multifamily definition	Joe Plummer	3/11/14
4.0	Added in average values and a deemed value for applications where the inputs are unknown	Franklin Energy Services	10/20/15
4.1	All hours of use changed to 365.25 and commercial usage updated	Franklin Energy Services	1/13/2016
5.0	Updated algorithm for kWh and kW savings, splitting out savings for kitchen and bathroom aerators, and using actual installed GPM and drain and throttling factors	Cadmus	10/2018

Residential Hot Water - Faucet Aerator with Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size gas water heaters
Actions	Replace Working
Required from Customer/Contractor	Confirmation of gas water heater, building type (single family or multi-family*), project location (county) * Includes buildings with 2+ units and townhomes
Version No.	5.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$6.70 (Ref. 6)

Measure Description

This measure includes replacing an existing faucet aerator with low-flow aerator.

Algorithms

Unit Dth Savings per Year = $(GPM_{BASE} \times TF_{BASE} - GPM_{LOW} \times TF_{LOW}) \times (PH * FLU / FH) \times DF \times 365 \times Density \times C_P \times (T_{OUT} - T_{IN}) / (ReEff * 1{,}000{,}000)$

Where:

GPM_{BASE}	=	Actual or 2.2 gallons per minute (Ref. 5)
TF_{BASE}	=	Throttling factor for base use, 0.83 (Ref. 8)
GPM_{LOW}	=	Actual
TF_{LOW}	=	Throttling factor for installed use, 0.95 (Ref. 8)
PH	=	Number of people per household, per Table 1 (Ref. 3)
FLU	=	Fixture length of use in minutes / person per day, per Table 2 (Ref. 2)
FH	=	Fixtures per home per Table 2 (Ref. 2)
DF	=	Drain factor per Table 2 (Ref. 7). Drain factor accounts for the fact that a portion of faucet use is dictated by volume, not time (generally filling vessels, as opposed to washing items).
365	=	Days per year
Density	=	8.34 lb / gal
C_P	=	1.0 Btu / (lb x °F)

T_{OUT}	=	Temperature of faucet usage per Table 2 (Ref. 2)
T_{IN}	=	Average groundwater temperature per Table 4 (Ref. 4)
ReEff	=	Recovery efficiency gas water heater per Table 1 (Ref. 7)
1,000,000	=	Conversion from Btu to Dth

Example:

Direct installation of a 1.5 GPM faucet aerator in an apartment with gas water heat located in Zone 1, room type unknown.

Unit Dth Savings per Year = (2.2 x 0.83 – 1.5 x 0.95) x (2.17 x 3.1 / 1.22) x 0.83 x 365 x 8.34 x 1 x (90 – 46.5) / (0.67 x 1,000,000) = 0.36 Dth

Deemed Input Tables

Table 1. People per Household (Ref. 3) and ReEff (Ref. 7)

Application	PH	ReEff
Single-Family	2.59	0.78
Multi-Family*	2.17	0.67
If unknown	2.38	0.73

* Includes buildings with 2+ units and townhomes

Table 2. Fixture Length of Use and T_{OUT} (Ref. 2), and Drain Factor (Ref. 7)

Location	FLU	T_{OUT}	DF
Kitchen	4.5	93°F	0.75
Bathroom	1.6	86°F	0.90
Unknown	3.1	90°F	0.83

Table 3. Fixtures Per Home (Ref. 2)

Application	Location	FH
Single-Family	Kitchen	1
	Bathroom	2.04
	Unknown	1.52
Multi-Family*	Kitchen	1
	Bathroom	1.43
	Unknown	1.22
Unknown	Unknown	1.37

Table 4. Average groundwater temperatures (Ref. 4)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

References

1. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values. http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf. Accessed on 7/31/12.
2. Cadmus and Opinion Dynamics. Showerhead and Faucet Aerator Meter Study. Memo to Michigan Evaluation Working Group. June 2013.
3. U.S. Census Bureau, *Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates)* for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table
4. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
5. Title 10, Code of Federal Regulations, Part 430 – Energy Conservation Program for Consumer Products, Subpart C – Energy and Water Conservation Standards and Their Effective Dates. https://www.ecfr.gov/cgi-bin/text-idx?SID=45151ba12ebfbba8afbf95d31bcd2ace&mc=true&node=pt10.3.430&rgn=div5#sp10.3.430.c
6. 2008 Database for Energy-Efficient Resources, Cost Values and Summary Documentation http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf. Accessed on 7/31/12.
7. Illinois Stakeholder Advisory Group. State of Illinois Energy Efficiency Technical Reference Manual, Version 6.0, Volume 3: Residential Measures. February 8th, 2017. Page 179. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf
8. M. Schuldt and D. Tachibana. *Energy-Related Water Fixture Measurements: Securing the Baseline for Northwest Single Family Homes*. August 2008. Page 1-265. http://www.seattle.gov/light/Conserve/Reports/paper_10.pdf

Revision History

Version	Description	Author	Date
1.0	Created standalone spec from ResidentialElectricDHW_v03.2	Joe Plummer	
2.0	Revised formatting and algorithms	Franklin Energy Services	7/27/2012
2.1	Update the measure life and measure cost	Franklin Energy Services	7/27/2012
3.0	Corrected Energy Factor equations	Franklin Energy Services	3/20/2013
3.1	Changed action from Direct Install to Replace Working	Joe Plummer	4/5/2013
3.2	Removed extra multiplication sign following Eff in savings algorithms	Joe Plummer	8/28/2013
3.3	Changed "electric or gas water heater" to "confirmation of gas water heater" in Required Inputs, changed efficiency to recovery efficiency of 0.75 and updated example accordingly	Joe Plummer	11/25/13
3.4	Added residence type (single family or multi-family) to required inputs	Joe Plummer	1/3/14
3.5	Removed “owner-occupied” from single-family and “renter-occupied” from multifamily in Table 1, added footnotes clarifying multifamily definition.	Joe Plummer	3/11/14
4.0	Added average input values and a deemed value for applications where the inputs are unknown.	Franklin Energy Services	10/20/15
5.0	Updated algorithm for kWh and kW savings, splitting out savings for kitchen and bathroom aerators, and using actual installed GPM and drain and throttling factors	Cadmus	10/2018

Residential Hot Water - Gas Water Heater Setback

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size gas water heaters
Actions	Operations and Maintenance
Required from Customer/Contractor	Confirmation of gas water heater, project location (county), building type (single family or multi-family*) * Includes buildings with 2+ units and townhomes
Version No.	3.2
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	2 (Ref. 2)
Unit Participant Incremental Cost	$0

Measure Description

This measure involves turning the water heater set point temperature to 120°F on residential storage-type gas water heaters. The action must be performed by a utility representative on site during a home energy audit or other home visit.

The existing temperature set point is assumed to be 130°F.

Algorithms

Unit Dth Savings per Year = SpecificHeat x Density x Gal_Person x People x 365 x (Tset - Tin) x Savings_Factor/ Eff / ConversionFactor

Where:

SpecificHeat = 1.0 btu / (lb x °F)

Density = 8.34 lbs / gal

Gal_Person = See Table 2; Daily hot water usage per person

People = See Table 3; Number of people per household

Tset1 = 130 °F (assumed average starting temperature)

Tin = Average groundwater temperature per Table 1

Eff (gas) = 0.59 (2004 Federal minimum Energy Factor for 40 gal tank = 0.67 - 0.0019 x 40)

Eff (elec) = 0.92 (2004 Federal minimum Energy Factor for 40 gal tank = 0.97 - 0.00132 x 40)

ConversionFactor = 3,412 Btu/kWh (electric water heater) or 1,000,000 Btu/MMBtu (gas water heater)

Savings_Factor = 4% (Ref. 3)

Example:

A direct install team reduces the set point of a gas water heater in a single-family home in Zone 1.

Unit Dth Savings per Year = (1.0 Btu/lb°F) x (8.34 lb/gal) x (20.4 gal/day/person) x (2.59 people) x (365 day/yr) x (130°F - 46.5°F) x 4% / (0.59) / (1,000,000 Btu/Dth) = 0.91 Dth saved

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 4)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Daily Hot Water Usage per Person (Ref. 6)

Application	Gal/day/person
Single-Family	20.4
Multi-Family*	18.7

* Includes buildings with 2+ units and townhomes

Table 3. People per Household (Ref. 7)

Application	Num_People
Single-Family	2.59
Multi-Family*	2.17

* Includes buildings with 2+ units and townhomes

Methodology and Assumptions

The savings from lowering the temperature setpoint 10°F is 3% to 5% of the overall domestic hot water energy. (Ref. 3)

The existing temperature is assumed to be 130°F (Ref. 5)

Notes

There are no current energy standards for this measure. The previous algorithm assumed that all hot water uses are done at max temperature, when in reality only a few are (i.e. clothes washer, dishwasher, misc. cleaning, etc.). The result of this was that the savings was being overestimated (i.e. 446 kWh, resulting in ~13% overall DHW savings). The IL TRM however, only accounts for the

aforementioned uses and ignores the reduction in standby losses by lowering the delta T. The result of this is that the savings is underestimated (i.e. 49 kWh). The DOE estimates a savings that is between these two values. The savings value given by DOE estimates are supported by Ref. 2 (Efficiency Vermont TRM).

The excel algorithms yield a savings of 158 kWh and 0.84 Dth, which is within 4% of the values for Zone 1-single-family applications. The difference in savings will increase in zones 2 and 3 and in multi-family applications.

References

1. Daily hot water usage is based on CEE's tankless water heater field study in Mpls/St. Paul (2008-2010); Supported by Focus on Energy's Residential Deemed Savings Review, page 4.
2. Efficiency Vermont Technical Reference User Manual (TRM), 2/19/2010. Page 409. This value is supported by the Illinois Technical Reference User Manual, 2012.
3. Average of 3-5% savings values on DOE website, Accessed 7/2 http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090.
4. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
5. Franklin Energy Services internal value.
6. Interpolated values from Table 38, Ohio Technical Reference Manual. October 15, 2009. p. 52.
7. U.S. Census Bureau, *Selected Housing Characteristics 2010 American Commnity Survey 1-Year Estimates)* for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table

Revision History

Version	Description	Author	Date
1.0	Originally part of ResidentialGasDHW_v03.2 which was derived from Nexant spec; changed algorithm to assume an average starting and final temperature rather than using an unsupported savings factor	Joe Plummer	
2.0	Updated algorithm to use Savings_Factor of 4%	Franklin Energy Services	7/26/2012
2.1	Updated measure lifetime per Ref. 2	Franklin Energy Services	7/27/2012
3.0	Updated the hot water usage to be consistent with the hot water heater measure algorithm	Franklin Energy Services	8/6/2012
3.1	Changed action type to Modify, changed "electric or gas water heater" to "confirmation of gas water heater" in Required Inputs, changed example to compute gas savings instead of electric	Joe Plummer	11/25/2013
3.2	Added footnotes clarifying multifamily definition. In Dth algorithm, replaced Gal/Day with Gal_Person x People.	Joe Plummer	3/18/2014

Residential Hot Water - Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Water Heating
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size gas water heaters
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Confirmation of gas water heater, tank size in gallons, new water heater uniform energy factor (UEF), UEF Usage Bin (High or Medium), single-family or multifamily*, project location (county) * Includes buildings with two or more units and townhomes
Version No.	5.2
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 years for storage models, 20 years for tankless models (Ref. 2)
Unit Participant Incremental Cost	See Table 4

Measure Description

This measure includes replacement of failed or working storage-type, domestic gas-fired storage and instantaneous water heaters in residential and multifamily buildings, as well as installation of gas-fired storage or instantaneous water heaters in new construction.

The baseline is assumed to be a natural gas-fired residential storage water heater, including for new instantaneous gas-fired water heater installations.

Algorithms

Unit Dth Savings per Year = $Energy_{HEATH2O}$ x (1 / UEF_{BASE} - 1 / UEF_{EFF}) / 1,000,000

$Energy_{HEATH2O} = C_P \times \rho \times$ Gallons/Person × People × 365 / Yr × ($T_{SET} - T_{COLD}$)

Where:

C_P = Specific heat of water, 1.0 btu/(lb·°F)

ρ = Density of water, 8.34 lbs/gal

Gallons/Person = Daily hot water usage per person, see Table 2

People = Number of people per household, see Table 3

365 = Days per year

T_{SET} = 120˚F (Ref. 4)

T_{COLD} = Average groundwater temperature, see Table 1

UEF_{BASE}	=	Base water heater uniform energy factor, 0.603 (see Notes) or use actual, see Table 5.
UEF_{EFF}	=	New water heater uniform energy factor
1,000,000	=	Conversion from Btu to Dth

Example:

A single-family customer in Zone 2 has installed a new 50-gallon gas-fired water heater (UEF = 0.7, Medium Usage Bin) to replace their previous gas-fired storage water heater.

UEF_{BASE}=0.6483 – (0.0017 x 50) = 0.5633

$Energy_{HEATH2O}$ = 1.0 btu / lb·˚F × 8.34 lbs / gal × 20.4 gal / person × 2.59 People × 365 Days / Yr × (120°F - 49.1°F) = 11,403,419 Btu / yr

Unit Dth Savings per Year = 11,403,419 x (1/0.5633 – 1/0.7) / 1,000,000 = 4.0 Dth

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 1)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Daily Hot Water Usage per Person (Ref. 5)

Application	(Gal/day)/person
Single-Family	20.4
Multi-Family*	18.7
If unknown	19.6

* Includes buildings with two or more units and townhomes

Table 3. People per Household (Ref. 6)

Application	Num_People
Single-Family	2.59
Multi-Family*	2.17
If unknown	2.38

* Includes buildings with 2+ units and townhomes

Table 4. Incremental Cost by Type (Ref. 2)

Type of Water Heater	Incremental Cost
Gas storage	$400
Condensing gas storage	$685
Instantaneous Gas	$605

Table 5. Baseline Efficiency (Ref. 8)

Tank Size	Draw Pattern	UEF Formula	UEF Value for Tank Size (Gallons)				
			30	40	50	55	75
≥20 gal and ≤55 gal	Very Small	0.3456 – (0.0020 * V)	0.2856	0.2656	0.2456	0.2356	n/a
	Low	0.5982 – (0.0019 * V)	0.5412	0.5222	0.5032	0.4937	
	Medium	0.6483 – (0.0017 * V)	0.5973	0.5803	0.5633	0.5548	
	High	0.6920 – (0.0013 * V)	0.6530	0.6400	0.6270	0.6205	
>55 gal and ≤100 gal	Very Small	0.6470 – (0.0006 * V)	n/a				0.6020
	Low	0.7689 – (0.0005 * V)					0.7314
	Medium	0.7897 – (0.0004 * V)					0.7597
	High	0.8072 – (0.0003 * V)					0.7847
Instant	Very Small	0.80	n/a				
	Low	0.81					
	Medium	0.81					
	High	0.81					

If the tank volume and draw pattern of the storage water heater are known, UEF_{BASE} should be calculated from the above table. For instant water heaters, a storage baseline with a 40 gallon tank can be assumed. If tank volume or draw pattern are unknown, a UEF_{BASE} of 0.603 can be assumed for storage or instant water heaters (see Notes).

Notes

Of the 1,047 storage water heaters and 350 instantaneous water heaters in the AHRI Certification Directory (Ref. 11), 0% are very low draw pattern, 1% are low, 28% are medium, and 71% are high. 9% are 29 – 30 gallon, 39% are 38 – 40 gallon, 42% are 48 – 55 gallon, and 10% are 74 – 100 gallon. Most installations are expected to be 40 to 50 gallon, medium or high draw pattern. The deemed UEF_{BASE} value of 0.603 is the average of the calculated UEF values for these scenarios.

Table 6. ENERGY STAR Equipment Standards, effective 4/16/2015 (Ref. 7)

Criteria		ENERGY STAR Requirements
Gas Storage Water Heaters	≤ 55 gallons	Medium Draw Pattern UEF ≥ 0.64
		High Draw Pattern UEF ≥ 0.68
	>55 gallons	Medium Draw Pattern UEF ≥ 0.78
		High Draw Pattern UEF ≥ 0.80
Gas Instantaneous Water Heaters		UEF ≥ 0.87

References

1. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.
2. Illinois Stakeholder Advisory Group. *2021 Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 9.0, Volume 3: Residential Measures.* September 25, 2020. https://ilsag.s3.amazonaws.com/IL-TRM_Effective_010121_v9.0_Vol_3_Res_09252020_Final.pdf
3. Values are from DOE, 2010 Residential Heating Products Final Rule Technical Support Document, Tables 8.2.13-14, 8.2.16 (http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_ch8.pdf). The values are interpreted with explanation in the "Cost Info" tab of this worksheet.
4. "Lower Water Heating Temperature for Energy Savings," Department of Energy website, http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090. Accessed 7/26/12.
5. Interpolated values from Table 38, Ohio Technical Reference Manual. October 15, 2009. Page 52.
6. U.S Census Bureau, Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates) for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table.
7. ENERGY STAR Water Heater Product Criteria. https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria
8. Code of Federal Regulations Section 430 Part 32. §430.32 Energy and water conservation standards and their compliance dates. https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-430/subpart-C/section-430.32

Revision History

Version	Description	Author	Date
1.0	Created standalone spec from ResidentialElectricDHW_v03.2	Joe Plummer	
2.0	Updated the groundwater temperatures	Franklin Energy Services	7/23/2012
2.1	Added example	Franklin Energy Services	7/23/2012
2.2	Amended description, measure requirements and EF_Efficient	Franklin Energy Services	7/23/2012
2.3	Updated the incremental costs	Franklin Energy Services	7/23/2012
3.0	Updated the hot water usage	Franklin Energy Services	8/6/2012
4.0	Updated measure lifetimes for tankless water heaters	Franklin Energy Services	3/20/13
4.1	Added footnotes clarifying multifamily definition, changed “tankless” to “instantaneous” since some instantaneous water heaters have small buffer tanks	Joe Plummer	3/12/2014
5.0	Added unknown input values	Franklin Energy Services	11/11/15
5.1	Updated EF efficiency value to UEF value	Franklin Energy Services	9/28/17
5.2	Allowed storage baselines for instant water heaters, added deemed UEF_{BASE} for when volume and draw are unknown	Cadmus	9/2021

Residential Hot Water - Heat Pump Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Water Heating
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size electric water heaters
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Tank size in gallons, new water heater uniform energy factor (UEF), UEF draw pattern (High, Medium, Low, or Very Small), single- or multi-family*, project location (county), space heat fuel source. * Includes buildings with two or more units and townhomes
Version No.	1.4
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	13 years (Ref. 3)
Unit Participant Incremental Cost	$784 (Ref. 3)

Measure Description

This measure includes replacement of failed or working storage-type electric resistance water heaters in residential and multifamily buildings with more efficient storage-type electric heat pump water heaters.

Algorithms

Unit kWh Savings per Year = $Energy_{HEATWATER}$ x ($1/UEF_{MIN}$ – 1/UEF) x ESAF / CF_1

Unit Peak kW Savings = (Unit kWh Savings per Year) / 8760 / ESAF

Unit Dth Savings per Year = (Unit kWh Savings per Year) / ESAF x CF_2 x GIF

Where:

$Energy_{HEATWATER}$ = SpecificHeat × Density × Gallons / Person × People × 365 Days / Yr × (T_{SET} – T_{COLD}

SpecificHeat = 1.0 btu / (lb·°F)

Density = 8.34 lbs / gal

Gallons/Person = See Table 2; daily hot water usage per person.

People = See Table 3; number of people per household.

T_{SET} = 120˚F (Ref. 7)

T_{COLD} = See Table 1; average groundwater temperature.

UEF_{MIN} = See Table 4; base water heater efficiency based on tank size. If draw pattern is unknown, assume medium.

UEF	=	Uniform Energy Factor (UEF) of new water heater
ESAF	=	0.68 if electric space heat,1.0 if gas space heat; electric savings adjustment factor. (Ref. 8)
GIF	=	-0.65 if gas space heat,0 if electric space heat; Gas Impact Factor. (Ref. 11)
CF_1	=	3,412 Btu / kWh
CF_2	=	0.003412 Dth/kWh

Example:

A single-family customer in Zone 2 has installed a new 50-gallon heat pump water heater with an UEF of 2.56, Medium Usage bin, in their electrically heated home.

UEF_min=0.9307 – (0.0002 × 50)=0.9207

$Energy_{HeatWater}$ = 1 × 8.34 × 20.4 × 2.59 × 365 × (120 - 49.1) = 11,411,230 Btu/yr

Unit kWh Savings per Year = 11,411,230 x (1/0.9207 – 1/2.56) x 0.68 / 3,412 = 1,582 kWh

Unit Peak kW Savings per Year = 1,582/8760/0.68 = 0.27 kW

Unit Dth Savings per Year = 1,582 / 0.68 x 0.003412 x 0 = 0 Dth

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 4)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Daily Hot Water Usage per Person (Ref. 6)

Application	(Gal/day)/person
Single-Family	20.4
Multi-Family*	18.7
If unknown	19.6

* Includes buildings with two or more units and townhomes

Table 3. People per Household (Ref. 7)

Application	Num_People
Single-Family	2.59
Multi-Family*	2.17
If unknown	2.38

* Includes buildings with two or more units and townhomes

Notes

Table 4. Baseline efficiency based federal minimum efficiency standards (UEF) (Ref. 4)

Product Class	Rated Storage Volume	Draw Patten	Uniform Energy Factor
Electric Storage Water Heaters	≥ 20 gallons and ≤ 55 gallons	Very Small	0.8808 – (0.0008 × Gal)
		Low	0.9254 – (0.0003 × Gal)
		Medium	0.9307 – (0.0002 × Gal)
		High	0.9349 – (0.0001 × Gal)
	> 55 gallons and ≤ 100 gallons	Very Small	1.9236 – (0.0011 × Gal)
		Low	2.0440 – (0.0011 × Gal)
		Medium	2.1171 – (0.0011 × Gal)
		High	2.2418 – (0.0011 × Gal)

Table 5. ENERGY STAR Equipment Standards, effective 4/16/2015 (Ref. 12)

Type of Equipment	Energy Factor
Electric Storage Water Heaters, ≤ 55 gallons	UEF ≥ 2.00
Electric Storage Water Heaters, > 55 gallons	UEF ≥ 2.20

References

1. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules. http://energy.gov/eere/buildings/building-america-analysis-spreadsheets Accessed 12/19/2014.
2. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.
3. NOTICE OF PROPOSED RULEMAKING TECHNICAL SUPPORT DOCUMENT ENERGY CONSERVATION PROGRAM FOR CONSUMER PRODUCTS: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters. Chapter 8. US Department of Energy. November 23, 2009.
4. Code of Federal Regulations Section 430 Part 32. Energy and water conservation standards and their compliance dates. https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8, accessed 9/28/17.

5. "Lower Water Heating Temperature for Energy Savings," Department of Energy website, http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090. Accessed 7/26/12.
6. Interpolated values from Table 38, Ohio Technical Reference Manual. October 15, 2009. Page 52.
7. U.S. Census Bureau, Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates) for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table.
8. This factor accounts for a mix of water heater locations (assumes 64 percent are in conditioned space, Ref. 9) and that no electric savings will occur in the heating season (50 percent of the year) if the space heat is electric. 0.68 = 1 - (64% x 50%).
9. 2011 Residential Building Stock Assessment: Single-Family Characteristics and Energy Use. Page 83. http://neea.org/docs/reports/residential-building-stock-assessment-single-family-characteristics-and-energy-use.pdf.
10. Heating system usage assumed to be 24 hours x 182.5 days/year = 4,380. Based on MN TRM v2.0 Electronic Ignition Hearth measure.
11. This factor accounts for the increase in gas usage that results from the water heater being located in conditioned space. 1.3 = 6.6/5.0 x 50 percent, where 6.6 kWh represents the increase in daily space heating usage and 5.0 kWh represents the daily DHW usage and 50 percent accounts for the heating season being approximately half of the year. *The Impact of Heat Pump Water Heaters on Whole-House Energy Consumption*, Canadian Mortgage and Housing Corporation.
12. ENERGY STAR® Water Heater Product Criteria. https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria.
13. Illinois Energy Efficiency Stakeholder Advisory Group. *V7.0 Errata Measures Effective 01/01/2019*. Page 166. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_7/v7.0_Errata_Measures_Memo_FINAL_09-12-2019.pdf

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	11/10/13
1.1	Added ENERGY STAR criteria, updated Table 4	Franklin Energy Services	9/27/16
1.2	Updated EF efficiency value to UEF value	Franklin Energy Services	9/28/17
1.3	Updated ENERGY STAR UEF value	Cadmus	10/2018

Residential Hot Water - Low Flow Showerheads with Electric Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential: Single-family and Multi-family
Target End Uses	DHW
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size electric water heaters
Actions	Replace Working
Required from Customer/Contractor	Confirmation of electric water heater, building type (single-family or multi-family*), project location (county) * Includes buildings with 2+ units and townhomes
Version No.	5.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 4)
Unit Participant Incremental Cost	$12 (Ref. 5)

Measure Description

This measure involves replacing a standard showerhead with a low flow showerhead.

Algorithms

Unit kWh Savings per Year = $(GPM_{BASE} – GPM_{LOW})$ x (PH x SPD x SL / SPH) x 365 x Density x C_P x $(T_{OUT} – T_{IN})$ / (ReEff x 3,412)

Unit Peak kW Savings = Unit kWh Savings per Year x CF / Hours

Where:

GPM_{BASE}	=	Actual or 2.5 gallons per minute (Ref. 3)
GPM_{LOW}	=	Actual
PH	=	Number of people per household per Table 2
SPD	=	Showers per person per day = 0.6 (Ref. 6)
SL	=	Shower length in minutes / shower = 7.8 (Ref. 6)
SPH	=	Showerheads per Household per Table 3
365	=	Days per year
Density	=	8.34 lbs/gal
C_P	=	1.0 Btu/(lb°F)
T_{OUT}	=	Temperature of typical shower usage = 101°F (Ref. 6)

T_{IN}	=	Average groundwater temperature per Table 1
ReEff	=	Recovery efficiency = 98% (electric water heater) (Ref. 6)
3,412	=	Conversion from Btu to kWh
CF	=	Coincidence factor = 0.0023 (Ref. 7)
Hours	=	Hours of use per year = (PH x SPD x SLU / SPH) x 365 / 60

Example:

Direct installation of a 1.5 GPM low-flow showerhead in an apartment with electric water heat located in Zone 3.

Unit kWh Savings per Year = (2.5 – 1.5) x (2.17 x 0.6 x 7.8 / 1.3) x 365 x 8.34 x 1 x (101 – 51.3) / (0.98 x 3,412) = 353 kWh

Hours = (2.17 x 0.6 x 7.8 / 1.3) x 365 / 60 = 47.5 hours

Unit Peak kW Savings = 353 x 0.0023 / 47.5 = 0.017 kW

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 2)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. People per Household (Ref. 1)

Application	PH
Single-Family	2.59
Multi-Family*	2.17
If unknown	2.38

* Includes buildings with 2+ units and townhomes

Table 3. Showerheads per Household (Ref. 7)

Application	SPH
Single-Family	1.50
Multi-Family*	1.11
If unknown	1.31

* Includes buildings with 2+ units and townhomes

References

1. U.S. Census Bureau, Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates) for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table
2. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules. http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
3. Title 10, Code of Federal Regulations, Part 430 – Energy Conservation Program for Consumer Products, Subpart C – Energy and Water Conservation Standards and Their Effective Dates. https://www.ecfr.gov/cgi-bin/text-idx?SID=45151ba12ebfbba8afbf95d31bcd2ace&mc=true&node=pt10.3.430&rgn=div5#sp10.3.430.c
4. Table C-6, Measure Life Report, Residential and Commercial/Industral Lighting and HVAC Measures, GDS Associates, June 2007. Evaluations indicate that consumer dissatisfaction may lead to reductions in persistence, particularly in Multi-Family, http://neep.org/uploads/EMV%20Forum/EMV%20Studies/measure_life_GDS%5B1%5D.pdf
5. Illinois Stakeholder Advisory Group. State of Illinois Energy Efficiency Technical Reference Manual, Version 6.0, Volume 3: Residential Measures. February 8th, 2017. Page 179. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf
6. Cadmus and Opinion Dynamics. Showerhead and Faucet Aerator Meter Study. Memo to Michigan Evaluation Working Group. June 2013.
7. Public Service Commision of Wisconsin. Wisconsin Focus on Energy 2017 Technical Reference Manual. Spring 2017. Page 642. https://focusonenergy.com/sites/default/files/Focus%20TRM-%20Spring%202017-%20Final%20for%20Posting%20May%202017_0.pdf

Revision History

Version	Description	Author	Date
1.0	Created standalone spec from ResidentialElectricDHW_v03.2	Joe Plummer	
2.0	Changed algorithm per IL TRM and modified the HW usage estimates	Franklin Energy Services	7/31/2012
2.1	Changed Measure Lifetime from 7 to 10	Franklin Energy Services	7/31/2012
3.0	Updated ShowerWater description to read "shower water…" instead of "hot water…"	Franklin Energy Services	1/4/2013
3.1	Changed action from Direct Install to Replace Working; Added residence type to list of required inputs from customer/vendor; Changed description of Tshower from "typical faucet usage" to "typical shower usage"; Changed "Required Inputs from Direct Installer" to "Required Inputs from Customer/Contractor"	Joe Plummer	4/8/2013
3.2	Changed “electric or gas water heater” to “confirmation of electric water heater” under required inputs, changed efficiency to recovery efficiency of 0.98 and updated example accordingly, changed annual hours to 8,766	Joe Plummer	11/25/2013
3.3	Added footnotes clarifying multifamily definition	Joe Plummer	3/18/2014
4.0	Added average input values and a deemed value for applications where the inputs are unknown	Franklin Energy Services	10/15/2015
4.1	All hours of use changed to 365.25	Franklin Energy Services	1/13/2016
5.0	Updated algorithm for kWh and kW savings, using measured values for shower duration and temperature and actual installed GPM	Cadmus	10/2018

Residential Hot Water - Low Flow Showerheads with Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size gas water heaters
Actions	Replace Working
Required from Customer/Contractor	Electric or gas water heater, residence type (single-family or multi-family*), project location (county) * Includes buildings with 2+ units and townhomes
Version No.	5.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10 (Ref. 4)
Unit Participant Incremental Cost	$12 (Ref. 5)

Measure Description

This measure involves replacing a standard showerhead with a low flow showerhead.

Algorithms

Unit Dth Savings per Year = $(GPM_{BASE} – GPM_{LOW}) \times (PH \times SPD \times SL / SPH) \times 365 \times Density \times C_P \times (T_{OUT} – T_{IN}) / (ReEff \times 1{,}000{,}000)$

Where:

GPM_{BASE}	=	Actual or 2.5 gallons per minute (Ref. 3)
GPM_{LOW}	=	Actual
PH	=	Number of people per household per Table 2
SPD	=	Showers per person per day = 0.6 (Ref. 6)
SL	=	Shower length in minutes / shower = 7.8 (Ref. 6)
SPH	=	Showerheads per Household per Table 3
Density	=	8.34 lbs / gal
C_P	=	1.0 Btu/(lb°F)
T_{OUT}	=	Temperature of typical shower usage = 101°F (Ref. 6)
T_{IN}	=	Average groundwater temperature per Table 1

ReEff	=	Recovery efficiency (gas water heater) per Table 2 (Ref. 5)
1,000,000	=	Conversion from Btu to Dth

Example:

Direct installation of a 1.5 GPM low-flow showerhead in an apartment with gas water heat located in Zone 3.

Unit Dth Savings per Year = (2.5 – 1.5) x (2.17 x 0.6 x 7.8 / 1.3) x 365 x 8.34 x 1 x (101 – 51.3) / (0.67 x 1,000,000) = 1.76 Dth

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 2).

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. People per Household (Ref. 1) and ReEff (Ref. 5)

Application	PH	ReEff
Single-Family	2.59	0.78
Multi-Family*	2.17	0.67
If unknown	2.38	0.73

* Includes buildings with 2+ units and townhomes

Table 3. Showerheads per Household (Ref. 6)

Application	SPH
Single-Family	1.50
Multi-Family*	1.11
If unknown	1.31

* Includes buildings with 2+ units and townhomes

References

1. U.S. Census Bureau, *Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates)* for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table
2. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules.* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html

3. Title 10, Code of Federal Regulations, Part 430 – Energy Conservation Program for Consumer Products, Subpart C – Energy and Water Conservation Standards and Their Effective Dates. https://www.ecfr.gov/cgi-bin/text-idx?SID=45151ba12ebfbba8afbf95d31bcd2ace&mc=true&node=pt10.3.430&rgn=div5#sp10.3.430.c
4. Table C-6, Measure Life Report, Residential and Commercial/Industial Lighting and HVAC Measures, GDS Associates, June 2007. Evaluations indicate that consumer dissatisfaction may lead to reductions in persistence, particularly in Multi-Family, http://neep.org/uploads/EMV%20Forum/EMV%20Studies/measure_life_GDS%5B1%5D.pdf
5. Illinois Stakeholder Advisory Group. State of Illinois Energy Efficiency Technical Reference Manual, Version 6.0, Volume 3: Residential Measures. February 8th, 2017. Page 179. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf
6. Cadmus and Opinion Dynamics. Showerhead and Faucet Aerator Meter Study. Memo to Michigan Evaluation Working Group. June 2013.

Revision History

Version	Description	Author	Date
1.0	Created standalone spec from ResidentialElectricDHW_v03.2	Joe Plummer	
2.0	Changed algorithm per IL TRM and modified the HW usage estimates; Changed Measure Lifetime from 7 to 10	Franklin Energy Services	7/31/2012
3.0	Updated ShowerWater description to read "shower water…" instead of "hot water…"	Franklin Energy Services	1/4/2013
3.1	Changed Action type from Direct Install to Replace Working; Added residence type to list of required inputs from customer/vendor; Changed description of Tshower from "typical faucet usage" to "typical shower usage"; Changed "Required Inputs from Direct Installer" to "Required Inputs from Customer/Contractor"	Joe Plummer	4/8/2013
3.2	Changed action type to Modify, changed "electric or gas water heater" to "confirmation of gas water heater" in Required Inputs, changed efficiency to recovery efficiency of 0.75 and updated example accordingly	Joe Plummer	11/25/2013
3.3	Added footnotes clarifying multifamily definition	Joe Plummer	3/18/2014
4.0	Added average input values and a deemed value for applications where the inputs are unknown.	Franklin Energy Services	10/20/2015
5.0	Updated algorithm for Dth savings, using measured values for shower duration and temperature and actual installed GPM	Cadmus	10/2018

Residential Hot Water - Pipe Insulation with Electric Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single-family, duplexes and townhomes with electric water heaters.
Actions	Modify
Required from Customer/Contractor	Length of pipe insulation (linear feet), confirmation of electric water heater
Version No.	3.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	13 (Ref. 3)
Unit Participant Incremental Cost	$3.63 per foot (Ref. 4)

Measure Description

This measure includes installing pipe insulation on un-insulated piping of an electric water heating system.

Algorithms

Unit kWh Savings per Year = (Qloss_base - Qloss_insul) x Hours x Length / ConversionFactor / Eff

Unit Peak kW Savings = Unit kWh Savings per Year / 8,760 hours

Where:

Qloss_base = See Table 1 for values. Heat loss (Btu/ft) from bare piping.

Qloss_insul = See Table 1 for values. Heat loss (Btu/ft) from insulated piping.

Length = Length of pipe insulation in linear feet (provided by customer)

Eff = 0.92

Hours = 4,823 hours; Hours when outside air temperature is above building balance point. Heat loss from pipe is wasted. (Ref. 5)

ConversionFactor = 3,412 Btu/kWh

Example:

A customer installed R-2 insulation on one foot of un-insulated hot water piping.

Unit kWh Savings per Year = (36.9 Btu/ft - 6.9 Btu/ft) x 4,823 hours x 1 ft. / 3,412 Btu/kWh / 0.92 = 46.1 kWh

Unit Peak kW Savings= 46.1 kWh / 8,760 hours = 0.0053 kW

Deemed Input Tables

Table 1. Average Heat Loss Figures (Ref. 5)

Location	Avg. Heat Loss of Bare Pipe (Btu/ft)	Avg. Heat Loss of Insulated Pipe (Btu/ft)
Zone 1, 2, and 3	36.9	6.9

Methodology and Assumptions

Pipes are assumed to be an equal mix of 1/2", 3/4" and 1" sizes. Insulation is assumed to be R-2 pipe insulation. T_hot = 120°F; (Ref. 2; to be consistent with other DHW measures). T_ambient = 60°F (Ref. 1)

Notes

Section N1103.3 of the 2006 International Residential Code requires mechanical system piping that is capable of carrying fluids above 105 degrees F or below 55 degrees F to be insulated to a minimum of R-2.

References

1. The ambient temperature is assumed to be 60°F, based on the estimated temperature of a basement where the water heater is assumed to be located.
2. "Lower Water Heating Temperature for Energy Savings," Department of Energy, Accessed 7/26/12. http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090.
3. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values. http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf. Accessed on 7/31/12.
4. 2008 Database for Energy-Efficient Resources, Cost Values and Summary Documentation (updated 6/2/2008 - NR linear fluorescent labor costs typo) http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf. Accessed on 7/31/12.
5. Xcel Energy 2010-2012 CIP Triennial (Docket No. E, G002/CIP-09-198), Pages 470-477.

Revision History

Version	Description	Author	Date
1.0	Based on original from Nexant, cleaned up and reformatted	Joe Plummer	
2.0	Reformatted	Franklin Energy Services	7/26/2012
2.1	Updated the measure cost value/source	Franklin Energy Services	7/31/2012
2.2	Updated the measure lifetime from 15 to 13	Franklin Energy Services	7/31/2012
2.3	Changed Action to Modify, changed Table1 so that same heat loss figures apply to all zones, delete zip code from required inputs, added confirmation of electric water heater to required inputs, changed annual hours to 8,766	Joe Plummer	11/24/13
3.0	Updated measure cost to “per foot”, moved T_hot and T_ambient to the Notes section, corrected sample calculation and removed some erroneous text.	Franklin Energy Services	1/6/16

Residential Hot Water - Pipe Insulation with Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	DHW
Applicable To	Residential customers in single-family, duplexes and townhomes with gas water heaters
Actions	Modify
Required from Customer/Contractor	Length of pipe insulation (linear feet), confirmation of gas water heater
Version No.	3.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	13 (Ref. 3)
Unit Participant Incremental Cost	$3.63 (Ref. 4)

Measure Description

This measure includes installing pipe insulation on un-insulated piping of a gas water heating system.

Algorithms

Unit Dth Savings per Year = (Qloss_base - Qloss_insul) x Hours x Length / ConversionFactor / Eff

Where:

Qloss_base = See Table 1 for values. Heat loss (Btu/ft) from bare piping; See "Btu per Foot" tab for explanation.

Qloss_insul = See Table 1 for values. Heat loss (Btu/ft) from insulated piping; See "Btu per Foot" tab for explanation.

Eff = 0.59

Hours = 4,823 hours; Hours when outside air temperature is above building balance point. Heat loss from pipe is wasted. (Ref. 5)

ConversionFactor = 1,000,000 Btu/Dth

Example:

A customer in Zone 1 installed R-2 insulation on one foot of un-insulated hot water piping

Unit Dth Savings per Year = (36.9 Btu/ft - 6.9 Btu/ft) x 4,823 hours x 1 ft. / 1,000,000 Btu/Dth / 0.59 = 0.245 Dth

Deemed Input Tables

Table 1. Average Heat Loss Figures (Ref. 5)

Location	Avg. Heat Loss of Bare Pipe (Btu/ft)	Avg. Heat Loss of Insulated Pipe (Btu/ft)
Zone 1, 2, and 3	36.9	6.9

Methodology and Assumptions

Pipes are assumed to be an equal mix of 1/2", 3/4" and 1" sizes.

Insulation is assumed to be R-2 pipe insulation.

T_hot = 120°F; (Ref. 2; to be consistent with other DHW measures)

T_ambient = 60°F (Ref. 1)

Notes

Section N1103.3 of the 2006 International Residential Code requires mechanical system piping capable of carrying fluids above 105 degrees F or below 55 degrees F to be insulated to a minimum of R-2.

References

1. The ambient temperature is assumed to be 60°F, based on the estimated temperature of a basement where the water heater is assumed to be located.
2. "Lower Water Heating Temperature for Energy Savings," Department of Energy website, http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090. Accessed 7/26/12.
3. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values. http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf. Accessed on 7/31/12.
4. 2008 Database for Energy-Efficient Resources, Cost Values and Summary Documentation (updated 6/2/2008 - NR linear fluorescent labor costs typo). Accessed on 7/31/12. http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf
5. Xcel Energy 2010-2012 CIP Triennial (Docket No. E, G002/CIP-09-198), Pages 470-477.

Revision History

Version	Description	Author	Date
1.0	Based on original from Nexant, cleaned up and reformatted	Joe Plummer	
2.0	Reformatted	Franklin Energy Services	7/26/2012
2.1	Updated the measure cost value/source	Franklin Energy Services	7/31/2012
2.2	Updated the measure lifetime from 15 to 13	Franklin Energy Services	7/31/2012
2.3	Changed Action to Modify, changed Table1 to use heat loss figures for all zones, delete zip code from required inputs, added confirmation of gas water heater to required inputs	Joe Plummer	11/24/13

Residential Hot Water - Thermostatic Restriction Valve with Electric Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential: Single-family and Multi-family
Target End Uses	DHW
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size electric water heaters
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Showerhead flow rate, zip code
Version No.	1.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$30 (Ref. 2)

Measure Description

This measure involves installing a thermostatically restricting shower valve that reduces the amount of excess hot shower water during warm-up periods.

Algorithms

Unit kWh Savings per Year = GPM_base x t_valve x Num_People x SPCD x 365 / SPH x EPG

Unit Peak kW Savings = Unit kWh Savings per Year / 8,760 hours

Where:

GPM_base = 1.5 gal/min, if unknown; Flow rate of showerhead.

T_valve = 0.94 minutes; Time that valve is restricted. (Ref. 3)

Num_People = Number of people per household per Table 1 (Ref. 4)

SPCD = 0.75; Showers per capita per day (Ref. 5)

SPH = Showerheads per Household per Table 2 (Ref. 5)

EPG = Energy to heat water in kWh/gal; = Density_H2O x Cp_H2O x (T_shower - T_cold) / (ReEff x C1)

Density_H2O = 8.33 lbs/gal

Cp_H2O = 1.0 Btu/lb-F

T_cold = See Table 3; Temperature of incoming water. (Ref. 7)

T_shower = 105 F; Temperature of shower water. (Ref. 5)

ReEff_electric = 0.98; Recovery efficiency of electric water heater (Ref. 6)

C1 = 3,412 Btu/kWh

Example:

Direct installation of a thermostatic restriction valve showerhead in an apartment with electric water heat located in Zone 3.

EPG (kWh/gal) = 8.33 lb/gal * 1.0 Btu/lb-°F * (105°F - 51.3°F) / (0.98 * 3,412 Btu/kWh) = 0.13378 kWh/gal

Unit kWh Savings per Year (kWh/yr) = 1.5 gal/min * 0.94 min * 2.21 * 0.75 * 365 days/yr / 1.3 x 0.13378 kWh/gal = 87.8 kWh

Peak kW Saved (kW) = 87.8 kWh / 8,760 hours = 0.010 kW

Deemed Input Tables

Table 1. People per Household (Ref. 4)

Application	Num_People
Single-Family (owner-occupied)	2.59
Multi-Family (renter-occupied)	2.17
If unknown	2.38

Table 2. Showerheads per Household (Ref. 5)

Application	SPH
Single-Family (owner-occupied)	1.79
Multi-Family (renter-occupied)	1.30
If unknown	1.55

Table 3. Average groundwater temperatures (Ref. 7)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

References

1. Pacific Gas and Electric Company Work Paper PGECODHW125. Accessed 07/20/15. http://www.water.ca.gov/waterenergygrant/2014Applications/Rising%20Sun%20Energy%20Center%20%20(201418760035)/Attachment%202%20-%20Att2_WE14_RisingSun_WEGHG_3ofTotal4.pdf.
2. Based on actual cost of the SS-1002CP-SB Ladybug Water-Saving Shower-Head adapter from Evolve showerheads. $29.95. Accessed 07/20/15. http://www.amazon.com/Evolve-Showerheads-SS-1002CP-SB-Water-Saving-Shower-Head/dp/B0017YXIKC.
3. This is a calculated value, based on information provided by the source in foonote 1 (shower length = 7.8 minutes) and Water and Energy Wasted During Residential Shower Events: Findings from a Pilot Field Study of Hot Water Distribution Systems by Jim Lutz, which concluded that 30% of shower water wasted and about 40% of energy used in the shower is wasted. 7.8 minutes * 30% * 40% = 0.94.
4. U.S. Census Bureau, Selected Housing Characteristics 2010 American Commnity Survey 1-Year Estimates) for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table.
5. Illinois Technical Reference Manual, 6/1/12. Pages 419-426. Accessed 07/20/15. http://ilsagfiles.org/SAG_files/Meeting_Materials/2012/June%2026,%202012%20Meeting/Illinois_Statewide_TRM_Final_Review.pdf.
6. Showerhead and Faucet Aerator Metering Study, Cadmus and Opinion Dynamics. June 2013.
7. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.

Revision History

Version	Description	Author	Date
1.0	Measure created	Franklin Energy Services	11/10/2015
1.1	Added conversion factor for gas	Franklin Energy Services	12/16/2015

Residential Hot Water - Thermostatic Restriction Valve with Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Residential: Single-family and Multi-family
Target End Uses	DHW
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size electric water heaters
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Showerhead flow rate, zip code
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$30 (Ref. 2)

Measure Description

This measure involves installing a thermostatically restricting shower valve that reduces the amount of excess hot shower water during warm-up periods.

Algorithms

Unit Dth Savings per Year = GPM_base x t_valve x Num_People x SPCD x 365 / SPH x EPG

Where:

GPM_base = 1.5 gal/min, if unknown; Flow rate of showerhead.

T_valve = 0.94 minutes; Time that valve is restricted. (Ref. 3)

Num_People = Number of people per household per Table 1 (Ref. 4)

SPCD = 0.75; Showers per capita per day (Ref. 5)

SPH = Showerheads per Household per Table 2 (Ref. 5)

EPG = Energy to heat water in Dth/gal; = Density_H2O x Cp_H2O x (T_shower - T_cold) / (ReEff x C1)

Density_H2O = 8.33 lbs/gal

Cp_H2O = 1.0 Btu/lb-F

T_cold = See Table 3; Temperature of incoming water. (Ref. 7)

T_shower = 105 F; Temperature of shower water. (Ref. 5)

ReEff_gas = 0.76; Recovery efficiency of gas water heater (Ref. 6)

C1 = 1,000,000 Btu/Dth

Example:

Direct installation of a thermostatic restriction valve showerhead in an apartment with gas water heat located in Zone 3.

EPG (kWh/gal) = 8.33 lb/gal * 1.0 Btu/lb-°F * (105°F - 51.3°F) / (0.76 * 1,000,000 Btu/Dth) = 0.000589 Dth/gal

Unit Dth Savings per Year (Dth/yr) = 1.5 gal/min * 0.89 min * 2.21 * 0.75 * 365 days/yr / 1.3 x 0.000589 Dth/gal = 0.366 Dth

Notes

Table 1. People per Household (Ref. 4)

Application	Num_People
Single-Family	2.59
Multi-Family*	2.17
If unknown	2.38

* Includes buildings with 2+ units and townhomes

Table 2. Showerheads per Household (Ref. 5)

Application	SPH
Single-Family	1.79
Multi-Family*	1.30
If unknown	1.55

* Includes buildings with 2+ units and townhomes

Table 3. Average groundwater temperatures (Ref. 7)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

References

8. Pacific Gas and Electric Company Work Paper PGECODHW125. Accessed 07/20/15. http://www.water.ca.gov/waterenergygrant/2014Applications/Rising%20Sun%20Energy%20Center%20%20(201418760035)/Attachment%202%20-%20Att2_WE14_RisingSun_WEGHG_3ofTotal4.pdf.
9. Based on actual cost of the SS-1002CP-SB Ladybug Water-Saving Shower-Head adapter from Evolve showerheads. $29.95. Accessed 07/20/15. http://www.amazon.com/Evolve-Showerheads-SS-1002CP-SB-Water-Saving-Shower-Head/dp/B0017YXIKC.

10. This is a calculated value, based on information provided by the source in foonote 1 (shower length = 7.8 minutes) and Water and Energy Wasted During Residential Shower Events: Findings from a Pilot Field Study of Hot Water Distribution Systems by Jim Lutz, which concluded that 30% of shower water wasted and about 40% of energy used in the shower is wasted. 7.8 minutes * 30% * 40% = 0.94.
11. U.S. Census Bureau, Selected Housing Characteristics 2010 American Commnity Survey 1-Year Estimates) for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table.
12. Illinois Technical Reference Manual, 6/1/12. Pages 419-426. Accessed 07/20/15. http://ilsagfiles.org/SAG_files/Meeting_Materials/2012/June%2026,%202012%20Meeting/Illinois_Statewide_TRM_Final_Review.pdf.
13. Showerhead and Faucet Aerator Metering Study, Cadmus and Opinion Dynamics. June 2013.
14. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.

Revision History

Version	Description	Author	Date
1.0	Measure created	Franklin Energy Services	11/10/2015

Residential Hot Water - Indirect Water Heaters

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Water Heating
Applicable To	Residential customers in single- and multi-family homes consisting of two units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size gas water heaters
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Confirmation of gas water heater, tank size in gallons, single-family or multifamily*, project location (county) * Includes buildings with two or more units and townhomes
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 (Ref. 4)
Unit Participant Incremental Cost	$988.50 (Ref. 5)

Measure Description

Indirect water heaters are applicable to any indirectly fueled water heater, and must be paired with a high-efficiency boiler. In addition, qualifying indirect water heaters must be whole-house units or used for domestic water heating.

Unlike other water heaters, indirect water heaters use a boiler as the heat source. The water heater may also have a direct energy source for non-heating seasons when the boiler is shut off and thus not able to meet the water heating demands

Algorithms

Unit Dth Savings per Year = $[Energy_{HEATWATER} \times (1/RE_{BASE} - 1/E_{C,EE}) + (UA_{BASE}/RE_{BASE} - UA_{EE}/E_{C,EE}) \times (T_{SET} - T_{ROOM}) * 8760] / 1{,}000{,}000$

Where:

$Energy_{HEAWATER}$ = SpecificHeat × Density × Gallons / Person × People × 365 Days / Yr × (T_{SET} – T_{COLD})

SpecificHeat = 1.0 btu/(lb·°F)

Density = 8.34 lbs/gal

Gallons/Person = See Table 2; daily hot water usage per person.

People = See Table 3; number of people per household.

T_{SET} = 120˚F (Ref. 7)

T_{COLD} = See Table 1; average groundwater temperature.

RE_{BASE}	=	base water heater recovery efficiency, Default = 0.77 (if efficiency is unknown) (Ref. 7)
$E_{C,EE}$	=	Combustion efficiency of energy-efficient boiler used to heat indirect water heater, Default = 0.95 (if efficiency is unknown)
UA_{BASE}	=	See Table 4; Overall heat loss coefficient of base tank type water heater (Btu/hr-°F)
UA_{EE}	=	See Table 4; Overall heat loss coefficient of indirect water heater storage tank (Btu/hr-°F)
T_{ROOM}	=	60˚F (Ref. 8)
1,000,000	=	Conversion from Btu to Dth

Example:

A single-family customer in Zone 2 has installed a 45 Gal. indirect water heater connecterd to a high efficiency boiler (EC = 0.95) to replace their previous gas-fired storage water heater.

$Energy_{HeatWater}$ = 1.0 btu / lb·°F × 8.34 lbs / gal × 20.4 gal / person × 2.59 People × 365 Days / Yr × (120°F - 49.1°F) = 11,403,419 Btu / yr

Unit Dth Savings per Year = [11,403,419 Btu / yr x (1/0.77 – 1/0.95) + (7.57 Btu/hr-°F /0.77 – 6.18 Btu/hr-°F /0.95 x (120°F – 60°F) x 8760] / 1,000,000 = 4.6 Dth

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 2)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Daily Hot Water Usage per Person (Ref. 1)

Application	(Gal/day)/person
Single-Family	20.4
Multi-Family*	18.7
If unknown	19.6

* Includes buildings with two or more units and townhomes

Table 3. People per Household (Ref. 3)

Application	Num_People
Single-Family	2.59
Multi-Family*	2.17
If unknown	2.38

* Includes buildings with 2+ units and townhomes

Table 4. Typical Values for UA based on size (Ref. 6)

Rated Storage Volume	UA, Baseline (gas storage water heater) (Btu/hr-°F)	UA, efficient (boiler) (Btu/hr-°F)
<40	6.88	4.79
40-79	7.57	6.18
80-120	13.80	7.43

Notes

This measure produces savings through both upgrading from the water heater recovery efficiency (RE) to the boiler combustion efficiency (Ec), and from the reduction in standby losses (represented by UA values for water heaters and boilers). Recommend using actual baseline water heater RE and boiler Ec. If the baseline RE is unknown, an average RE is provided by examining current AHRI data. Average UA values are also provided from AHRI data.

References

1. Daily hot water usage is based on CEE's tankless water heater field study in Minneapolis/St. Paul (2008-2010); Supported by Focus on Energy's Residential Deemed Savings Review, page 4.
2. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.
3. U.S Census Bureau, Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates) for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table.
4. Natural Gas Energy Efficiency Potential in Massachusetts. April 22, 2009. http://ma-eeac.org/wordpress/wp-content/uploads/5_Natural-Gas-EE-Potenial-in-MA.pdf
5. Average of Mean and Median costs using both approaches in table 1-4 from New York Statewide Residential Gas HighEfficiency Heating Equipment Programs. August 5, 2014 https://www.nationalfuelforthought.com/wp-content/uploads/2018/03/August-2014-New-York-Statewide-Residential-Gas-High-Efficiency-Heating-Equipment-and-National-Fuel-Gas-Distribution-Corporations-Residential-Rebate-Program-Impact-Evaluation.pdf

6. Based on average value from AHRI data for indirect water heaters. https://www.ahridirectory.org/Search/QuickSearch?category=8&searchTypeId=3&producttype=19
7. Based on average value from AHRI data for gas storage water heaters. https://www.ahridirectory.org/Search/QuickSearch?category=8&searchTypeId=3&producttype=15
8. The ambient temperature is assumed to be 60°F, based on the estimated temperature of a basement where the water heater is assumed to be located.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Cadmus	10/2018

Appliances

Residential Appliances - ENERGY STAR Clothes Washers

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Plug Loads
Applicable To	Residential customers in single-family homes and multi-family housing of 2 or more units (including 3- and 4-family homes, duplexes, townhomes and apartment complexes)
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Washer capacity in ft3, electric or gas water heating, electric or gas drying, confirmation of ENERGY STAR rating
Version No.	3.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	11 (Ref. 1)
Unit Participant Incremental Cost	$28.79 for top loading $210.12 for front loading $163.49 for unknown (Ref. 11)

Measure Description

This measure includes replacement of failed or working clothes washer in existing homes and multifamily common areas with ENERGY STAR clothes washers, or installation of an ENERGY STAR clothes washer in a new home or multifamily common area.

Algorithms

Unit kWh Savings per Year = $[(Cap/IMEF_{BASE} \times N) \times (CW_{BASE} + (DHW_{BASE} \times \%Elec_{DHW}) / R_{EFF} + (Dry_{BASE} \times \%Elec_{DRY}))] - [(Cap/IMEF_{EE} \times N) \times (CW_{EE} + (DHW_{EE} \times \%Elec_{DHW}) / R_{EFF} + (Dry_{EE} \times \%Elec_{DRY}))]$

Unit Peak kW Savings = Unit kWh Savings per Year / Hours x CF

Unit Dth Savings per Year = $[[(Cap/IMEF_{BASE} \times N) \times (DHW_{BASE} \times (1 - \%Elec_{DHW}) / R_{EFF} + Dry_{BASE} \times (1 - \%Elec_{DRY}))] - [(Cap/IMEF_{EE} \times N) \times (DHW_{EE} \times (1- \%Elec_{DHW}) / R_{EFF} + Dry_{EE} \times (1 - \%Elec_{DRY}))]] \times 0.003412$

Where:

Cap	=	Clothes washer capacity (ft^3); If unknown, assume 3.45 ft^3 (Ref. 12)
$IMEF_{BASE}$	=	See Table 1; Integrated Modified Energy Factor (ft^3/kWh/cycle)
$IMEF_{EE}$	=	See Table 2

N	=	For SF: 258 cycles/yr (Ref. 2); for MF: 1241 cycles/yr (Ref. 14)
CW_{BASE}	=	7 percent (Ref. 4); Percentage of total energy consumption for clothes washer operation
CW_{EE}	=	6 percent (Ref. 4)
DHW_{BASE}	=	33 percent (Ref. 4); Percentage of total energy consumption for water heating
DHW_{EE}	=	31 percent (Ref. 4)
Dry_{BASE}	=	59 percent (Ref. 4); Percentage of total energy consumption for dryer operation
Dry_{EE}	=	62 percent (Ref. 4)
$\%Elec_{DW}$	=	See Table 4; Percentage of domestic hot water savings assumed to be electric
$\%Elec_{DRY}$	=	See Table 4; Percentage of dryer savings assumed to be electric
RE	=	0.78 (gas water heater); 0.98 (electric water heater); recovery efficiency (Ref. 7)
0.003412	=	Conversion from kWh to Dth
Hours	=	For SF: 258 hrs; for MF: 1241 hrs; assumes 1 hour per cycle.
CF	=	For SF: 0.038 (Ref. 8); for MF: 0.045 (Ref. 16)

Example:

A residential customer installed a new ENERGY STAR clothes washer (unknown capacity) in a SF home with an electric water heater and electric dryer.

Unit kWh Savings per Year = [(3.45 / 1.64 x 258) x (7% + (33% x 100%) / 0.98 + (59% x 100%))] - [(3.45 / 2.24 x 258) x (6% + (31% x 100%) / 0.98 + (62% x 100%))] = 145.25 kWh

Unit Peak kW Savings = 145.25 / 258 x 0.038 = 0.021 kW

Deemed Input Tables

Table 1. Baseline Clothes Washer Performance Characteristics (Ref. 3 & Ref. 13)

Unit Type	$IMEF_{BASE}$	IWF	Used for Savings Calculations
Federal Minimum Front-Loading Unit, ≥ 1.6 ft^3	≥ 1.84	≤ 4.7	
Federal Minimum Top-Loading Unit, ≥ 1.6 ft^3	≥ 1.57	≤ 6.5	
Federal Minimum Top & Front-Load Average	**1.64**		**Single family**
Federal Minimum Front-Loading Commercial Front-Load	**2.00**		**Multifamily**
Federal Minimum Top-Loading Commercial Front-Load	1.35		

Table 2. Proposed Clothes Washer Performance Characteristics (Ref. 8)

Unit Type	$IMEF_{EE}$	IWF	Used for Savings Calculations
ENERGY STAR Front-Loading Unit, > 2.5 ft^3	≥ 2.76	≤ 3.2	
ENERGY STAR Top-Loading Unit, > 2.5 ft^3	≥ 2.06	≤ 4.3	
ENERGY STAR Top & Front-Load Average	**≥ 2.24**		**Single family**
ENERGY STAR Commercial Front-Load	**≥ 2.20**		**Multifamily**

Table 3. Distribution of Energy Use (Ref. 4)

	Clothes Washer Operation (CW)	Domestic Hot Water Heating (DHW)	Dryer Operation (Dry)
Base	7%	33%	59%
EE	6%	31%	62%

Table 4. Fuel Type Factors (Ref. 5 & Ref. 6)

Fuel Type	$\%Elec_{DHW}$	$\%Elec_{DRY}$
Electric	100%	100%
Gas	0%	0%
Unknown (Ref. 5 and Ref. 6)	39%	86%

Table 5. Incremental Costs (Ref. 11)

Unit Type	Incremental Cost
Top-Loading Clothes Washer	$28.79
Front-Loading Clothes Washer	$210.12
Average for Top & Front-Load Unit	**$163.49**

Notes

Table 6. Summarized Savings Values for SF, 3.45 ft^3 capacity

	Electric DHW Electric Dryer	Gas DHW Electric Dryer	Electric DHW Gas Dryer	Gas DHW Gas Dryer	Unknown DHW Unknown Dryer
Energy Savings, kWh	145.25	88.13	71.29	14.16	99.73
Demand Savings, kW	0.021	0.013	0.011	0.002	0.015
Gas Savings, Dth	0.000	0.210	0.293	0.503	0.170

Table 7. Summarized Savings Values for MF, 3.45 ft^3 capacity

	Electric DHW Electric Dryer	Gas DHW Electric Dryer	Electric DHW Gas Dryer	Gas DHW Gas Dryer	Unknown DHW Unknown Dryer
Energy Savings, kWh	194.77	33.08	138.33	33.08	122.15
Demand Savings, kW	0.007	0.001	0.005	0.001	0.004
Gas Savings, Dth	0.000	0.281	0.392	0.673	0.228

Table 8. Determination of Annual Loads

Clothes Washer Use	West North Central Census Division (IA, KS, MN, MO, ND, NE, SD) (Ref. 4)	Average Loads per Week
Use a Clothes Washer		
0 Loads per Week		0
1 to 4 Loads Each Week	4.1	2.5
5 to 9 Loads Each Week	1.9	7
10 to 15 Loads Each Week	0.8	12.5
More than 15 Loads Each Week		15
Do Not Use a Clothes Washer at Home	1.2	
Weighted Average		**4.93**
Estimated Annual Loads		**258**

Table 9. Determination of front vs top loading

Clothes Washer Use	West North Central Census Division (IA, KS, MN, MO, ND, NE, SD) (Ref. 15)	% of population
Top-Loading	5.2	74%
Front-Loading	1.8	26%

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. Weighted average of 258 clothes washer cycles per year (based on 2015 Residential Energy Consumption Survey (RECS) national sample survey of housing appliances section, West North Central Region. https://www.eia.gov/consumption/residential/data/2015/hc/php/hc3.7.php
3. 10 CFR Part 430 [Docket Number EERE–2008–BT–STD– 0019] RIN 1904–AB90 Energy Conservation Program for Consumer Products: Energy Conservation and Water Conservation Standards.. https://www.ecfr.gov/cgi-bin/text-idx?SID=86e70cbc87e5af18caca2e5c205bd107&mc=true&node=se10.3.430_132&rgn=div8
4. The percentage of total energy consumption that is used for the machine, heating the hot water or by the dryer is different depending on the efficiency of the unit. Values are based on a sales

weighted average of top loading and front loading units based on data from Life-Cycle Cost and Payback Period Excel-based analytical tool, available online at: http://www1.eere.energy.gov/buildings/appliance_standards/residential/clothes_washers_support_stakeholder_negotiations.htm.

5. The percentage of total (gas and electric fuel types) water heating units that are electric calculated from 2015 Residential Energy Consumption Survey (RECS) data. https://www.eia.gov/consumption/residential/data/2015/hc/php/hc8.7.php Fuel used by main water heater section.
6. The percentage of total (gas and electric fuel types) dryer units that are electric calculated from 2015 Residential Energy Consumption Survey (RECS) data. https://www.eia.gov/consumption/residential/data/2015/hc/php/hc3.7.php
7. To account for the different efficiency of electric and Natural Gas hot water heaters (gas water heater): recovery efficiencies ranging from 0.74 to 0.85 (0.78 used), and electric water heater with 0.98 recovery efficiency.
8. Calculated from Itron eShapes, 8,760 hourly data by end-use for Missouri, as provided by Ameren. Reference is from Illinois Technical Reference Manual June 1, 2012. Page 303.
9. ENERGY STAR. Product Specification for Clothes Washers. Version 8.1. https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Version%208.1%20Clothes%20Washer%20Final%20Specificaiton%20-%20Partner%20Commitments%20and%20Eligibility%20Criteria.pdf
10. ENERGY STAR Calculator. https://www.energystar.gov/sites/default/files/asset/document/appliance_calculator.xlsx
11. Based on the average clothes washer volume of all units that pass the new Federal Standard on the California Energy Commission (CEC) database of Clothes Washer products accessed on 08/28/2014. Reference is from Illinois Technical Reference Manual September 28, 2018.
12. Department of Energy. ENERGY EFFICIENCY PROGRAM FOR CERTAIN COMMERCIAL AND INDUSTRIAL EQUIPMENT. https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=08fdbac2df2f7ef118bf97844a8f7453&r=PART&n=10y3.0.1.4.19#se10.3.431_1156
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16. Electronic Code of Federal Regulations (eCFR) eCFR :: 10 CFR 430.32 -- Energy and water conservation standards and their compliance dates.

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/15/2012
2.0	Used algorithm from IL TRM	Franklin Energy Services	8/16/2012
2.1	Added text to clarify that Tables 3-5 are for 3.5 ft^3 washers; Changed End Use from HVAC to Plug Load	Joe Plummer	4/2/2013
2.2	Added new ENERGY STAR standards to notes	Franklin Energy Services	8/1/2014
2.3	Updated algorithm and savings to new ENERGY STAR standard, updated loads per week, and cost.	Franklin Energy Services	12/18/2014
2.4	Corrected example, added unknown DHW, Dryer to summarized savings values, rearranged tables, corrected gas algorithm, corrected typos	Joe Plummer	1/6/2015
2.5	Updated notes to include future federal standards. Updated table numbers and added standard summary table	Franklin Energy Services	8/17/2016
2.6	Updated to include new federal minimum and ENERGY STAR Clothes Washers Version 8.0 requirements. Updated gas and electric water heater recovery efficiency. Updated example calculations	Franklin Energy Services	12/4/2017
3.0	Updated to include MF units, updated average capacity, number of cycles per year, IMEF standards	Cadmus	10/2018
3.1	Slight reorganization	Cadmus	9/2021

Residential Appliances - ENERGY STAR Clothes Dryers

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Plug Loads, Other
Applicable To	Residential customers in single-family homes and multi-family housing of 2 or more units (including 3- and 4-family homes, duplexes, townhomes and apartment complexes)
Actions	Replace on Fail, Replace Working
Required from Customer/Contractor	Confirmation of ENERGY STAR rating, electric or gas dryer, Product class (standard or compact and, if electric, vented or ventless, 120V or 240V)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	14 (Ref. 1)
Unit Participant Incremental Cost	$152 (Ref. 2)

Measure Description

This measure includes replacement of failed or working clothes dryers in existing homes with ENERGY STAR clothes dryers, or installation of an ENERGY STAR clothes dryer in a new home.

Algorithms

For electric and gas dryers

kWh_{SAVED} = Load x (1 / CEF_{BASE} – 1 / CEF_{EFF}) x N_{CYCLES} x %Electric / ADJ_{CEF}

kW_{SAVED} = kWh_{SAVED} / Hours x CF

For gas dryers

Dth_{SAVED} = Load x (1 / CEF_{BASE} – 1 / CEF_{EFF}) x N_{CYCLES} x 0.003412 x %Gas / ADJ_{CEF}

Where:

Load = Average total weight of clothes per drying cycle per Table 1 (Ref. 3, Ref. 9, see Notes)

CEF_{BASE} = Combined energy factor of baseline unit per Table 1 (Ref. 4)

CEF_{EFF} = Combined energy factor of efficient unit per Table 1 (Ref. 3)

N_{CYCLES} = Annual number of dryer cycles per Table 2 (Ref. 5)

%Electric = Percent of energy savings from electricity, = 100% for electric dryers and 16% for gas dryers (Ref. 6, see Notes)

ADJ_{CEF} = CEF adjustment factor, = 0.7 for standard dryers and 1.2 for compact dryers (Ref. 5)

Hours	=	Annual run hours of clothes dryer = 234 (Ref. 7, See Assumptions)
CF	=	Coincidence factor = 2.9% (Ref. 8)
0.003412	=	Conversion from kWh to Dth
%Gas	=	Percent of energy savings from gas, = 0% for electric dryers and 84% for gas dryers (Ref. 6, see Notes)

Example:

A customer installed a new standard sized gas clothes dryer in a dwelling unit of unknown type.

kWh_{SAVED} = 8.45 x (1 / 3.30 – 1 / 3.48) x 265 x 0.16 / 0.7 = 8.0 kWh

kW_{SAVED} = 8.0 / 234 x 0.029 = 0.001 kW

Dth_{SAVED} = 8.45 x (1 / 3.30 – 1 / 3.48) x 265 x 0.003412 x 0.84 / 0.7 = 0.144 Dth

Deemed Input Tables

Table 1. Loads and CEF Values Across Dryer Types

Product Class	Load (lbs)	CEF_{BASE}	CEF_{EFF}
Electric, Ventless or Vented, Standard	8.45	3.73	3.93
Electric, Ventless or Vented, Compact (120V)	8.45*	3.61	3.80
Electric, Vented, Compact (240V)	8.45*	3.27	3.45
Electric, Ventless, Compact (240V)	8.45*	2.55	2.68
Gas, Vented, Standard	8.45	3.30	3.48
Gas, Vented, Compact	8.45*	3.30	3.48

* While the ENERGY STAR criteria assume 3 lb loads for compact dryers, they are likely higher (Ref. 5)

Table 2. Dryer Cycles Per Year

Housing Type	N_{CYCLES}	
	Existing (default)	New Construction (if known)
Single family	285	350
Multifamily	185	195
Unknown	265	

Notes

Some of the savings from gas dryers comes from electricity (motors, controls, etc). The Consumer Savings tab of the ENERGY STAR Residential Clothes Dryer Data and Analysis spreadsheet (Ref. 6) shows 30 kWh (102 kBtu) electric and 540 kbtu gas annual savings. Gas savings are therefore 540 / (540 + 102) = 84% of total reduced energy consumption.

NEEA's dryer field study (Ref. 7) showed a mean dryer cycle length of 56 minutes. Annual run hours are therefore 250 x 56 / 60 = 234.

A recent field assessment of heat pump clothes dryers (Ref. 5) recommends some modifications to the above algorithm for traditional dryers. From its metering results, it found that the CEF ratings for standard-size dryers underestimate energy consumption, and that the ratings for compact dryers overestimate consumption. It recommends that different yearly load numbers be used across single family and multifamily housing types, based on more recent RECS data. Finally, it reasons that an assumption of 3 pounds per load for compact dryers must be incorrect, and that it is more appropriate to use the standard dryer value of 8.45 pounds.

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Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Cadmus	11/2018
2.0	Updated to reflect CARD study findings	Cadmus	9/2021

Residential Appliances - ENERGY STAR Dishwashers

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Plug Loads
Applicable To	Residential customers in single-family homes and multi-family housing of 2 or more units (including 3- and 4-family homes, duplexes, townhomes and apartment complexes)
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Electric or gas water heater, unit size (standard or compact). Standard-sized is defined as having capacity for least 8 place settings plus 6 serving pieces. Compact-sized is defined as having capacity for less than 8 place settings plus 6 serving pieces. (Ref. 6)
Version No.	1.3
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$50 (Ref. 2)

Measure Description

This measure includes replacement of failed or working dishwashers in existing homes with ENERGY STAR dishwashers, or installation of ENERGY STAR dishwashers in new homes.

Algorithms

Unit kWh Savings per Year = (kWh_base - kWh_EE) + (Loads * (WF_base – WF_EE) * EPG * %ElecDHW / ConversionFactor1 / R_eff)

Unit Peak kW Savings = Unit kWh Savings per Year / Hours x CF

Unit Dth Savings per Year = Loads * (WF_base – WF_EE) * EPG * (1-%ElecDHW) / ConversionFactor2/R_eff

Where:

kWh_EE = 270 kWh for standard unit or 203 kWh for compact unit; Energy consumed by efficient dishwasher (Ref. 6)

kWh_base = 307 kWh for standard unit or 222 kWh for compact unit; Energy consumed by minimum efficiency dishwasher (Ref. 7)

WF_base = 5.0 gallons/cycle for standard unit or 3.5 gallons/cycle for compact unit (Ref. 7)

WF_EE = 3.5 gallons/cycle for standard unit or 3.1 gallons/cycle for compact unit (Ref. 6)

EPG = Energy per Gallon to heat water.

= SpecificHeat * Density *(Thot – Tcold)

SpecificHeat = 1.0 Btu / (lb x °F)

Density = 8.34 lb / gal

Thot = 130 °F (assumed average starting temperature)

Tcold = Average groundwater temperature per Table 1 (Ref. 9)

%Elec_DHW = 100% (electric water heating)
= 0% (gas water heating)
= 39% (if unknown) (Ref. 3)

R_eff = Typical gas recovery efficiency is 0.78; a typical electric recovery efficiency is 0.98. (Ref. 2).

Hours = 269 hours (Ref. 4)

Loads = 179 (Ref. 4)

CF = 0.10; electrical peak coincidence factor (Ref. 5)

ConversionFactor1 = 3,412 Btu/kWh

ConversionFactor2 = 1,000,000 Btu/Dth

Example:

A residential customer installed a new Standard-sized ENERGY STAR dishwasher in a home with electric water heat.

EPG = 1.0 Btu/lb-°F * 8.34 lb/gal * (130°F – 49.0°F) = 675.54 Btu/gal

Unit kWh Savings per Year = (307 kWh - 270 kWh) + (179 load * (5.0 gal/cycle – 3.5 gal/cycle) * 675.54 Btu/gal / 3412 Btu/kWh / 0.98) = 91.2 kWh

Unit Peak kW Savings = 91.2 kWh / 269 hours x 0.10 = 0.034 kW

Notes

Federal Standard requires standard sized dishwashers manufactured after 5/30/2013 use ≤ 307 kWh/yr and ≤ 5.0 gallons of water/cycle (Ref. 7)

Federal Standard requires compact sized dishwashers manufactured after 5/30/2013 use ≤ 222 kWh/yr and ≤ 3.5 gallons of water/cycle (Ref. 7)

ENERGY STAR requires standard sized dishwashers use ≤ 270 kWh/yr and ≤ 3.5 gallons of water/cycle (Ref. 6)

ENERGY STAR requires compact sized dishwashers use ≤ 203 kWh/yr and ≤ 3.1 gallons of water/cycle (Ref. 6)

As of September 2016, the US Department of Energy is currently undertaking a rulemaking to consider new energy conservation standards for residential dishwashers (Ref. 8).

Table 1. Average groundwater temperatures (Ref. 9)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Summarized per unit savings, ENERGY STAR Standard Units, location unknown

Water Heater	Peak kW	kWh	therms
Electric	0.034	91.2	0.000
Gas	0.014	37.0	2.325
Unknown	0.022	58.2	1.419

Table 3. Summarized per unit savings, ENERGY STAR Compact Units, location unknown

Water Heater	Peak kW	kWh	therms
Electric	0.012	33.5	0.000
Gas	0.007	19.0	0.620
Unknown	0.009	24.6	0.378

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Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/15/2012
1.1	Correct kWh_base and kWh_prop (values were reversed)	Joe Plummer	4/2/2013
1.2	Changed Target End Use from HVAC to Plug Load	Joe Plummer	4/2/2013
1.3	Updated to current ENERGY STAR and federal standards	Franklin Energy Services	9/6/2016

Residential Appliances - ENERGY STAR Refrigerators and Freezers

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Plug Loads
Applicable To	Residential customers in single-family homes and multi-family housing of 2 or more units (including 3- and 4-family homes, duplexes, townhomes and apartment complexes)
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Appliance (refrigerator (≥7.75 ft^3), compact refrigerator (<7.75 ft^3), or freezer ((≥7.75 ft^3)), Product Class (see Tables 1 through 3)
Version No.	2.3
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	14 years for refrigerators, 11 years for freezers (Ref. 1)
Unit Participant Incremental Cost	$20 (refrigerators), $0 (compact refrigerators), $0 (freezers) (Ref. 2)

Measure Description

This measure includes the replacement of failed or working refrigerators or freezers in residential homes, as well as installation of high efficiency refrigerators and freezers in new homes.

Algorithms

Unit kWh Savings per Year = kWh_base - kWh_ee

Unit Peak kW Savings = (Unit kWh Savings per Year) / 8,760

Where:

kWh_base = Annual energy consumption of the baseline efficiency unit (Refer to Tables 1 through 3 based on Product Class)

kWh_ee = Annual energy consumption of the energy efficient (ENERGY STAR) unit (Refer to Tables 1 through 3 based on Product Class)

8,760 = Assumed annual operating hours per year

Example:

A conventional side-by-side refrigerator with automatic defrost is replaced with a similar ENERGY STAR side-by-side refrigerator.

Electric Energy Savings (kWh/yr) = 426 - 384 = 42 kWh/yr

Electric Peak Demand Savings (kW) = 42 kWh / 8,760 = 0.0048 peak kW

Deemed Input Tables

Table 1. High Efficiency and Conventional Refrigerator Default Energy Usage and Incremental Cost (Ref. 4)

Product Class	ENERGY STAR Rated Model (kWh/year)	Conventional Model (kWh/year)
Refrigerator-freezer or refrigerator only (manual or partial-auto defrost)	311	346
Top-mounted freezer or refrigerator only (automatic defrost)	320	356
Side-by-side (automatic defrost)	384	426
Side-by-side with through-the-door ice (automatic defrost)	514	562
Bottom-mounted freezer (automatic defrost)	406	451
Bottom-mounted freezer with through-the-door ice (automatic defrost)	562	615

Table 2. High Efficiency and Conventional Compact Refrigerator Default Values (Ref. 4)

Product Class	ENERGY STAR Rated Model (kWh/year)	Conventional Model (kWh/year)
Compact refrigerator or compact refrigerator-freezer (manual defrost)	260	289
Compact refrigerator-freezer (partial automatic defrost)	324	360
Compact top-mounted freezer or refrigerator only (automatic defrost)	349	387
Compact bottom-mounted freezer (automatic defrost)	349	387

Table 3. High Efficiency and Conventional Freezer Default Values (Ref. 4)

Product Class	ENERGY STAR Rated Model (kWh/year)	Conventional Model (kWh/year)
Chest	272	302
Compact chest	345	383
Compact upright (manual defrost)	411	456
Compact upright (auto defrost)	560	623
Upright (manual defrost)	308	342
Upright (auto defrost)	412	458

Notes

The Federal efficiency standards in place as of September 2016 for residential refrigerators and freezers are as follows:

Table 4. Correction Factor and Adjusted Volume Algorithm by Product Class (Ref. 5)

Product Class	Correction Factor (CRF)	Adjusted Volume (AV) Algorithm
Freezers with Automatic Icemakers*	1.76	AV = (VT x CRF)
Refrigerator-Freezers	1.63	AV = (VF x CRF) + VFF
All-Refrigerators	1.00	AV = (VF x CRF) + VFF
Refrigerators (other than All-Refrigerators)	1.44	AV = (VF x CRF) + VFF
Freezers	1.73	AV = (VT x CRF)

VT = Total Refrigerated Volume (ft^3)
VF = Freezer Compartment Volume (ft^3)
VFF = Fresh Food Compartment Volume (ft^3)
* The volume occupied by the automatic icemaker, including its ice storage bin, is to be included in the volume measurement (VT).

Table 5. Federal and ENERGY STAR Maximum Energy Use Algorithm by Product Class (Ref. 6, 7)

Product Class	Federal Maximum Energy Use Algorithm	ENERGY STAR Maximum Energy Use Algorithm
Refrigerators		
1. Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.	7.99 * AV + 225.0	7.19 * AV + 202.5
1A. All-refrigerators–manual defrost.	6.79 * AV + 193.6	6.11 * AV + 174.2
2. Refrigerator-freezers–partial automatic defrost	7.99 * AV + 225.0	7.19 * AV + 202.5
3. Refrigerator-freezers–automatic defrost with top-mounted freezer without an automatic icemaker.	8.07 * AV + 233.7	7.26 * AV + 210.3
3-BI. Built-in refrigerator-freezer–automatic defrost with top-mounted freezer without an automatic icemaker.	9.15 * AV + 264.9	8.24 * AV + 238.4
3I. Refrigerator-freezers–automatic defrost with top-mounted freezer with an automatic icemaker without through-the-door ice service.	8.07 * AV + 317.7	7.26 * AV + 294.3
3I-BI. Built-in refrigerator-freezers–automatic defrost with top-mounted freezer with an automatic icemaker without through-the-door ice service.	9.15 * AV + 348.9	8.24 * AV + 322.4
3A. All-refrigerators–automatic defrost.	7.07 * AV + 201.6	6.36 * AV + 181.4
3A-BI. Built-in All-refrigerators–automatic defrost.	8.02 * AV + 228.5	7.22 * AV + 205.7
4. Refrigerator-freezers–automatic defrost with side-mounted freezer without an automatic icemaker.	8.51 * AV + 297.8	7.66 * AV + 268.0
4-BI. Built-In Refrigerator-freezers–automatic defrost with side-mounted freezer without an automatic icemaker.	10.22 * AV + 357.4	9.20 * AV + 321.7
4I. Refrigerator-freezers–automatic defrost with side-mounted freezer with an automatic icemaker without through-the-door ice service.	8.51 * AV + 381.8	7.66 * AV + 352.0

Product Class	Federal Maximum Energy Use Algorithm	ENERGY STAR Maximum Energy Use Algorithm
4I-BI. Built-In Refrigerator-freezers–automatic defrost with side-mounted freezer with an automatic icemaker without through-the-door ice service.	10.22 * AV + 441.4	9.20 * AV + 405.7
5. Refrigerator-freezers–automatic defrost with bottom-mounted freezer without an automatic icemaker.	8.85 * AV + 317.0	7.97 * AV + 285.3
5-BI. Built-In Refrigerator-freezers–automatic defrost with bottom-mounted freezer without an automatic icemaker.	9.40 * AV + 336.9	8.46 * AV + 303.2
5I. Refrigerator-freezers–automatic defrost with bottom-mounted freezer with an automatic icemaker without through-the-door ice service.	8.85 * AV + 401.0	7.97 * AV + 369.3
5I-BI. Built-In Refrigerator-freezers–automatic defrost with bottom-mounted freezer with an automatic icemaker without through-the-door ice service.	9.40 * AV + 420.9	8.46 * AV + 387.2
5A. Refrigerator-freezer–automatic defrost with bottom-mounted freezer with through-the-door ice service.	9.25 * AV + 475.4	8.33 * AV + 436.3
5A-BI. Built-in refrigerator-freezer–automatic defrost with bottom-mounted freezer with through-the-door ice service.	9.83 * AV + 499.9	8.85 * AV + 458.3
6. Refrigerator-freezers–automatic defrost with top-mounted freezer with through-the-door ice service.	8.40 * AV + 385.4	7.56 * AV + 355.3
7. Refrigerator-freezers–automatic defrost with side-mounted freezer with through-the-door ice service.	8.54 * AV + 432.8	7.69 * AV + 397.9
7-BI. Built-In Refrigerator-freezers–automatic defrost with side-mounted freezer with through-the-door ice service.	10.25 * AV + 502.6	9.23 * AV + 460.7
Freezers		
8. Upright freezers with manual defrost.	5.57 * AV + 193.7	5.01 * AV + 174.3
9. Upright freezers with automatic defrost without an automatic icemaker.	8.62 * AV + 228.3	7.76 * AV + 205.5
9I. Upright freezers with automatic defrost with an automatic icemaker.	8.62 * AV + 312.3	7.76 * AV + 289.5
9-BI. Built-In Upright freezers with automatic defrost without an automatic icemaker.	9.86 * AV + 260.9	8.87 * AV + 234.8
9I-BI. Built-in upright freezers with automatic defrost with an automatic icemaker.	9.86 * AV + 344.9	8.87 * AV + 318.8
10. Chest freezers and all other freezers except compact freezers.	7.29 * AV + 107.8	6.56 * AV + 97.0
10A. Chest freezers with automatic defrost.	10.24 * AV + 148.1	9.22 * AV + 133.3

Product Class	Federal Maximum Energy Use Algorithm	ENERGY STAR Maximum Energy Use Algorithm
Compact Refrigerators		
11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.	9.03 * AV + 252.3	8.13 * AV + 227.1
11A.Compact all-refrigerators–manual defrost.	7.84 * AV + 219.1	7.06 * AV + 197.2
12. Compact refrigerator-freezers–partial automatic defrost	5.91 * AV + 335.8	5.32 * AV + 302.2
13. Compact refrigerator-freezers–automatic defrost with top-mounted freezer.	11.80 * AV + 339.2	10.62 * AV + 305.3
13I. Compact refrigerator-freezers–automatic defrost with top-mounted freezer with an automatic icemaker.	11.80 * AV + 423.2	10.62 * AV + 389.3
13A. Compact all-refrigerators–automatic defrost.	9.17 * AV + 259.3	8.25 * AV + 233.4
14. Compact refrigerator-freezers–automatic defrost with side-mounted freezer.	6.82 * AV + 456.9	6.14 * AV + 411.2
14I. Compact refrigerator-freezers–automatic defrost with side-mounted freezer with an automatic icemaker.	6.82 * AV + 540.9	6.14 * AV + 495.2
15. Compact refrigerator-freezers–automatic defrost with bottom-mounted freezer.	11.80 * AV + 339.2	10.62 * AV + 305.3
15I. Compact refrigerator-freezers–automatic defrost with bottom-mounted freezer with an automatic icemaker.	11.80 * AV + 423.2	10.62 * AV + 389.3
Freezers		
16. Compact upright freezers with manual defrost.	8.65 * AV + 225.7	7.79 * AV + 203.1
17. Compact upright freezers with automatic defrost.	10.17 * AV + 351.9	9.15 * AV + 316.7
18. Compact chest freezers.	9.25 * AV + 136.8	8.33 * AV + 123.1

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7. ENERGY STAR Program Requirements for Residential Refrigerators and Freezers, Table I.1. https://www.energystar.gov/ia/partners/product_specs/program_reqs/Refrigerators_and_Freezers_Program_Requirements_V5.0.pdf?5509-e2b6. Accessed 08/18/16.

Revision History

Version	Description	Author	Date
2.3	Updated all standard and ENERGY STAR default savings values, added federal standards in Notes, updated references, updated example with new standard values.	Franklin Energy Services	9/15/2016

Residential Appliances - Secondary Refrigerator/Freezer Removal

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Appliances
Applicable To	Residential customers in single-family homes, duplexes, and townhomes
Actions	Remove
Required from Customer/Contractor	Equipment type being recycled (freezer or refrigerator), confirmation of working unit, confirmation of secondary unit
Version No.	3.0
Unit kWh Savings per Year	See algorithm (Ref. 1)
Unit Peak kW Savings	See algorithm (Ref. 1)
Unit Dth Savings per Year	0
Measure Lifetime (years)	8 (Ref. 2)
Unit Participant Incremental Cost	$110.00 (Ref. 1)

Measure Description

This measure includes the removal and recycling of unneeded secondary residential refrigerators and freezers. Existing units must be working, secondary, refrigerators or freezers. Units must be recycled or otherwise rendered inoperable.

Algorithms

Unit kWh Savings per Year = $kWh_{UNADJUSTED}$ x PUF

Unit Peak kW Savings = $kWh_{UNADJUSTED}$ / HOU x P x PUF

Where:

$kWh_{UNADJUSTED}$ = The assumed gross savings from removing and recycling a refrigerator or freezer that would have been plugged in for the entire year (Refer to Table 1).

PUF = Part-Use Factor, to account for units that may not have been plugged in before being recycled. (Refer to Table 1)

HOU = Annual operating hours, 8,760

P = Peak intensity factor; this captures the increase in compressor cycling time in summer peak conditions relative to average annual conditions (Refer to Table 1)

Example:

A secondary refrigerator with unknown use throughout the year is retired and properly recycled.

Unit kWh Savings per Year = 962 x 0.86 = 827

Unit Peak kW Savings = 962 / 8,760 * 0.86 * 1.01 = 0.095

Deemed Input Tables

Table 1. Gross Annual kWh, kW Savings per Unit (Ref. 1)

Appliance Type	$kWh_{UNADJUSTED}$	PUF	P	Annual kWh	Gross kW
Refrigerator or Combo Unit	962	0.86	1.01	827	0.095
Freezer Only	926	0.76	1.08	704	0.087

Methodology and Assumptions

Energy savings are based on a linear regression, using metered data and modeling in Wisconsin.

References

1. Cadmus and Public Service Commision of Wisconsin. *Wisconsin Focus on Energy 2019 Technical Reference Manual*. 2019. Page 1,313. https://focusonenergy.com/sites/default/files/inline-files/Focus%20on%20Energy%202021%20TRM.pdf
2. KEMA, "Residential Refrigerator Recycling Ninth Year Retention Study," July 22, 2004

Revision History

Version	Description	Author	Date
1.0	New specification based on Nexant version	Joe Plummer	
2.0	Added measure description; Changed algorithm and source for algorithm for energy savings and demand savings; Added sources for default values; Added required information from customer/contractor; Changed measure life and EUL source; Changed measure incremental cost and cost source; Added example	Franklin Energy Services	7/30/2012
2.1	Added confirmation of working unit, secondary unit to Required Inputs, revised appliance descriptions for clarity	Joe Plummer	3/29/14
3.0	Updated to reflect more recent analysis in nearby state	Cadmus	9/2021

Residential Appliances - ENERGY STAR Air Purifiers

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Plug loads
Applicable To	Residential customers in single-family homes and multi-family housing of 2 or more units (including 3- and 4-family homes, duplexes, townhomes and apartment complexes)
Actions	Replace on Fail, Replace Working
Required from Customer/Contractor	Air purifier capacity in cubic feet per minute
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	9 (Ref. 1)
Unit Participant Incremental Cost	$0 (Ref. 1)

Measure Description

This measure covers the purchase and installation of an air purifier unit meeting ENERGY STAR specification (Ref. 2) in place of a Base unit.

Algorithms

The algorithm follows savings as calculated by the ENERGY STAR appliance savings calculator (Ref. 1)

$kWh_{SAVED} = (kWh_{BASE,OPER} + kWh_{BASE,STBY}) – (kWh_{ES,OPER} + kWh_{ES,STBY})$

$kWh_{BASE,OPER} = (Cap_{BASE} / Eff_{BASE}) \times Hours_{OPER} / 1{,}000$

$kWh_{BASE,STBY} = kW_{STBY,BASE} \times (8{,}760 – Hours_{OPER}) / 1000$

$kWh_{ES,OPER} = (Cap_{ES} / Eff_{ES}) \times Hours_{OPER} / 1{,}000$

$kWh_{ES,STBY} = kW_{STBY,ES} \times (8{,}760 – Hours_{OPER}) / 1000$

$kW_{SAVED} = kWh_{SAVED} / Hours_{OPER} * CF$

Where:

Cap_{BASE}	=	Clean air delivery rate (CADR) for base unit (see Table 1)
Eff_{BASE}	=	1.0 CFM/watt; air delivery efficiency for base unit
$Hours_{OPER}$	=	5,840 hours; annual hours of operation
$kW_{STBY,BASE}$	=	1.0 watts; standby power consumption for base unit
8,760	=	Total hours per year.
Cap_{ES}	=	CADR for ENERGY STAR unit (see Table 1)

Eff_{ES} = 3.0 CFM/watt; air delivery efficiency for ENERGY STAR unit

$kW_{STBY,ES}$ = 0.6 Watts; standby power consumption for ENERGY STAR unit

CF = 0.67; coincidence factor (= 5,840 / 8,760)

Table 1. Clean Air Delivery Rates and Savings

CADR Range (CFM)	CADR for Calculation (CFM)	kWh_{SAVED}	kW_{SAVED}
51 – 100	75	293	0.034
101 – 150	125	488	0.056
151 – 200	175	683	0.078
201 – 250	225	877	0.101
250+	275	1072	0.123

Example:

A customer installed an ENERGY STAR air purifier with a clean air delivery rate of 75 cubic feet per minute.

kWh_{SAVED} = (75 CUFT/min / (1.0 CADR/W * 1,000) * 5,840 hours/year + (8,760 hours/year – 5,840 hours/year) * 1.0 W / 1,000) – (75 CUFT/min / (3.0 CADR/W * 1,000) * 5,840 hours/year + (8,760 hours/year – 5,840 hours/year) * 0.6 W / 1,000) = 293 kWh

References

1. ENERGY STAR. Savings Calculator for ENERGY STAR Appliances. https://www.energystar.gov/sites/default/files/asset/document/appliance_calculator.xlsx
2. ENERGY STAR. *ENERGY STAR Program Requirements, Produce Specification for Room Air Cleaners*. Version 1.2. https://www.energystar.gov/sites/default/files/specs/private/Room_Air_Cleaners_Final_V1.2_Specification.pdf

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Cadmus Group	11/9/2018

Misc

Residential Load Management Technologies

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	HVAC, DHW
Applicable To	Residential customers in single-family homes
Actions	Modify, Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Load control technology installed (A/C cycling, electric heat cycling, electric water heater curtailment, electric thermal storage for space heating), installation location (county), average number of load control events in a typical year Optional: Cost of load control equipment, installation, and any metering costs
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	kW savings per event
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 years (Ref. 2)
Unit Participant Incremental Cost	See Table 4

Measure Description

This measure includes the following residential load management technologies: A/C cycling, electric heat cycling, electric water heater curtailment, and electric thermal storage for space heating. Load management programs are primarily intended to reduce peak electrical demand and/or shift energy use to off-peak hours. Therefore, the primary impact is peak kW savings, though secondary kWh savings also result except from electric thermal storage.

Algorithms

Unit kWh Savings per Year = (average # of events) x (kWh savings per event)

Where:

Average # of events	=	average number of load control events during a typical year, provided by utility
kWh savings per event	=	modeled net kWh savings per load control event per installation, including snapback (refer to Tables 1-3.)
kW savings per event	=	modeled peak kW savings per load control event per installation (refer to Tables 1-3)

Example:

An A/C cycling device is installed at a single family home in Zone 3. Based on historical experience and load growth projections, the utility expects that on average, two load control events will occur in a typical year. From Table 3.

Unit kWh Savings per Year = 2 x 0.71 = 1.42 kWh

Unit Peak kW Savings = 0.30 kW

Deemed Input Tables

Table 1. Modeled kWh and kW savings per Load Control Event per Unit, Zone 1 (Ref. 1)

Technology	kWh Savings	Summer kW Savings	Winter kW Savings
A/C Cycling	0.01	0.07	0.00
Electric Heat Cycling	2.54	0.00	2.00
DHW Curtailment	0.58	0.54	0.76
Electric Thermal Storage	0.00	0.00	26.90

Table 2. Modeled kWh and kW savings per Load Control Event per Unit, Zone 2 (Ref. 1)

Technology	kWh Savings	Summer kW Savings	Winter kW Savings
A/C Cycling	0.65	0.23	0.00
Electric Heat Cycling	1.62	0.00	1.27
DHW Curtailment	0.43	0.49	0.76
Electric Thermal Storage	0.00	0.00	24.00

Table 3. Modeled kWh and kW savings per Load Control Event per Unit, Zone 3 (Ref. 1)

Technology	kWh Savings	Summer kW Savings	Winter kW Savings
A/C Cycling	0.71	0.30	0.00
Electric Heat Cycling	3.11	0.00	1.42
DHW Curtailment	0.40	0.60	0.84
Electric Thermal Storage	0.00	0.00	22.43

Table 4. Default Incremental Cost (Equipment plus Installation) by Technology

Technology	Incr. Cost	Ref.
A/C Cycling	$200	2
Electric Heat Cycling	$200	2
DHW Curtailment Summer	$200	2
DHW Curtailment Winter	$200	2
Electric Thermal Storage	$11,700	3, 4

Methodology and Assumptions

Current Smart Measure™ implementation of this measure on ESP® does not support winter kW savings at this time.

Default incremental costs include equipment and installation only. If the program includes meter installation, some portion of these costs should be included in a cost-effectiveness analysis.

Energy and demand impacts are based on simulation results by Michaels Energy using BEopt and EnergyPlus for a median residential home as defined in Ref. 1 in Zones 1, 2, and 3.

- A demand response event was simulated on July 15 and the air conditioning was cycled every 15 minutes during the event, which lasted for 7 hours, from 1 pm to 8 pm. A domestic water heater demand response event was also simulated on these homes on both winter (January 28) and summer peak days. The winter demand event occurred from 4 pm to 7 pm. TMY3 (typical meteorological year, third collection) weather data was used in all of the simulations using the designated cities for each climate zone (Minneapolis, Saint Cloud, Duluth). The summer event schedule was selected based on the data provided by the two utilities in this study, which showed that 1 pm to 8 pm was the most common control period. The winter event schedule was selected based on the fact that the IOU triggers events on winter afternoons and the G&T Co-op's website shows that their winter loads peak in the late afternoon and early evening hours. Although there are a variety of control methods, 50% cycling of air conditioners was used in this model because it is the most commonly used scheme in Minnesota. Load curtailment during the event was used for domestic water heaters, since that is the most common form of control for those systems, according to the websites of both of the utilities. July 15 was selected as the summer peak day because the TMY3 weather data showed that the outdoor air temperature was near the annual peak and the following day had a nearly identical temperature profile in order to properly evaluate snapback effects that may linger into the next day after a demand response event. (Ref. 1)
- January 28th was selected for the winter event (except in Minneapolis; see footnote) because it was a typical winter day in the TMY3 weather data and the following day's temperature profile was very similar.
- TMY3 data were used for all simulations. Duluth was selected for Zone 1; St. Cloud was selected for Zone 2; and Minneapolis was selected for Zone 3.
- A/C cycling
  - A load control event was simulated on July 15 between 1 pm and 8pm. The A/C was cycled every 15 minutes during the event.

- Domestic hot water (DHW) curtailment
  - Load control events were simulated on both winter (January 28 except for Zone 3) and summer (July 15) peak days. The winter demand event occurred from 4 pm to 7 pm. The summer demand event occurred from 1 pm to 8 pm.
  - The weather file data for Minneapolis on January 28 contained temperatures well below the design temperature for Minneapolis, while the other two climates had temperatures above their design temperatures on that data. Therefore, January 7 was selected for Minneapolis as a suitable replacement since it had a similar daily load profile at more typical temperatures with the following day (January 8) having a similar load profile.
- Electric heat cycling
  - Winter demand events occurred from 1 pm to 8 pm on January 28 except for Zone 3.
- Electric thermal storage
  - Days were selected to match the heating design temperatures in the TRM: Zone 1: -22F, Zone 2: -16.5F, Zone 3: -14.5F. In each case, the following day had a similar load profile.

References

1. Michaels Energy. *Demand Response and Snapback Impact Study.* August 2013. Prepared for Minnesota Department of Commerce, Division of Energy Resources under a grant through the Conservation Applied Research and Development (CARD) program. https://www.cards.commerce.state.mn.us/CARDS/security/search.do?method=showPoup&documentId={0E17848D-92FB-4522-B02B-EABAE9D71BE9}&documentTitle=85669&documentType=6
2. Average of pricing data from two Minnesota utilities. Includes equipment and installation costs. Does not include metering costs.
3. Efficiency Maine. *Energy Efficient Heating Options: Pilot Projects and Relevant Studies.* April 8, 2013. http://www.efficiencymaine.com/docs/EMT_Energy-Efficient-Heating-Options-Report_2013_4_8.pdf, accessed February 11, 2014. Average cost of electric thermal storage furnace = $13,000.
4. Web research on 2.11.14 and 2.12.14. Average price of 25 kW electric forced-air furnace = $1,300. Models: WMA60-25 (sold under names of Hamilton Home Products and Winchester 81,912 BTU 5 TON Multi-Position Electric Furnace); 21D25 (Nortron D-series 25 kW). Retailers: Northern Tool, Ecco Supply, Home Depot, Lowes.

Revision History

Version	Description	Author	Date
1.0	New measure	Joe Plummer	2/11/14

Residential Plug Load - Tier 1 Advanced Power Strips

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Misc. Electric Loads
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes) with audio-visual home entertainment systems
Actions	Modify
Required from Customer/Contractor	n/a
Version No.	2.0
Unit kWh Savings per Year	67.6 kWh
Unit Peak kW Savings	0.009 kW
Unit Dth Savings per Year	0
Measure Lifetime (years)	7 years (Ref. 2)
Unit Participant Incremental Cost	$20 (Ref. 6)

Measure Description

This measure relates to tier 1 advanced power strips, which are multi-plug surge protector power strips with the ability to automatically disconnect specific connected loads depending upon the power draw of a control load, also plugged into the strip. Power is disconnected from the switched (controlled) outlets when the control load power draw is reduced below a certain adjustable threshold, thus turning off the appliances plugged into the switched outlets. By disconnecting, the standby load of the controlled devices, the overall load of a centralized group of equipment (i.e. entertainment centers and home office) can be reduced. Uncontrolled outlets are also provided that are not affected by the control device and so are always providing power to any device plugged into it.

Algorithms

Unit kWh Savings per Year = kWh_{BASE} x SF

Unit Peak kW Savings = (Unit kWh Savings per Year) x CF / HOU

Where:

kWh_{BASE} = 356 kWh; yearly average consumption of baseline power strip (Ref. 3)

SF = 0.19; savings factor (Ref. 4)

CF = 0.83; coincidence factor (Ref. 5)

HOU = 6,588; hours of use (Ref. 4)

Example:

Installing a tier 1 advanced power strip in a single family home.

Unit kWh Savings = 356 kWh x 0.19 = 67.6 kWh

Unit kW Savings = 67.6 kWh x 0.83 / 6,588 = 0.009 kW

Methodology and Assumptions

The estimated electric energy savings for this measure represent average savings per advanced power strip installed. The baseline consumption comes from a recent study measuring pre- and post-install consumption in Wisconsin homes receiving tier 2 advanced power strips (Ref. 3). The savings factor comes from a separate study of tier 1 power strips, showing baseline consumption of 391.5 kWh and savings of 75 kWh, or a savings factor of 19%.

References

1. Illinois Stakeholder Advisory Group. Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 6.0, Volume 3. February 8, 2017. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_3_Res_020817_Final.pdf
2. Electronics and Energy Efficiency: A Plug Load Characterization Study SCE0284, Southern California Edison, Ohio Energy Utilities Technical Resource Manual.
3. Cadmus, Only as Smart as Its Owner: A Connected Device Study. August 2018. https://cadmusgroup.com/papers-reports/only-as-smart-as-its-owner-a-connected-device-study/
4. Illume, Overview of the Tier 1 Advanced PowerStrip: Potential Savings and Programmatic Uses. September 15, 2014. http://www.amconservationgroup.com/wp-content/uploads/2014/12/Illume-Advanced-Powerstrip-Case-Study.pdf
5. Efficiency Vermont, Technical Reference User Manual (TRM), page 15. March 16, 2015. https://puc.vermont.gov/sites/psbnew/files/doc_library/ev-technical-reference-manual.pdf
6. New York State Energy Research and Development Authority. *Advanced Power Strip Research Report*. August 2011. Page 6. https://energy.mo.gov/sites/energy/files/advanced-power-strip-research-report.pdf

Revision History

Version	Description	Author	Date
1.0	Document Created	Franklin Energy Services	9/7/17
2.0	Updated savings based on more recent data	Cadmus	10/2018

Residential Plug Load - Tier 2 Advanced Power Strips

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Misc. Electric Loads
Applicable To	Residential customers in single-family homes, duplexes, townhomes, and multi-family homes (including 3- and 4-family homes) with audio-visual home entertainment systems
Actions	Modify
Required from Customer/Contractor	n/a
Version No.	2.0
Unit kWh Savings per Year	117.5 kWh
Unit Peak kW Savings	0.015 kW
Unit Dth Savings per Year	0
Measure Lifetime (years)	8 years (Ref. 1)
Unit Participant Incremental Cost	$70 (Ref. 1)

Measure Description

Tier 2 advanced power strips (APS) use an external sensor paired with a configurable countdown timer to manage both active and standby power loads for controlled devices in a complete system. Tier 2 APS may operate either with or without a master control socket. Those without a master control socket sense power of all devices connected to the controlled sockets; those with a master control socket sense power for the device connected to the control socket. The external sensor of a Tier 2 APS may utilize an infrared-only sensor, or it may utilize a “multi-sensor” which detects both infrared (IR) remote control signals and motion to determine device inactivity and deliver additional savings as compared to a Tier 1 APS device. Both versions of external sensor use IR filtering to prevent inappropriate switching events which may have otherwise resulted from natural interference such as sunlight or light bulbs.

Algorithms

Unit kWh Savings per Year = kWh_{BASE} x SF

Unit kW Savings per Year = (Unit kWh Savings per Year) x CF / HOU

Where:

kWh_{BASE} = 356 kWh; yearly average consumption of baseline power strip (Ref. 2)

SF = 0.33; savings factor (Ref. 2)

CF = 0.83; coincidence factor (Ref. 5)

HOU = 6,588; hours of use (Ref. 4)

Example:

Installing a tier 2 advanced power strip in a single-family home.

Unit kWh Savings per Year = 356 kWh x 0.33 = 117.5 kWh

Unit kW Peak Savings = 117.5 kWh x 0.83 / 6,588 = 0.015 kW

Methodology and Assumptions

The estimated electric energy savings for this measure represent average savings per advanced power strip installed. The baseline consumption and savings factor come from a recent study measuring pre- and post-install consumption in Wisconsin homes receiving tier 2 advanced power strips (Ref. 3).

References

1. "Electricity Savings Opportunities for Home Electronics and Other Plug-In Devices in Minnesota Homes", Energy Center of Wisconsin, May 2010.
2. Cadmus, Only as Smart as Its Owner: A Connected Device Study. August 2018. https://cadmusgroup.com/papers-reports/only-as-smart-as-its-owner-a-connected-device-study/
3. Illume, Overview of the Tier 1 Advanced PowerStrip: Potential Savings and Programmatic Uses. September 15, 2014. http://www.amconservationgroup.com/wp-content/uploads/2014/12/Illume-Advanced-Powerstrip-Case-Study.pdf
4. Efficiency Vermont, Technical Reference User Manual (TRM), page 15. March 16, 2015. https://puc.vermont.gov/sites/psbnew/files/doc_library/ev-technical-reference-manual.pdf

Revision History

Version	Description	Author	Date
1.0	Document Created	Franklin Energy Services	10/15/15
2.0	Updated savings based on more recent data	Cadmus	10/2018

Residential - Variable Speed Pool Pumps

Measure Detail	Measure Value
Target Market Segments	Residential
Target End Uses	Misc. Electric Loads
Applicable To	Residential customers
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Model number, pool size, pump type, hp, hydraulic hp (hhp)
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1, Page 10)
Unit Participant Incremental Cost	Use actual, or $809 (Ref. 2, Page 18)

Measure Description

This measure involves installation of variable speed pool pumps to replace single speed units.

Algorithms

Unit kWh Savings per Year = (V_{POOL} x N_{TURN}) * (1/WEF_{BASE} - 1/WEF_{EFF}) * Days / 1,000

Unit Peak kW Savings = Unit kWh Savings per Year / (Days * 24) x CF

Where:

WEF_{BASE}	=	Baseline weighted energy factor, kgal/kWh, based on pump type and hydraulic horsepower, see Table 1
WEF_{EFF}	=	Efficient weighted energy factor, kgal/kWh, use actual
V_{POOL}	=	22,000 gallons, if unknown. Volume of swimming pool. (Ref. 2, Page 33)
N_{TURN}	=	2 turnovers/day; (Ref. 2, Page 11)
Days	=	122 days; Annual day pool is in operation. (Ref. 2, Page 33)
24	=	Hours per day
CF	=	0.78 (Ref. 3)

Example:

A residential customer installed a new self-priming 0.5 hhp variable speed pool pump with WEF = 7.7.

WEF_{BASE} = -1.3 * ln(0.5) + 2.9 = 3.8

Unit kWh Savings per Year = (22,000 gal * 2 turnovers/day) * (1/3.8 - 1/7.7 WEF) * 122 days / (1,000 W / kW) = 715 kWh

Unit Peak kW Savings = 715 kWh / (122 days * 24 hr/day) * 0.78 = 0.190 kW

Deemed Input Tables

Table 1. Baseline WEF Formulas and WEF Values from ENERGY STAR Database

Equipment Class			Baseline WEF		Mean WEF from ENERGY STAR		
Pool Pump Type	hhp range	Motor phase	Standard	Value Range	Base	New	Model Count
Self-priming, w/ filter	hhp < 0.13	single	5.55	5.55	3.7	10.4	41
	0.13 ≤ hhp < 0.771		-1.3 × ln(hhp) + 2.9	3.24 to 5.55			
	0.771 ≤ hhp < 2.5		-2.3 × ln(hhp) + 6.59	4.49 to 7.16	6.1	7.7	152
Non self-priming, w/ filter	hhp < 0.13	any	4.60	4.60	4.6	8.2	8
	0.13 ≤ hhp < 2.5		-0.85 × ln(hhp) + 2.87	2.09 to 4.60			
Pressure cleaner booster	any	any	0.42	0.42	0.4	0.6	5

Methodology and Assumptions

Pump motor must be EC, DC brushless, or permanent magnet style

Pump motor must be capable of variable speed operation

Motor must include integrated “smart” controls that will modulate flow based on demand

If hydraulic horsepower is unknown, the average values from the ENERGY STAR database may be used, per the rightmost columns of Table 1.

References

1. "Analysis of Standards Options for Residential Pool Pumps, Motors, and Controls," Davis Energy Group 2004. Accessed 07/20/15. http://consensus.fsu.edu/FBC/Pool-Efficiency/CASE_Pool_Pump.pdf.
2. CEE High Efficiency Residential Swimming Pool Initiative. Accessed 5/21/15. https://library.cee1.org/system/files/library/9986/CEE_Res_SwimmingPoolInitiative_01Jan2013_Corrected.pdf.
3. Cadmus. Wisconsin Focus on Energy 2020 Technical Reference Manual. https://www.focusonenergy.com/sites/default/files/Focus_on_Energy_2020_TRM.pdf
4. ENERGY STAR. Certified Product List for variable speed pool pumps. Accessed August 2020. https://www.energystar.gov/productfinder/download/certified-pool-pumps/

Revision History

Version	Description	Author	Date
1.0	Measure created	Franklin Energy Services	11/10/2015
2.0	Updated to new standard	Cadmus	9/2020

Commercial and Industrial

Lighting

C/I Lighting - Lighting End Use

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Required from Customer/Contractor	Existing fixtures and quantities (retrofits only), installed fixtures and quantities, building type, HVAC system (heating only, heating & cooling, exterior/unconditioned)
Version No.	2.3
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	see Table 3
Unit Participant Incremental Cost	see Appendix B

Measure Description

The commercial lighting measures use a standard set of variables for hours of use, HVAC cooling interaction effects, and coincident factors. The following section provides the algorithms used for energy savings and the tables of supporting information.

Algorithms

Unit kWh Savings per Year = (kW_Base - kW_EE) x Hrs x HVAC_cooling_kWhsavings_factor

Unit Peak kW Savings = CF x (kW_Base - kW_EE) x HVAC_cooling_kWsavings_factor

Unit Dth Savings per Year = (kW_Base - kW_EE) x Hrs x HVAC_heating_penalty_factor

Where:

kW_Base = Baseline fixture wattage (kW per fixture): see Appendix B

kW_EE = High Efficiency fixture wattage (kW per fixture): see Appendix B

Hrs = Deemed annual operating hours from Table 2 based on building type

CF = Coincidence Factor, the probability that peak demand of the lights will coincide with peak utility system demand. CF will be determined based on customer provided building type in Table 2.

HVAC_cooling_kWhsavings_factor = Cooling system energy savings factor resulting from efficient lighting from Table 1. Reduction in lighting energy results in a reduction in cooling energy, if the customer has air conditioning.

HVAC_cooling_kWsavings_factor = Cooling system demand savings factor resulting from efficient lighting from Table 1. Reduction in lighting demand results in a reduction in cooling demand, if the customer has air conditioning.

HVAC_heating_penalty_factor = Heating system penalty factor resulting from efficient lighting from Table 1.

Example:

Replace (1) 60W incandescent with a 9W LED lamp in an office space with heating and cooling.

kWh Savings = (0.043-0.009) x 4,439 x 1.095 = 165.23 kWhkW Savings = 0.7 x (0.043-0.009) x 1.254 = 0.0298 kW

Heating Penalty = (0.043-0.009) x 4,439 x -0.0023 = -0.347 Dth/year

Deemed Input Tables

Table 1. HVAC Interactive Factors by HVAC System (Ref. 2)

Lighting Measures	HVAC Cooling kW Savings Factor		HVAC Cooling kWh Savings Factor		HVAC Heating Penalty Factor (Dth/kWh)
	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only or Heating & Cooling
All Except Exterior/ Unconditioned	1.00	1.254	1.00	1.095	-0.0023
Exterior/ Unconditioned Space	1.00	1.00	1.00	1.00	0

Table 2. Deemed Peak Demand Coincidence Factors (Ref. 3) and Annual Operating Hours by Building Type (Ref. 4)

Building Type	CF	Hrs
Office	70%	4,439
Restaurant	80%	3,673
Retail	83%	4,719
Grocery/Supermarket	90%	5,802
Warehouse	70%	4,746
Elementary School	71%	2,422
Secondary School	58%	4,311
College	81%	3,540
Health	75%	5,095
Hospital	75%	6,038
Hotel/Motel	21%	3,044
Manufacturing	92%	5,200
Other/Misc.	66%	4,576

Building Type	CF	Hrs
24-Hour Facility	100%	8,760
Safety or Code Required	100%	8,760
Exterior Lighting	0%	4,380

Table 3. Measure Life

Installed Technology	Measure Life (yrs)	Reference
Ceramic Metal Halide	13	8
Ceramic Metal Halide - Integrated Ballast	13	8
High Bay Fluorescent	15	6
High Bay LED	11.3	20
LED Exterior Canopy	10.2	7
LED Exterior (Wall & Area)	10.2	7
Low wattage plug in CFL	1.8	16
Low wattage T8	15	6
Pin based CFL	2.3	17
Pulse Start Metal Halide	15	9
CFL Standard to Low Wattage	2.3	1
Controls (not networked lighting controls)	8	6
Networked lighting controls	11	
Exit Sign Retrofit with LED/LEC	16	6
Exterior Canopy/Soffit Retrofit with LEDs	10.2	7
Exterior Wall Pack Retrofit with LEDs	10.2	7
Parking Garage Fluorescent	15	6
High Pressure Sodium	15	18
Interior LED Screw-in Lamps	3.4	14
Interior LED Luminaire	11.3	15
Pin-Based CFL	2.3	9
Pin-Based LED	11.3	21
T5 fixtures	15	6
T8 fixtures	15	6
Refrigerator/Freezer Case LEDs	10	10
Stairwell Fixtures with Integral Occupancy	14.4	11
T8 Standard to Low Wattage Retrofit	8.1	12
Energy Standard Exempt T12 HO ballasts for outdoor signs and electronic ballast T12s	15	6
Nonexempt 8-foot magnetic ballast T12s are 4 years in 2013, 3 years in 2014, 2 years in 2015, and 1 year in 2016, 1 year in 2017, 1 year in 2018, 1 year in 2019	1	13
T8 Optimization	15	6
LED Linear Replacement Lamp	11.3	22

Methodology and Assumptions

HVAC cooling and heating interactive factor data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes (see http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf), and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Notes

New construction requirements and information is available in the New Construction section.

References

1. CFL lamp-rated hours of 10,000 is divided by the average operating hours (except safety, 24-hr, and exterior) of 4,431 hours to arrive at 2.3 years for measure life.
2. HVAC cooling and heating interactive factor data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes (see http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf), and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).
3. Database of Energy Efficient Resources 2008 Measure Energy Analysis Revisions Version 2008.2.05-09-11 Planning/Reporting Version.
4. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18, 2012 Effective June 1, 2012; Section 6.5., Illinois TRM summarizes recent studies including: DEER 2005, DEER 2008, ComEd FY1 and FY2 evaluations, AmerEn Missouri Final Report: Evaluation of Business Energy Efficiency Program Custom and Standard Incentives, and Focus on Energy Evaluation, ACES Deemed Savings Desk Review, November 2010.
5. Lighting Efficiency input wattage guide, Xcel Energy, July 2008, kW.
6. Database of Energy Efficient Resources 2008 Effective Useful Life Summary 10-1-08.
7. Product life based on 50,000 minimum rated life from Design Lights Consortium V4.0 Specification. https://designlights.org/resources/file/TRT_V40_Final_FULLTABLE_FINAL_highlights 50,000 divided by the exterior hours of 4,903 arrives at 10.2 years.
8. State of Wisconsin Public Service Commission of Wisconsin Focus on Energy Evaluation *Business Programs: Measure Life Study* Final Report: August 25, 2009.
9. Residential and Commercial/Industrial Lighting and HVAC Measures for use as Energy Efficiency Measures/Programs Reference Document for the ISO Forward Capacity Market (FCM) June 2007 GDS Associates, Inc.
10. Assumes 6,205 hrs, per year, operation (17 hrs/day) and a lifetime of approximately 62,082 hours (this is the average rated life from DLC qualified product list). Accessed 7/31/12.

11. Xcel Energy 2013-2015 Triennial CIP Plan (Docket No. E,G002/CIP-12-447). Average of fixture lifetime (20 years) and control lifetime (~8 years).
12. Product life assumption of 36,000 hours determined from survey of on-line retailers, July 2012. 36,000 hours is divided by the average operating hours (except safety, 24-hr, and exterior) of 4,431 hours to arrive at 8.1 years for measure life.
13. Measure life reduction due to legislation and market. See T12 up to 4-Foot Retrofit section for more information.
14. LED lamp rated hours of 15,000 (ENERGY STAR qualified minimum) is divided by the average operating hours (except safety, 24-hr, and exterior) of 4,431 hours to arrive at 3.4 years for measure life.
15. Product life based on 50,000 minimum rated life from Design Lights Consortium V4.0 Specification
    https://designlights.org/resources/file/TRT_V40_Final_FULLTABLE_FINAL_highlights
    LED luminaire rated hours of 50,000 is divided by the average operating hours (except safety, 24-hr, and exterior) of 4,431 hours to arrive at 11.3 years for measure life.
16. Measure life for plug in low wattage CFL lamps is based on 8,000 hours of life divided by the average annual operating hours of 4,431 to arrive at 1.81 years.
17. CFL lamps rated hours of 10,000 is divided by the average operating hours (except safety, 24-hr, and exterior) of 4,431 hours to arrive at 2.3 years for measure life.
18. Xcel Energy uses 20 years in 2013-2015 Minnesota CIP Triennial Plan (Docket No. E,G002/CIP-12-447), per communication with Commerce staff. Fixture may be considered permanent once installed; however, life was decreased to 15 years for consistency with maximum lifetimes for other technologies.
19. ANSI/ASHRAE/IES Standard 90.1-2010 edition.
20. LED highbay-rated hours of 50,000 is divided by the average operating hours (except safety, 24-hr, and exterior) of 4,431 hours to arrive at 11.3 years.
21. DLC is expected to adopt this category of lamps in late 2016; minimum rate lifetime will be 50,000 hours. 50,000 is divided by the average operating hours (except safety, 24-hr, and exterior) of 4,431 hours to arrive at 11.3 years.
22. Minimum rated lifetime will be 50,000 hours. 50,000 is divided by the average operating hours (except safety, 24-hr, and exterior) of 4,431 hours to arrive at 11.3 years.
23. C/I Lighting - Controls measure

Revision History

Below is a summary of the revision history for the entire C/I Lighting section.

Version	Description	Author	Date
2.0	Updated format, baseline and efficient wattages, costs, energy standards, and requirements where applicable through the lighting section. Added fluorescent to LED High Bay and LED Troffer Measures	Franklin Energy Services	11/12/2015
2.1	Updated measure lives to reflect ENERGY STAR Version 2.0 for Lamps and Design Lights Consortium Version 4.0 Specifications	Franklin Energy Services	9/30/2016
2.2	Added LED Linear Replacement Lamps. Decreased exterior lighting hours to 4,383	Franklin Energy Services	8/4/2017
2.3	Updated EUL for networked lighting controls	Cadmus	10/2020

C/I Lighting - CFL Standard to Low Wattage Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working, Replace on Fail
Version No.	3.4

Measure Description

This measure replaces standard wattage plug-in CFL lamps with lower wattage plug-in CFL lamps, nominally 40 watt lamps replaced by 28 watt or 25 watt lamps. These lamps plug into the fixture and can be used with the existing ballast and base. Commonly referred to as Dulux, Biax, or PL lamps.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Revision History

Version	Description	Author	Date

C/I Lighting - Controls

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Modify (all) New Construction (some)
Required from Customer/Contractor	Control type/quantity, connected load (kW) to each control, building type, HVAC system (heating only, heating & cooling, exterior/unconditioned)
Version No.	4.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	11 years or fixture lifetime for NLC with LLLC (see Notes), 8 years for other controls including NLC without LLLC (Ref. 1)
Unit Participant Incremental Cost	See Table 2

Measure Description

Lighting control technologies reduce energy use by automatically turning lights off and adjusting brightness levels, rather than relying on people to remember to switch lights off when leaving a space. There are several different lighting control technologies, including:

- **Occupancy sensors**. These measure the movement of people within a space. When movement is detected, the lights turn on automatically; they then shut off after a period of not sensing movement.
- **Daylight sensors**. These take advantage of available daylight in perimeter building spaces (open spaces within 10' to 15' of windows) or other areas that have access to daylight infiltration. Daylight sensor lighting controls can be used to turn lights on or off, stepped dimming (high/low or inboard/outboard), or continuous dimming based on light levels from available daylight.
- **Personal tuning**. This consists of adjusting individual light levels by occupants according to their personal preferences. Requires continuous or multilevel dimming, and largely applies to private offices and individual cubicles in open offices.
- **Task tuning**. Also known as institutional tuning or high-end trim, this is similar to personal tuning but involves tuning light levels broadly across an entire office or other space, often through commissioning, and often involving the provision of switches or controls for areas or groups of occupants.
- **Networked lighting controls (NLC)**. Also known as connected lighting controls, this consists of an intelligent network of individually addressable luminaires and control devices, allowing for the interactive application of multiple control strategies. Sensor mechanisms for NLC may be integrated into the fixtures themselves. This practice is called luminaire-level lighting controls

(LLLC), and there is evidence that it saves more energy than NLC with sensors that are separate from the fixtures.

Note that Minnesota state energy code as of March 31, 2020 (Ref. 7) follows 2018 IECC standards (Ref. 8). These standards require that occupancy sensors are required in classrooms, office spaces, restrooms, locker rooms, storage rooms, warehouses, and more, and that daylight controls are employed in sidelit and toplit zones. For new construction in these spaces, these controls shall be the baseline.

Algorithms

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Unit kWh Savings per Year = kW x (SF_new - SF_old) x Hrs x HVAC_cooling_kWhsavings_factor

Unit Peak kW Savings = CF x kW x (SF_new - SF_old) x HVAC_cooling_kWsavings_factor

Unit Dth Savings per Year = kW x (SF_new - SF_old) x Hrs x HVAC_heating_penalty_factor

Where:

kW = Total connected fixture load, determined as the sum of stipulated fixture wattages from the Retrofit Tables in the C/I Lighting Measure.

Hrs = Deemed annual operating hours from Table 2 based on building type, in Lighting End Use section.

SF_new = Deemed Savings Factor for newly installed lighting control per Table 1 and Table 2.

SF_old = Savings factor for existing lighting control, or often occupancy or daylighting controls for New Construction, per Table 1.

CF = Coincidence Factor, the probability that peak demand of the lights will coincide with peak utility system demand. CF will be determined based on customer provided building type in table 2, in Lighting End Use section.

HVAC_cooling_kWhsavings_factor = Cooling system energy savings factor resulting from lighting from Table 1, in Lighting End Use section. Reduction in lighting energy results in a reduction in cooling energy, if the customer has air conditioning.

HVAC_cooling_kWsavings_factor = Cooling system demand savings factor resulting from lighting from Table 1, in Lighting End Use section. Reduction in lighting demand results in a reduction in cooling demand, if the customer has air conditioning.

HVAC_heating_penalty_factor = Heating system penalty factor resulting from lighting control from Table 1, in Lighting End Use section.

Example:

Install a wall mounted occupancy sensor with a connected load of 0.560 kW (10 - 2L 32W T8 fixtures) in an office space.

kWh = 0.560kW * 0.22 * 4,439 * 1.095 = 598.8 kWh

kW = 0.7 * 0.560 * 0.22 * 1.254 = 0.108 kW

Deemed Input Tables

Table 1. Deemed Savings Factors

Control Type	Building type	Savings Factor	SF Source
Occupancy Sensor	Office	0.22	Ref. 2, Table 7 For warehouse new construction, occupancy sensors with 50% dimming are required (Ref. 8). This reduces the baseline NC savings factor in this scenario to SF_{OCC} * (1 - 0.50) = 0.31 * 0.50 = 0.16
	Warehouse	0.31 (upgrade) 0.16 (NC baseline)	
	Lodging	0.45	
	Education	0.18	
	Assembly	0.36	
	Healthcare, outpatient	0.23	
	Other / unknown	0.24	Ref. 2, Abstract
Daylighting	Office	0.27	Ref. 2, Table 7
	Warehouse	0.28	
	Education	0.29	
	Retail	0.29	
	Assembly	0.36	
	Other / unknown	0.28	Ref. 2, Abstract
Personal tuning	Office	0.21	Ref. 2, Ref. 5: 0.35 x 0.22 / 0.36 = 0.21 (see Notes)
	Education	0.04	Ref. 2, Ref. 5: 0.06 x 0.22 / 0.36 = 0.04 (see Notes)
	Other / unknown	0.19	Ref. 2, Ref. 5: 0.31 x 0.22 / 0.36 = 0.19 (see Notes)
Task tuning	Office	0.37	Ref. 6 and Ref. 9, see Notes
	Education	0.26	
	Manufacturing	0.05	
	Warehouse	0.07	
	Other / unknown	0.22	Ref. 5
Multiple of the above		0.38	Ref. 2, Abstract

Table 2. Deemed Savings Factors for NLC

Control Type	Subtype	Savings Factor			SF Source
		With LLLC	Without LLLC	Unknown	
Networked lighting controls	Assembly	0.32	0.24	0.28	Ref. 3, Table 1 and Table 7, see Notes
	Manufacturing	0.51	0.26	0.40	Ref. 3, Table 1 and Table 7
	Office	0.77	0.40	0.64	Ref. 3, Table 1 and Table 7
	Education	0.52	0.35	0.41	Ref. 3, Table 1 and Table 7
	Restaurant	0.67	0.51	0.59	Ref. 3, Table 1 and Table 7, see Notes
	Retail	0.50	0.38	0.44	Ref. 3, Table 1 and Table 7, see Notes
	Warehouse	0.78	0.58	0.68	Ref. 3, Table 1 and Table 7, see Notes
	Other / unknown	0.63	0.35	0.49	Ref. 3, Table 1 and Table 7

Table 3. Deemed Incremental Costs

Control Type	Subtype	Incrmental Cost	IC Source
Occupancy Sensor	Wall switch mount	$55 per sensor	Ref. 4
	Fixture mount	$67 per sensor	
	Remote or wall mount	$125 per sensor	
	Integrated	$40 per sensor	
Daylighting	Fixture mount	$50 per sensor	Ref. 4
	Remote or wall mount	$65 per sensor	
Dual occupancy and daylighting sensor	Integrated	$50 per sensor	Ref. 4
	Fixture-mounted	$100 per sensor	
Personal tuning		Actual, or $0.06 per sq ft controlled	Ref. 5
Institutional tuning			
Networked lighting controls		Actual cost	

Notes

Savings fractions by building type for task tuning were derived from Table 2 of a 2020 Slipstream paper (Ref. 6), which shows savings fractions by space type, and space type splits for each building type (Ref. 9). Those values are seen in Table 3 below.

Table 3. Savings Factors for Task Tuning by Building

Space Type	Space Type Savings Factor (Ref. 6)	Space Distribution by Building Type (Ref. 9)			
		Office	Education	Manufacturing	Warehouse
Office	39%	70%	5%	10%	10%
Conference	34%	4%	0%	0%	0%
Warehouse	4%	0%	0%	25%	87%
Storage	0%	6%	3%	0%	0%
Corridor	86%	10%	21%	0%	0%
Other	0%	10%	34%	5%	3%
Manufacturing	0%	0%	0%	60%	0%
Classroom	17%	0%	35%	0%	0%
Weighted Average Building Savings Factor		**37%**	**26%**	**5%**	**7%**

The savings fractions for personal tuning employ values from Ref. 2 (Table 7 for Office and Education, Abstract for Other) but normalizes based on findings from Ref. 5 showing that the institutional tuning SF = 0.22 on average, rather than 0.31 from the Ref. 2 Abstract. The savings factor for personal tuning is normalized from the Ref. 2 values by 0.22 / 0.36 = 61%.

Savings fractions for NLC for three building types (manufacturing, office, education) and other / unknown buildings were derived directly from Table 7 of a NEEA study examining NLC with and without LLLC (Ref. 3). This study found sufficient diversity in savings across NLCs with and without LLLC for these three building types that their savings factors were listed.

For the other four building types (assembly, restaurant, retail, warehouse), the study only lists savings factors for NLC as a whole, without a differentiation for having or not having LLLC. While the study did find that LLLC produced more savings on average across all surveyed buildings together, it cautions this may not be the case for each individual building type and that more study is needed. However, for this measure an attenuated difference is applied for those four other building types.

Savings for those building types with and without LLLC are normalized by the "Other / unknown" (overall) savings, with a 50% attenuation: LLLC savings are normalized by [(0.63 / 0.49 – 1) * 0.5] + 1 = 1.14, and non-LLLC savings are normalized by [(0.35 / 0.49 – 1) * 0.5] + 1 = 0.86. Therefore, for instance, assembly buildings with LLLC are deemed a savings factor of 0.28 * 1.14 = 0.32. As new research on LLLC is produced, these savings fractions will be revisited.

Because networked lighting controls with LLLC are installed integrated into fixtures, the measure lifetime for networked lighting controls with LLLC is assumed to match the fixtures themselves, generally 11 years for LEDs per the lighting end use section. However, if the lifetimes of the LED units being installed with networked lighting controls with LLLC are known to be higher than 11 years, those lifetimes may be applied to networked lighting controls associated with those units.

References

1. California Energy Commission and California Public Utilities Commission. Database for Energy Efficient Resources. EUL Table. 2014. http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EUL-table-update_2014-02-05.xlsx
2. Williams, A. et al. *A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings*. Lawrence Berkeley National Laboratory. LBNL-5095E. September 2011. https://eta.lbl.gov/sites/default/files/publications/a_meta-analysis_of_energy_savings_from_lighting_controls_in_commercial_buildings_lbnl-5095e.pdf
3. NEEA. Energy Savings from Networked Lighting Control Systems With and Without Luminaire Level Lighting Controls. October 6, 2020. Table 1 and Table 7. https://neea.org/resources/energy-savings-from-networked-lighting-control-systems-with-and-without-luminaire-level-lighting-controls
4. Illinois Energy Efficiency Stakeholder Advisory Group. *2020 Illinois Statewide Technical Reference Manual for Energy Efficiency Version 8.0*. Volume 2: Commercial and Industrial Measures. October 17, 2019. https://ilsag.s3.amazonaws.com/IL-TRM_Effective_0-10-120_v8.0_Vol_2_C_and_I_10-17-19_Final.pdf
5. Seventhwave. *Adjusting lighting levels in commercial buildings.* August 2015. https://mn.gov/commerce-stat/pdfs/card-report-lighting-levels-commercial.pdf. Approximate cost range for task tuning from $0.03 to $0.06 per square foot. $0.06 chosen, and also used for personal tuning, which may not require photometric measurements but does require additional labor and perhaps material cost.
6. Slipstream. *Light Level Analysis in Commercial Buildings: A Minnesota Market Study*. 2020. https://slipstreaminc.org/sites/default/files/documents/research/light-level-analysis-minnesota-commercial-buildings.pdf
7. U.S. Department of Energy Building Energy Codes Program. Minnesota. https://www.energycodes.gov/adoption/states/minnesota
8. 2018 International Energy Conservation Code. Chapter 4 section C405.2. https://codes.iccsafe.org/content/iecc2018/chapter-4-ce-commercial-energy-efficiency
9. Review of DOE Prototype Models and eQuest Wizard defaults

Revision History

Version	Description	Author	Date
3.5			
4.0	Modified savings values and references, added several control methods	Cadmus	9/2020
4.1	Added separate savings for LLLC, updated savings for NLC, added costs	Cadmus	9/2021

C/I Lighting - Exit Sign Retrofit with LED/LEC

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working, Replace on Fail
Version No.	3.4

Measure Description

This measure evaluates the retrofit and replacement of incandescent exit signs with energy efficient LED and LEC exit signs. ENERGY STAR labeled exit signs operate on five watts or less per sign, compared to the standard signs, which use as much as 40 watts per sign.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Notes

EPA suspended the ENERGY STAR Exit Sign specification effective May 1, 2008. In EPAct 2005, Congress passed a new minimum federal efficiency standard for electrically-powered, single-faced exit signs with integral light sources that are equivalent to ENERGY STAR levels for input power demand. EPAct 2005 references the ENERGY STAR Version 2.0 specification. All exit signs manufactured on or after January 1, 2006 must have an input power demand of 5 watts or less per face.

References

1. Database of Energy Efficient Resources 2008 Effective Useful Life Summary 10-1-08
2. Calculated through energy modeling be FES 2012
3. Lighting Efficiency input wattage guide, Xcel Energy, July, 2008, kW
4. NYSERDA Deemed Savings Database, Labor cost assumes 25 minutes @ $18/hr taken from the State of Illinois Technical Reference Manual 2012 and 2012 manufacturer product survey and project data.

Revision History

Version	Description	Author	Date

C/I Lighting - Exterior Canopy/Soffit Retrofit with LEDs

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Exterior canopy/soffit lighting at any facility type
Actions	Replace Working, Replace on Fail
Version No.	3.3

Measure Description

Exterior high pressure sodium, metal halide, mercury vapor, and pulse start metal halide fixtures can all be replaced with energy efficient LED exterior light fixtures in canopy and soffit applications. Utilizing LED lighting, a large energy savings can be accomplished without a great lumen reduction in the area.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date

C/I Lighting - Exterior Wall Pack Retrofit with LEDs

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Exterior wall pack lighting at any facility type
Actions	Replace Working, Replace on Fail
Version No.	1.1

Measure Description

Exterior high pressure sodium, metal halide, mercury vapor, and pulse start metal halide fixtures can all be replaced with energy efficient LED exterior wall pack fixtures. Utilizing LED lighting, a large energy savings can be accomplished without a great lumen reduction in the area.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date

C/I Lighting - Fluorescent to LED High Bay Systems

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working
Version No.	1.0

Measure Description

LED high bay fixtures offer increased efficiency with nearly equivalent light output as compared to linear fluorescent high bay systems. Integrated LED high bays also offer advanced controllability leading to an even greater increase in efficiency.

LED systems are often utilized in high bay ceiling applications over 15 feet. LED fixtures also offer an increased life time, reduced maintenance, and no decreased in operational performance in colder temperatures.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that LED High Bay fixtures appear on the Design Lights Consortium Qualified Product List under the High Bay category.

Revision History

Version	Description	Author	Date

C/I Lighting - High Pressure Sodium Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace on Fail, Replace Working
Version No.	3.4

Measure Description

This measure evaluates high pressure sodium fixtures replaced by pulse start metal halides, high bay fluorescent fixtures, parking garage fluorescent, and ceramic metal halides.

Pulse start metal halide systems typically consume 20 percent less energy than high pressure sodium systems, produce the same light at lower wattages, and can often use more efficient ballasts depending on the application.

High bay fluorescent systems are often utilized in high bay ceiling applications over 15 feet. High bay fluorescent and parking garage fluorescent systems offer lower depreciation rates, better dimming options, virtually instant start-up and re-strike, better color rendition, and reduced glare.

Ceramic metal halides can be utilized to replace high pressure sodium in lower wattage applications and result in better color rendition, lower wattage consumption, and improved color temperature.

Algorithm and Assumptions:

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Notes

New construction wattage tables are available in the CI Lighting New Construction file.

The Energy Independence and Security Act of 2007 legislation sets standards for ballasts used in new metal halide luminaires that operate lamps from 150 to 500 watts. New metal halide luminaires must contain ballasts that meet new efficiency standards. Pulse-start metal halide ballasts must have a minimum ballast efficiency of 88%, magnetic probe-start ballast a minimum efficiency of 94%. New metal halides operating lamps of 150-500 watts manufactured on or after January 1, 2009 contain pulse-start, magnetic or electronic, metal halide ballasts with a minimum efficiency of 88%.

Revision History

Version	Description	Author	Date

C/I Lighting - Incandescent Over 100W Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working, Retrofit
Version No.	3.3

Measure Description

This measure replaces Incandescent fixtures over 100 watts with various technologies including ceramic metal halides, high pressure sodium fixtures, integrated ballast ceramic metal halides, LED lamps, LED luminaire, pin-based CFL, pulse start metal halides, T5 fixtures, and T8 fixtures. The replacement fixture technology will depend on the specific application and environment.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org and LED and CFL lamps appear on the ENERGY STAR Qualified Product list available at www.energystar.gov.

Revision History

Version	Description	Author	Date

C/I Lighting - Incandescent Up to 100W Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working, Retrofit
Version No.	3.5

Measure Description

This measure replaces Incandescent fixtures up to 100 watts with various technologies including ceramic metal halides, LED lamps, LED luminaire, pin-based CFL, pulse start metal halides, and T8 fixtures. The replacement fixture technology will depend on the specific application and environment.

Algorithm and Assumptions:

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org and LED and CFL lamps appear on the ENERGY STAR Qualified Product list available at www.energystar.gov.

Revision History

Version	Description	Author	Date

C/I Lighting - LED Pin-Base Lamps Replacing CFLs

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working, Replace on Fail
Version No.	1.0

Measure Description

This measure replaces CFL pin-base lamps, commonly referred to as Dulux, Biax, or PL lamps, with LED pin-base lamps. These lamps plug into the existing fixture and can be used with the existing ballast and socket.

As of September 2016, Lighting Design Lab (www.lightingdesignlab.com) maintains a qualified product list of pin-base CFL replacement products. Design Lights Consortium is expected to have a qualified product list available for this category in late 2016.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Revision History

Version	Description	Author	Date

C/I Lighting - LED Screw-In Lamps in Walk-in Coolers and Freezers

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Lighting
Applicable To	Grocery stores, convenience stores and other refrigerated sales facilities; refrigerated warehouses
Actions	Replace on Fail, Replace Working
Required from Customer/Contractor	Unit type (refrigerator or freezer), existing wattage, installed wattage
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15,000/Hrs; default = 1.7 (Ref. 2)
Unit Participant Incremental Cost	Proposed lamp cost. See Appendix B.

Measure Description

This measure involves replacement of existing incandescent screw-in lamps with ENERGY STAR-qualified LED screw-in lamps in walk-in coolers and freezers or refrigerated warehouses.

Algorithm

Unit kWh Savings per Year = (kW_base - kW_EE) x Hrs x (1 + Refr_Factor)

Unit Peak kW Savings = CF x (kW_base - kW_EE) x (1 + Refr_Factor)

Where:

kW_base = Baseline lamp wattage, see Appendix B

kW_EE = Efficient lamp wattage, see Appendix B

Hrs = 8,760 hours or estimate on-time if controlled (Ref. 1)

CF = 1.0; peak electrical coincidence factor (Ref. 1)

Refr_Factor = 0.40 (for refrigerator applications, assumes COP of 2.5) (Ref. 3)
= 0.77 (for freezer applications, assumes COP of 1.3) (Ref. 3)

Example:

A convenience store retrofits its walk-in cooler with 9W ENERGY STAR-qualified LED lamps. The existing lamps are 60W incandescent. The baseline for this lamp is a 43W halogen per EISA.

Unit kWh Savings per Year = (0.043 - 0.009) * 8,760 * (1 + 0.40) = 417 kWh

Unit Peak kW Savings = 1.0 * (0.043 - 0.009) * (1 + 0.40) = 0.05 kW

References

1. Without lighting controls, walk-in cooler and freezer lighting is considered always on.
2. Assumes 8,760 hrs per year operation and a lifetime of approximately 15,000 hours (ENERGY STAR minimum requirement from V2.0); equates to 1.7 years.
3. US DOE Publication #46230-00, “Energy Savings Potential for Commercial Refrigeration Equipment", 1996, Arthur C. Little, Inc

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	9/28/2016

C/I Lighting - LED Troffer Retrofit Kits

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working
Version No.	1.0

Measure Description

LED Troffers offer an energy efficient alternative to T8 linear fluorescent fixtures. Kits are available to convert an existing recessed troffer to LED without requiring removal of the fixture. LED integrated fixtures offer similar light output with a reduction of energy consumption. Integrated LED fixtures also offer controllability beyond capabilities of linear fluorescent technology and integration with many complex control systems.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date

C/I Lighting - LED Troffers

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working
Version No.	1.0

Measure Description

LED Troffers offer an energy efficient alternative to T8 linear fluorescent fixtures. The LED integrated fixtures offer similar light output with a reduction of energy consumption. Integrated LED fixtures also offer controllability beyond capabilities of linear fluorescent technology and integration with many complex control systems.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date

C/I Lighting - LED Tube Replacement Lamps

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working, Replace on Fail
Version No.	1.0

Measure Description

LED Tube replacement lamps offer an energy efficient alternative to traditional linear fluorescent lamps. These are available in three types: Underwriters Laboratory (UL) Type A (direct replacement), UL Type B (hard wired), or UL Type C (remote driver). The three variations allow for a retrofit in nearly every linear fluorescent application.

Type A tubes contain an internal driver that allows the tube to operate directly from an existing fluorescent ballast. Type B tubes contain an integrated driver that is designed to be powered directly from line voltage supplied to the existing fluorescent fixture. Type C tubes are designed to be powered from a remote driver.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED lamps appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date

C/I Lighting - Mercury Vapor Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace on Fail, Replace Working
Version No.	3.5

Measure Description

This measure evaluates mercury vapor fixtures replaced by pulse start metal halides, high bay fluorescent fixtures, high pressure sodium fixtures, parking garage fluorescent fixtures, and ceramic metal halides.

Pulse start metal halide systems typically consume 20 percent less energy than mercury vapor systems, produce the same light at lower wattages, and can often use more efficient ballasts depending on the application.

High bay fluorescent systems are often utilized in high bay ceiling applications over 15 feet. High bay fluorescent and parking garage fluorescent systems offer lower depreciation rates, better dimming options, virtually instant start-up and re-strike, better color rendition, and reduced glare.

Ceramic metal halides can be utilized to replace mercury vapor systems in lower wattage applications and result in better color rendition, lower wattage consumption, and improved color temperature.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Revision History

Version	Description	Author	Date

C/I Lighting - Metal Halide Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace on Fail, Replace Working
Version No.	3.6

Measure Description

This measure evaluates probe start metal halides replaced by pulse start metal halides, high bay fluorescent fixtures, and ceramic metal halides. Pulse start metal halide systems typically consume 20 percent less energy than standard metal halide systems, produces the same light at lower wattages, and can often use more efficient ballasts depending on the application.

High bay fluorescent and parking garage fluorescent systems are often utilized in high bay ceiling applications over 15 feet. High bay fluorescent and parking garage fluorescent systems offer lower depreciation rates, better dimming options, virtually instant start-up and re-strike, better color rendition, and reduced glare.

Ceramic metal halides can be utilized to replace probe start metal halides in lower wattage applications and result in better color rendition, lower wattage consumption, and improved color temperature.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Revision History

Version	Description	Author	Date

C/I Lighting - New Construction

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	New Construction
Version No.	3.5

Measure Description

The following measures are used in new construction in place of the less efficient standard practice. New construction technologies include ceramic metal halide, integral ballast ceramic metal halide, high bay fluorescent, LED exterior canopy, LED exterior wallpacks and area/pole lighting, LED parking garage wallpack and area lighting, LED lamps and fixtures, LED troffers, LED street lighting, low wattage plug in CFLs, low wattage T8, Pin based CFLs, and pulse start metal halides.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Notes

EPAct 2005 and 2000 DOE Ballast Rule. 2000 DOE Ballast Rule no longer allows ballasts that do not pass the new requirements to be manufactured after July 1, 2010 and EPAct 2005 no longer allows ballasts that do not pass the new requirements to be sold after October 1, 2010.

Ballasts affected by the rulemaking are those that operate:

- T12 4-foot linear and 2-foot U-shaped Rapid Start lamps with medium bi-pin bases
- T12 8-foot Instant Start lamps with single pin bases
- T12 8-foot Rapid Start HO lamps with recessed double contact (RDC) bases

Exceptions to the ballast standards:

- Dimming ballasts that dim to 50% or less of maximum output
- T12 HO ballasts capable of starting at ambient temperatures as low as -20° F or less and for use in outdoor illuminated signs
- Ballasts having a power factor of less than 0.90 and designed and labeled for use only in residential applications.
- 2 foot and 3 foot lamp and ballast systems

2009 DOE Lamp Rulemaking for GSFL and IRL Lamps. New efficiency standards for General Service Fluorescent lamps (GSFLs), linear and U-shaped require these covered lamp types to meet minimum lumen per watt (LPW) requirements; products that do not meet the minimum LPW requirements as of July 14, 2012 can no longer be produced.

The following lamp types are affected by these standards:

- Lamp Type| Energy Conservation Standard (lm/W)
- 4-foot (T8-T12) Medium Bi-pin ≥25W 89/88
- 2-foot (T8-T12) U-Shaped ≥25W 84/81
- 8-foot (T8-T12) Single Pin Slimline ≥52W 97/93
- 8-foot (T8-T12) High Output 92/88
- 4-foot (T5) Miniature Bi-pin Standard Output ≥26W 86/81
- 4-foot (T5) Miniature Bi-pin high Output ≥49W 76/72
- New T12 lamps that meet the new standards are now available in the market allowing T12s to still be installed.

ASHRAE 90.1 2010 Section 9 (ref 6) states the following:

> The alteration of lighting systems in any building space or exterior area shall comply with the lighting power density (LPD) requirements of Section 9 applicable to that space or area and the automatic shutoff requirements of 9.4.1.1. Such alterations shall include all luminaires that are added, replaced, or removed. This requirement shall also be met for alterations that involve only the replacement of lamps plus ballasts. Alterations do not include routine maintenance or repair situations.
>
> Exception: Alterations that involve less than 10% of the connected lighting load in a space or area need not comply with these requirements provided that such alterations do not increase the LPD.

Maximum LPDs using Building Area Method are shown below.

Table 1. Lighting Power Densities Using Building Area Method (Ref 22). Refer to ASHRAE 90.1-2010, Table 9.6.1 for Lighting Power Densities using the Space-by-Space Method.

Building Area Type	LPD (W/ft2)
Automotive Facility	0.82
Convention Center	1.08
Courthouse	1.05
Dining: Bar lounge/leisure	0.99
Dining: cafeteria/fast food	0.90
Dining: Family	0.89
Dormitory	0.61
Exercise Center	0.88
Fire Station	0.71
Gymnasium	1.00
Health-care clinic	0.87
Hospital	1.21
Hotel	1.00

Building Area Type	LPD (W/ft2)
Library	1.18
Manufacturing Facility	1.11
Motel	0.88
Motion picture theater	0.83
Multifamily	0.60
Museum	1.06
Office	0.90
Parking Garage	0.25
Penitentiary	0.97
Performing arts theater	1.39
Police station	0.96
Post office	0.87
Religious building	1.05
Retail	1.40
School/university	0.99
Sports arena	0.78
Town hall	0.92
Transportation	0.77
Warehouse	0.66
Workshop	1.20

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org and LED and CFL lamps appear on the ENERGY STAR Qualified Product list available at www.energystar.gov.

Revision History

Version	Description	Author	Date

C/I Lighting - Pulse Start Metal Halide Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public, Other
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace on Fail, Replace Working
Version No.	3.6

Measure Description

This measure evaluates pulse start metal halide fixtures replaced by lower wattage pulse start metal halides, high bay fluorescent fixtures, and ceramic metal halides.

Pulse start metal halide fixtures can be replaced by lower wattage pulse start metal halides when the space they are in is considered over lit.

High bay fluorescent and fluorescent systems are often utilized in high bay ceiling applications over 15 feet. High bay fluorescent and fluorescent systems offer lower depreciation rates, better dimming options, virtually instant start-up and re-strike, better color rendition, and reduced glare.

Ceramic metal halides can be utilized to replace pulse start metal halides in lower wattage applications and result in better color rendition, lower wattage consumption, and improved color temperature.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Revision History

Version	Description	Author	Date

C/I Lighting - Refrigerator/Freezer Case LEDs

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Lighting
Applicable To	Grocery stores, convenience stores and other refrigerated sales facilities
Actions	Replace on Fail, Replace Working
Required from Customer/Contractor	Unit type (refrigerator or freezer), existing fixture wattage, proposed fixture wattage
Version No.	2.3
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	See Appendix B or use actual proposed fixture cost

Measure Description

This measure involves replacement of existing vertical and horizontal fluorescent refrigerated case lighting with more efficient LED lighting. It is recommended that qualifying product criteria include presence on the Design Lights Consortium Qualified Product List at www.designlights.org.

Algorithms

Unit kWh Savings per Year = (kW_base – kW_EE) * Hrs * (1+Refr_Factor)

Unit Peak kW Savings = CF * (kW_base – kW_EE) * (1+Refr_factor)

Where:

kW_base = Baseline fixture wattage (kW per fixture): see Appendix B

kW_EE = Proposed fixture wattage (kW per fixture) see Appendix B

Hrs = 6,205 (Ref. 3); annual case light hours.

Refrig_Factor = 0.40 (for refrigerator applications, assumes COP of 2.5) (Ref. 4)
= 0.77 (for freezer applications, assumes COP of 1.3) (Ref. 4)

CF = 0.9; electrical peak coincidence factor (Ref. 5)

Example:

A DLC-qualified LED strip light replaces a 6-foot T8 fluorescent lamp in a reach-in cooler. The fixture wattage will be reduced from 81W (0.081 kW) to 40W (0.040 kW).

Unit kWh Savings per Year = (0.081-0.040)*6205*(1+0.4) = 356 kWh

Unit Peak kW Savings = 0.9*(0.081-0.040)*(1+0.0.4) = 0.05 kW

Notes

The Design Lights Consortium is a collaboration of utility companies and regional energy efficiency organizations that provide criteria and guidelines as well as a qualified products list (QPL) for high-efficiency, high-quality LED products. For more information visit: www.designlights.org

References

1. LED lifetime of 10 years assumes 6,205 hrs per year operation (17 hrs/day) and a lifetime of approximately 62,082 hours, the averaged rated life from DLC qualified product list. Accessed 7/31/12.
2. Illuminating Engineering Society (IES) Handbook, 9th edition, Figure 6-34, p. 6-29.
3. State of Ohio Technical Reference Manual, 2010. Source: Theobald, M. A., Emerging Technologies Program: Application Assessment Report #0608, LED Supermarket Case Lighting Grocery Store, Northern California, Pacific Gas and Electric Company, January 2006. Assumes refrigerated case lighting typically operates 17 hours per day, 365 days per year.
4. US DOE Publication #46230-00, “Energy Savings Potential for Commercial Refrigeration Equipment", 1996, Arthur C. Little.
5. State of Wisconsin Public Service Commission of Wisconsin "Focus on Energy Evaluation Business Programs: Deemed Savings Parameter Development”, KEMA, November 13, 2009, Page A-14.

Revision History

Version	Description	Author	Date
2.3	Added horizontal lighting	Franklin Energy Services	12/5/16

C/I Lighting – Refrigerator/Freezer Case Occupancy Controls

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Lighting
Applicable To	Commercial facilities having refrigerated cases with internal LED lighting; mainly retail spaces
Actions	Modify
Required from Customer/Contractor	Unit type (refrigerator or freezer), connected fixture wattage per sensor
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$125 installed cost per sensor (Ref. 2)

Measure Description

This measure involves installing occupancy controls for refrigerated cases with internal LED lighting. Without occupancy sensors, case lighting typically runs at 100% power on a continuous basis. Installing sensors allows lights to turn fully on only when motion is detected in the store aisle. When no motion is detected for a preset period of time, the lights automatically dim to a lower power state, generating substantial energy savings.

Unlike fluorescent lighting, LED lighting can be turned on and off in cooler conditions without adversely affecting the life of the equipment; in fact, the effective lifespan of the LEDs may actually increase compared to being left at 100% power continuously (Ref. 7). As the market penetration of LED lighting in refrigerated cases increases, the opportunity for occupancy control follows.

Algorithms

Unit kWh Savings per Year = kW_base * SF * Hrs * (1+Refr_Factor)

Unit Peak kW Savings = CF * kW_base * SF * (1+Refr_factor)

Where:

kW_base = Total connected fixture load in kW, provided by customer/contractor.

SF = 0.31 (Ref. 3); savings factor for occupancy sensor representing reduction in relative full load power hours.

Hrs = 6,205 (Ref. 4); annual case light hours.

Refrig_Factor = 0.40 (for refrigerator applications, assumes COP of 2.5) (Ref. 5)
= 0.77 (for freezer applications, assumes COP of 1.3) (Ref. 5)

CF = 0.9; electrical peak coincidence factor (Ref. 6)

Example:

An occupancy sensor is installed to control the lighting in a 5-door reach-in cooler case with LEDs. The total connected lighting wattage is 120 W or 0.12 kW.

Unit kWh Savings per Year = 0.12 * 0.31 * 6205 * (1 + 0.40) = 323 kWh

Unit Peak kW Savings = 0.9 * 0.12 * 0.31 * (1 + 0.40) = 0.05 kW

Methodology and Assumptions

Lifetime of sensors is assumed to be the same as LED lighting.

References

1. Lifetime of sensors is assumed to be the same as LED lighting. LED lifetime of 10 years assumes 6,205 hrs per year operation (17 hrs/day) and a lifetime of approximately 62,082 hours, the averaged rated life from DLC qualified product list. Accessed 7/31/12.
2. *Demonstration Assessment of Light-Emitting Diode (LED) Freezer Case Lighting.* Prepared for the U.S. Department of Energy by Pacific Northwest National Laboratory, October 2009. Section 3.2, p. 11. Occupancy sensor and installation cost was $125 for a 5-door case.
3. *Ibid.* Section 3.1, p. 9. Results of a field study in which occupancy sensors were installed on individual cases to reduce LED lighting power to 20% of full power when no motion is detected for 30 seconds. The store was open 18 hours per day, with case lighting on 24/7 in the baseline.
4. State of Ohio Technical Reference Manual, 2010. Source: Theobald, M. A., Emerging Technologies Program: Application Assessment Report #0608, LED Supermarket Case Lighting Grocery Store, Northern California, Pacific Gas and Electric Company, January 2006. Assumes refrigerated case lighting typically operates 17 hours per day, 365 days per year.
5. US DOE Publication #46230-00, “Energy Savings Potential for Commercial Refrigeration Equipment", 1996, Arthur C. Little.
6. State of Wisconsin Public Service Commission of Wisconsin "Focus on Energy Evaluation Business Programs: Deemed Savings Parameter Development”, KEMA, November 13, 2009, Page A-14.
7. “Watt Stopper/Legrand Helps Wal-Mart Achieve Environmental Goals”. *Lighting Controls Association,* September 2007. http://lightingcontrolsassociation.org/projects/watt-stopper-legrand-helps-wal-mart-achieve-environmental-goals/, accessed 9/29/16.
8. Illuminating Engineering Society (IES) Handbook, 9th edition, Figure 6-34, p. 6-29.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	12/5/16

C/I Lighting - Stairwell Fixtures with Integral Occupancy Sensors

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace on Fail, Replace Working
Version No.	1.1

Measure Description

This measure involves replacement of existing fluorescent stairwell fixtures with fluorescent or LED stairwell fixtures with integral occupancy sensors and step-dimming ballasts, allowing for automatic adjustment of light output based on stairwell occupancy.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Methodology and Assumptions

The efficient wattages in Appendix B include multipliers reflecting the rated level of dimming and an average duty cycle of 3% determined from M&V of a large installation sponsored by Xcel Energy.

Notes

In 2009 the Department of Energy announced new lamp rulemaking for general service fluorescent lamps. The efficiency standard requires general service fluorescent lamps covered in this rulemaking to meet minimum lumen per watt (LPW) requirements; products that do not meet the minimum LPW requirements as of July 14, 2012 can no longer be produced. 700 series T8 lamps affected by this rulemaking have been postponed for two years until July 2014. T12 lamps remain on the same timeline.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date

C/I Lighting - T12 8-Foot Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace on Fail, Replace Working
Version No.	3.6

Measure Description

This measure evaluates the replacement of 8 foot T12 lamps and magnetic or electronic ballasts with energy efficient T8, T5, and T5HO lamps and ballasts. The replacements can be 8 foot or 4 foot lamps. Changing from T12 lamp and ballast systems to T8, T5, or T5HO systems will reduce the energy consumption of the system while maintaining similar light outputs.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Methodology and Assumptions

Measure Life is reduced based on remaining useful life of magnetic ballasts in the market place. Using the analysis completed in the Texas Docket 39146 Appendix C, a current remaining useful life of T12 magnetic ballasts at the end of 2012 is 4.1 years, or 4 years. The following documents were used in this analysis:

- "Fluorescent Lamp Ballasts Preliminary Analytical Tools: National Impact Analysis" (Ref. 7)
- "Fluorescent Lamp Ballast Technical Support Document for the Final Rule, 2000" (Ref. 8)

The Illinois Statewide Technical Reference Manual goes further to conclude the measure life should decrease from four years in 2012 to three years in 2013, two years in 2014, and one year in 2015. (Ref. 9)

Notes

EPAct 2005 and 2000 DOE Ballast Rule. 2000 DOE Ballast Rule no longer allows ballasts that do not pass the new requirements to be manufactured after July 1, 2010 and EPAct 2005 no longer allows ballasts that do not pass the new requirements to be sold after October 1, 2010.

Ballasts affected by the rulemaking are those that operate:

- T12 4-foot linear and 2-foot U-shaped Rapid Start lamps with medium bi-pin bases
- T12 8-foot Instant Start lamps with single pin bases
- T12 8-foot Rapid Start HO lamps with recessed double contact (RDC) bases

Exceptions to the ballast standards:

- Dimming ballasts that dim to 50% or less of maximum output
- T12 HO ballasts capable of starting at ambient temperatures as low as -20° F or less and for use in outdoor illuminated signs
- Ballasts having a power factor of less than 0.90 and designed and labeled for use only in residential applications.
- 2 foot and 3 foot lamp and ballast systems
- 2009 DOE Lamp Rulemaking for GSFL and IRL Lamps. New efficiency standards for General Service Fluorescent lamps (GSFLs), linear and U-shaped require these covered lamp types to meet minimum lumen per watt (LPW) requirements; products that do not meet the minimum LPW requirements as of July 14, 2012 can no longer be produced.

The following lamp types are affected by these standards:

- Lamp Type| Energy Conservation Standard (lm/W)
- 4-foot (T8-T12) Medium Bi-pin ≥25W 89/88
- 2-foot (T8-T12) U-Shaped ≥25W 84/81
- 8-foot (T8-T12) Single Pin Slimline ≥52W 97/93
- 8-foot (T8-T12) High Output 92/88
- 4-foot (T5) Miniature Bi-pin Standard Output ≥26W 86/81
- 4-foot (T5) Miniature Bi-pin high Output ≥49W 76/72
- New T12 lamps that meet the new standards are now available in the market allowing T12s to still be installed

References

1. DOE 2010b "Fluorescent Lamp Ballasts Preliminary Analytical Tools: National Impact Analysis" U.S. Department of Energy: 2010.
2. DOE 2000b. "Fluorescent Lamp Ballast Technical Support Document for the Final Rule, 2000." September 2000.
3. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 Section 6.5.

Revision History

Version	Description	Author	Date

C/I Lighting - T12 Up to 4-Foot Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working, Retrofit
Version No.	3.6

Measure Description

This measure evaluates the replacement of T12 lamps and magnetic or electronic ballasts up to 4 feet in length with energy efficient T8, T5, and T5HO lamps and ballasts. The replacement of T12 lamps and ballasts with T8, T5, and T5HO lamp and ballast systems results in a lower wattage system with similar light output.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Methodology and Assumptions

Measure Life is reduced based on remaining useful life of magnetic ballasts in the market place and the July 14, 2012 Federal Standards eliminating standard T12 lamps.

Reviewing the market and a pending study of the T12s in the Minnesota market, the measure life is 1 year at full savings for T12s. The remaining 14 years of the measure life will utilize T8 baseline for savings.

This is set to be re-visited at the completion of the T12 market study.

Notes

EPAct 2005 and 2000 DOE Ballast Rule. 2000 DOE Ballast Rule no longer allows ballasts that do not pass the new requirements to be manufactured after July 1, 2010 and EPAct 2005 no longer allows ballasts that do not pass the new requirements to be sold after October 1, 2010.

Ballasts affected by the rulemaking are those that operate:

- T12 4-foot linear and 2-foot U-shaped Rapid Start lamps with medium bi-pin bases
- T12 8-foot Instant Start lamps with single pin bases
- T12 8-foot Rapid Start HO lamps with recessed double contact (RDC) bases

eptions to the ballast standards:

- Dimming ballasts that dim to 50% or less of maximum output
- T12 HO ballasts capable of starting at ambient temperatures as low as -20° F or less and for use in outdoor illuminated signs

- Ballasts having a power factor of less than 0.90 and designed and labeled for use only in residential applications.
- 2 foot and 3 foot lamp and ballast systems

2009 DOE Lamp Rulemaking for GSFL and IRL Lamps. New efficiency standards for General Service Fluorescent lamps (GSFLs), linear and U-shaped require these covered lamp types to meet minimum lumen per watt (LPW) requirements; products that do not meet the minimum LPW requirements as of July 14, 2012 can no longer be produced.

The following lamp types are affected by these standards:

- Lamp Type| Energy Conservation Standard (lm/W)
- 4-foot (T8-T12) Medium Bi-pin ≥25W 89/88
- 2-foot (T8-T12) U-Shaped ≥25W 84/81
- 8-foot (T8-T12) Single Pin Slimline ≥52W 97/93
- 8-foot (T8-T12) High Output 92/88
- 4-foot (T5) Miniature Bi-pin Standard Output ≥26W 86/81
- 4-foot (T5) Miniature Bi-pin high Output ≥49W 76/72
- New T12 lamps that meet the new standards are now available in the market allowing T12s to still be installed

Requirements

It is suggested that high performance and reduced wattage T8 lamps appear on the Consortium for Energy Efficiency Qualified Product List available at www.cee1.org.

References

1. DOE 2010b "Fluorescent Lamp Ballasts Preliminary Analytical Tools: National Impact Analysis" U.S. Department of Energy: 2010.
2. DOE 2000b. "Fluorescent Lamp Ballast Technical Support Document for the Final Rule, 2000." September 2000.
3. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 Section 6.5.
4. ANSI/ASHRAE/IES Standard 90.1-2010 edition

Revision History

Version	Description	Author	Date

C/I Lighting - T8 Optimization

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace Working
Version No.	3.6

Measure Description

Optimization means reducing the light output of a fluorescent fixture in an overlit space through permanently reducing the quantity of linear fluorescent lamps used in a fixture, or switching to a shorter length fixture with the same quantity of lamps. Optimization must be done properly so as to maintain the minimum light level required by code. This measure includes both lamp and ballast changes and not lamp changes only.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Revision History

Version	Description	Author	Date

C/I Lighting - T8 Standard to Low Wattage Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Replace on Fail, Replace Working, New Construction
Version No.	3.5

Measure Description

High performance T8 lighting with low wattage lamps incorporates improvements to lamp and ballast technologies. They deliver light levels comparable with standard 32 watt T8 systems at lower wattages and with improved lamp life. This measure replaces 32W standard T8 systems with low watt T8 systems.

Algorithm and Assumptions

Refer to Lighting End Use for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all low wattage T8 lamps appear on the Consortium for Energy Efficiency Qualified Product list available at www.cee1.org.

Revision History

Version	Description	Author	Date

Public - LED Traffic Signal

Measure Detail	Measure Value
Target Market Segments	Public
Target End Uses	Lighting
Applicable To	Exterior traffic signals
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Efficient lamp type/quantity
Version No.	1.6
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	See Table 1
Unit Participant Incremental Cost	See Table 3

Measure Description

Light Emitting Diode (LED) Traffic Signals are an efficient and effective alternative to traditional incandescent signals. The two main advantages of LED signals are - very low power consumption and very long life. When compared with the typical energy needs of an incandescent bulb, the savings resulting from the low energy usage of LED signals can be as high as 93%.

Algorithms

Unit kWh Savings per Year = (kW_Base - kW_EE) x Hrs

Unit Peak kW Savings = (kW_Base - kW_EE) X DF

Where:

kW_Base = Baseline fixture wattage (kW per fixture) determined from Table 2

kW_EE = High Efficiency fixture wattage (kW per fixture) determined from Table 2

Hrs = Deemed annual operating hours from Table 1 based on lamp type

DF = Deemed diversity factor (see Table 1)

Example:

Replace (1) incandescent 12" red ball lamp with (1) LED 12" red ball lamp

kWh Savings = (0.135-0.011) x 4,820 = 597.7 kWh

kW Savings = (0.135-0.011)*0.55 = 0.0682 kW

Deemed Input Tables

Table 1. Diversity Factor (Ref. 1), Hours (Ref. 1), Measure Life (Ref. 2)

LED Lamp Type	Diversity Factor	Hours	Measure Life
12" Red Arrow	0.90	7,885	6.3
8" Red Arrow	0.90	7,885	6.3
12" Green Ball	0.43	3,675	13.6
8" Green Ball	0.43	3,675	13.6
12" Red Ball	0.55	4,820	10.4
8" Red Ball	0.55	4,820	10.4
12" Yellow Ball	0.02	175	20*
8" Yellow Ball	0.02	175	20*
12" and 8" Yellow Arrow	0.02	701	20*
12" and 8" Green Arrow	0.10	701	20*
Combination walking man/hand large	0.96	4,380	11.4
Walking Man Large	0.21	4,380	11.4
Orange Hand Large	0.75	4,380	11.4
Combination walking man/hand small	0.96	4,380	11.4
Walking Man Small	0.21	4,380	11.4
Orange Hand Small	0.75	4,380	11.4

*Measure life capped for persistence due to an extremely long calculated lifetime based on annual operating hours.

Table 2. Fixture Wattage (Ref.3) and Costs (Ref. 4)

Baseline Device	Efficient Device	kW_base	kW_EE	Incremental Cost
Incandescent, 12" Red Arrow	LED, 12" Red Arrow	0.135	0.009	$60.00
Incandescent, 8" Red Arrow	LED, 8" Red Arrow	0.069	0.007	$115.00
Incandescent, 12" Green Ball	LED, 12" Green Ball	0.135	0.015	$115.00
Incandescent, 8" Green Ball	LED, 8" Green Ball	0.069	0.012	$115.00
Incandescent, 12" Red Ball	LED, 12" Red Ball	0.135	0.011	$60.00
Incandescent, 8" Red Ball	LED, 8" Red Ball	0.069	0.008	$48.00
Incandescent, 12” Yellow Ball	LED, 12” Yellow Ball	0.150	0.013	$60.00
Incandescent, 8” Yellow Ball	LED, 8” Yellow Ball	0.069	0.010	$48.00
Incandescent, 12” and 8” Yellow Arrow	LED, 12” and 8” Yellow Arrow	0.116	0.007	$100.00
Incandescent, 12” and 8” Green Arrow	LED, 12” and 8” Green Arrow	0.116	0.007	$100.00
Incandescent, Pedestrian Large	LED, Combination Walking Man/Hand Large	0.116	0.010	$90.00
Incandescent, Pedestrian Large	LED, Walking Man Large	0.116	0.010	$90.00
Incandescent, Pedestrian Large	LED, Orange Hand Large	0.116	0.010	$90.00
Incandescent, Pedestrian Small	LED, Combination Walking Man/Hand Small	0.069	0.008	$70.00

Baseline Device	Efficient Device	kW_base	kW_EE	Incremental Cost
Incandescent, Pedestrian Small	LED, Walking Man Small	0.069	0.008	$70.00
Incandescent, Pedestrian Small	LED, Orange Hand Small	0.069	0.008	$70.00

References

1. Technical Reference User Manual Efficiency Vermont 2010, Combination walking man/hand signals used the combined walk & hand signal CFs because it is assumed they will be on the same total time.
2. Measure life in years determined by dividing product lifetime of 50,000 hours by annual operating hours.
3. Consortium of Energy Efficiency
4. NWPCC LEDTrafficSignals_rev-1.xls

Revision History

Version	Description	Author	Date
1.0	New version replacing LEDTrafficSignalPedestrian_V01, LEDTrafficSignalRedArrow_v01, LEDTrafficSignalRed_v01, LEDTrafficSignalGreen_v01	Joe Plummer	
1.1	Changed to deemed wattages and incremental costs	Joe Plummer	3/23/2012
1.2	Updated costs, format	Franklin Energy Services	8/31/2012
1.3	Updated CF	Franklin Energy Services	11/15/2012
1.4	Minor revisions	Joe Plummer	2/7/2013
1.5	Added Yellow ball, Yellow Arrow, and Green Arrow signals	Franklin Energy Services	2/27/2014
1.6	Minor formatting revisions	Joe Plummer	5/15/2014
1.7	Sample calculation updated	Franklin Energy Services	1/13/2016

HVAC

C/I HVAC - Boiler Blowdown Controls

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC, Industrial Process
Applicable To	Commercial/industrial customers with natural gas-fired steam boilers
Actions	Modify, New Construction
Required from Customer/Contractor	Boiler HP or Input Btu/h, steam pressure in psig
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	5 (Ref. 1)
Unit Participant Incremental Cost	$4,250 (Ref. 2) or use actual

Measure Description

In a steam boiler, the water boiled within evaporates and leaves behind suspended solids. These suspended solids can form a sediment in the boiler and reduce the effectiveness of its heat transfer; also resulting are dissolved solids which create foaming and can encourage boiler water leaving with the steam. To reduce the number of suspended solids, the boiler periodically purges some of its contents from the bottom of the tank, which is called bottom blowdown. The dissolved solids are removed by skimming the surface of the boiler water, which is called surface blowdown. Surface blowdown is often a continual process. Excessive blowdown can waste energy by unnecessarily purging heated water.

Excessive blowdown can be reduced by automatic blowdown control systems. These systems measure the characteristics of the water (conductivity, total dissolved solids (TDS), alkalinity and silica and chloride concentrations) and allow the boiler to blowdown only when needed.

Algorithms

Unit Dth Savings per Year = (Feedwater_pre – Feedwater_post) x Hours x (h_bd – h_fw) / Eff / C

Where:

Feedwater_pre = (Delivery_rate) / (1 – BDR_pre), boiler feedwater consumption with no blowdown controls in pounds per hour.

Feedwater_post = (Delivery_rate) / (1 – BDR_post), boiler feedwater consumption with blowdown controls installed in pounds per hour.

Delivery_rate = 34.5 x Boiler_HP, boiler delivery rate in pounds of steam per hour.

Boiler_HP = boiler horsepower rating, 1 boiler HP = 33,475 Btu/h

BDR_pre = blowdown ratio with no controls. If unknown, assume 8% (Ref. 2).

BDR_post	=	blowdown ratio with controls. If unknown, assume BDR_pre – 2% (Ref. 3)
h_bd	=	enthalpy of blowdown water in Btu/lb., see Table 1.
h_fw	=	enthalpy of feedwater in Btu/lb., see Table 2. If feedwater temperature is unknown, assume 49˚
EFLH	=	effective full load hours of boiler operation per year. See Table 3 or use actual if available.
Eff	=	boiler efficiency. If unknown, use typical value of 80%.
C	=	1,000,000 Btu/Dth, conversion factor.

Example:

Blowdown controls are installed on a 60HP steam boiler producing steam at 90 psig. The boiler is used for process heating and operates at full load 8,760 hours per year.

Delivery_rate = 34.5 x 60 = 2,070 lbs./hour

Feedwater_pre = 2,070/(1-0.08) = 2,250 lbs./hour

Feedwater_post = 2,070 (1-0.06) = 2,202 lbs./hour

From Table 1, using 90 psig steam, h_bd = 302 Btu/lb.

From Table 2, assuming 49˚F feedwater, h_fw = 17 Btu/lb.

Unit Dth Savings per Year = (2,250-2,202) x 8,760 x (302-17) / 0.80 / 1,000,000 = 149 Dth

Deemed Input Tables

Table 1. Steam Table

Gauge Pressure (psig)	Temperature (°F)	Enthalpy (Btu/lb.)
0	212	180
1	215	183
2	219	187
3	222	190
4	224	192
5	227	195
6	230	198
7	232	200
8	233	201
9	237	205
10	239	207
12	244	212
14	248	216
16	252	220
18	256	224
20	259	227

Gauge Pressure (psig)	Temperature (°F)	Enthalpy (Btu/lb.)
22	262	230
24	265	233
26	268	236
28	271	239
30	274	243
32	277	246
34	279	248
36	282	251
38	284	253
40	286	256
42	289	258
44	291	260
46	293	262
48	295	264
50	298	267
55	300	271
60	308	278
65	312	282
70	316	287
75	320	290
80	324	295
85	327	298
90	331	302
95	335	305
100	338	309
105	341	312
110	344	316
115	347	319
120	350	322
125	353	325
130	356	328
135	358	330
140	361	333
145	363	336
150	366	339
155	368	341
160	371	344
165	373	346
170	375	348
175	377	351
180	380	353
185	382	355

Gauge Pressure (psig)	Temperature (°F)	Enthalpy (Btu/lb.)
190	384	358
195	386	360
200	388	362
205	390	364
210	392	366
215	394	368
220	395	370
225	397	372
230	399	374
235	401	376

Table 2. Water Table

Temperature (°F)	Enthalpy (Btu/lb.)
45	13
46	14
47	15
48	16
49	17
50	18
51	19
52	20
53	21
54	22
55	23
56	24
57	25
58	26
59	27
60	28
61	29
62	30
63	31
64	32
65	33
66	34
67	35
68	36
69	37
70	38

Table 3. Effective Full Load Hours of Operation by Building Type (Ref. 4)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community College/University	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Methodology and Assumptions

With manual blowdown, blowdown ratio typically varies between four and eight percent but can be as high as 20 percent if extremely poor-quality feedwater (Ref. 2 and Ref. 3). Blowdown controls typically reduce boiler energy usage by two and five percent (Ref. 2). Blowdown controls typically cost between $2,500 and $6,000 (Ref. 2). Measure life is assumed to be five years for consistency with other boiler control measures in Ref. 1.

References

1. KEMA, Focus on Energy Evaluation, Business Programs: Measure Life Study, August 25, 2009.
2. US Department of Energy, Steam Tip Sheet #23, “Install an Automatic Blowdown-Control System”, January 2012.
3. N.C. Division of Pollution Prevention and Environmental Assistance Fact Sheet: Boiler Blowdown, August 2004.
4. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.).

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	12/4/17

C/I HVAC - Chiller Systems

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers where chillers can be installed to meet space cooling requirements
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	New chiller type, nominal cooling capacity in tons, integrated part load value, full load value; building type (refer to Table 2), project location (county), chilled water leaving temperature, condenser leaving temperature and condenser gpm; if water cooled centrifugal chiller is not designed to operate at standard AHRI conditions
Version No.	3.0
Unit Peak kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 years (Ref. 1)
Unit Participant Incremental Cost	See Table 1

Measure Description

This measure analyzes the space cooling savings potential of the installation of high efficiency chillers including; all air cooled chillers, water cooled screw, scroll, and centrifugal chillers. This measure is applicable to chillers with efficiencies provided at AHRI conditions, but also accommodates water cooled centrifugal chillers with efficiencies provided at other conditions. The incremental cost is associated with base equipment cost and does not include any installation costs.

Algorithms

kWh_{SAVED} = Nominal Capacity x ($IPLV_{BASE}$ – $IPLV_{EE}$) x $EFLH_{Cool}$

kW_{SAVED} = Nominal Capacity x (FLV_{BASE} – FLV_{EE}) x CF

Where:

Nominal Capacity = the nominal rating of the cooling capacity of the energy efficient chiller (tons)

$IPLV_{EE}$ = the integrated part load value (IPLV) of the energy efficient chiller (kW/ton) at AHRI standard conditions*

For efficiencies provided at other than AHRI conditions:

$IPLV_{EE}$ = $IPLV_{CS}$ / K_{ADJ} = the integrated part load value of energy efficient chiller at operating conditions divided by k_{ADJ} for water cooled centrifugal chillers if chiller designed not to operate at AHRI standard conditions

$IPLV_{BASE}$ = the integrated part load efficiency of the baseline chiller (kW/ton), $IPLV_{BASE} = IPLV_{AHRI}$ per Table 1.

$EFLH_{COOL}$ = the equivalent full load hours of cooling per zone from Table 2 per building type

FLV_{EE} = the equivalent full load value of the energy efficient chiller (kW/ton), FLV at AHRI standard conditions*provided by the contractor/customer.

For efficiencies provided at other than AHRI conditions:

FLV_{EE} = FLV_{CS} / k_{ADJ} = the equivalent full load value of the energy efficient chiller at operating conditions divided by k_{ADJ} for water cooled centrifugal chillers if chiller not designed not to operate at AHRI standard conditions

FLV_{BASE} = the full load efficiency of the baseline chiller (kW/ton), $FLV_{BASE} = FLV_{AHRI}$ per Table 1.

CF = Deemed coincident demand factor, equal to 0.90 (Ref. 2)

For Water Cooled Centrifugal Chillers not tested at AHRI Standard Conditions** (Ref. 3):

$IPLV_{CS}$ = for water cooled centrifugal chillers not designed to run at AHRI Standard test conditions*, the integrated part load value provided by customer/contractor at operating conditions (kW/ton)

FLV_{CS} = for water cooled centrifugal chillers not tested at AHRI Standard test conditions*, the equivalent full load value provided by customer/contractor at operating conditions (kW/ton)

$k_{ADJ} = A \times B$

Where:

A = $0.00000014592 \times (LIFT)^4 - 0.0000346496 \times (LIFT)^3 + 0.00314196 \times (LIFT)^2 - 0.147199 \times (LIFT) + 3.9302$

B = 0.0015 * LvgEvap + 0.934

LIFT = LvgCond – LvgEvap

LvgCond = Full Load Condenser leaving fluid temperature (°F)

LvgEvap = Full Load Evaporator leaving fluid temperature (°F)

Standard AHRI test conditions are 44°F leaving chilled water temperature, 85°F entering condenser water temperature with 3 gpm/ton condenser water flow.

These adjustment factors are applicable to centrifugal chillers designed for a minimum leaving water temperature of at least 36°F and a maximum condenser entering water temperature of 115 °F and LIFT ≥ 20°F and ≤ 80°F.

Example:

Retrofit of an existing water cooled centrifugal chiller installed in a Hospital, 600 ton cooling capacity not rated at AHRI conditions. Design FLV = 0.50 and Design IPLV of 0.45, Climate Zone 3. The new chiller is full-load optimized and designed to operate with a condenser water leaving temperature of 91.16°F and evaporator leaving temperature of 42°F.

Lift = 91.16°F – 42°F = 49.16°F

$A = 0.00000014592 \times (49.16)^4 - 0.0000346496 \times (49.16)^3 + 0.00314196 \times (49.16)^2 - 0.147199 \times (49.16) + 3.9302 = 1.0228$

$B = 0.0015 \times 42 + 0.934 = 0.997$

$K_{ADJ} = 1.0228 \times 0.997 = 1.02$

$FLV_{EE} = 0.50 / 1.02 = 0.49$

$IPLV_{EE} = 0.40 / 1.02 = 0.44$

$kWh_{SAVED} = 600 \times (0.54 - 0.44) \times 1298 = 79{,}865$ kWh

$kW_{SAVED} = 600 \times (0.57 - 0.49) \times 0.9 = 43.0$ kW

Deemed Input Tables

Table 1. Deemed Full Load and Integrated Part Load Baseline Efficiencies per AHRI 550/590 and Incremental Cost (Ref. 4, Ref. 5)

Equipment	PATH A****		PATH B*****		Incremental Cost ($/ton)
	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)	
Water Cooled Scroll or Screw Chiller < 75 tons	0.780	0.630	0.800	0.600	130
Water Cooled Scroll or Screw Chiller ≥ 75 and < 150 tons	0.775	0.615	0.790	0.586	90
Water Cooled Scroll or Screw Chiller ≥ 150 and < 300 tons	0.680	0.580	0.718	0.540	90
Water Cooled Scroll or Screw Chiller ≥ 300 tons	0.620	0.540	0.639	0.490	40
Water Cooled Centrifugal Chiller < 150 tons	0.634	0.596	0.639	0.450	130
Water Cooled Centrifugal Chiller ≥ 150 and < 300 tons	0.634	0.596	0.639	0.450	85
Water Cooled Centrifugal Chiller ≥ 300 and < 600 tons	0.576	0.549	0.600	0.400	85
Water Cooled Centrifugal Chiller ≥ 600 tons	0.570	0.539	0.590	0.400	40
Air Cooled Chiller with Condenser < 150 tons	1.255	0.96	NA	NA	110
Air Cooled Chiller with Condenser ≥ 150	1.255	0.94	NA	NA	110

* Path A is for traditional applications and where the intended applications are expected to have significant operating times at full load conditions, typically a non VFD controlled unit.

** All Path B chillers must be equipped with demand limiting controls or VFD controlled units.

*** FLV_AHRI = 12 / EER and IPLV_AHRI = 12 / SEER

Table 2. Equivalent Full Load Hours of cooling ($EFLH_{Cool}$) per zone in Minnesota by building type (Ref. 6)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	647	825	986
Education - Community College/University	682	782	785
Education – Primary	289	338	408
Education – Secondary	484	473	563
Health/Medical – Clinic	558	738	865
Health/Medical – Hospital	663	1089	1298
Lodging	401	606	754
Manufacturing	347	472	589
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Methodology and Assumptions

$EFLH_{COOL}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Assumed ventilation rates complied with the requirements of ASHRAE standard 62.1 – 2004.

Notes

Savings are based upon AHRI rated chillers and those water cooled centrifugal chillers operating within the limits of the nonstandard conditions listed above.

Table 1 chiller sizes were expanded to cover the scope the 2015 MN Energy Code, Table C.403.2.3 (7), Minimum Efficiency Requirements: Water Chilling Packages

References

1. ASHRAE, 2007, Applications Handbook, Ch. 36, table 4, Comparison of Service Life Estimates
2. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, and primary data has not been identified.
3. 2015 Minnesota Energy Code, Section C403.2.3.1 Water-cooled centrifugal chilling packages. https://codes.iccsafe.org/public/document/code/357/5880017
4. 2015 Minnesota Energy Code, Table C.403.2.3 (7), Minimum Efficiency Requirements: Water Chilling Packages. https://codes.iccsafe.org/public/document/code/357/5880017

5. 2008 Deer www.deeresources.com - Average across Tier 1 equivalent equipment.
6. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012.

Revision History

Version	Description	Author	Date
1.0	New specification replacing ChillersAirCooled_v03 and ChillersCentrifugal_v03. Followed methodology in Xcel Energy 2010-2012 CIP Plan (Docket No. E,G002/CIP-09-198)	Joe Plummer	
1.1	Changed 'Equivalent' to 'Equivalent' for Table 1	SK	
1.2	Revised format to customer's current replacement. Updated Nonstandard conditions calculations. Revised hours in Table 2. Added/updated references 3, 5, and 6. Updated incremental costs. Reordered references and tables to make them sequential. Added Table 3.	Franklin Energy Services	
1.3	Changed 'ARI' to 'AHRI' throughout, wording changes	Joe Plummer	
2.0	Updated measure to reflect new MN Code	Franklin Energy Services	
3.0	Updated FLV and IPLV values	Cadmus	10/2018

C/I HVAC - Chiller Tune-Up

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers where chillers are used to meet space cooling requirements
Actions	O&M
Required from Customer/Contractor	Chiller type, nominal cooling capacity in tons, integrated part load value, full load value; building type (refer to Table 2), project location (county)
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 1)
Unit Participant Incremental Cost	$5/ton (default/planning figure; Use actual cost of tune-up) (Ref. 2)

Measure Description

Commercial or Industrial air cooled or water chiller tune-up completed in accordance with the following recommended tune-up requirements:

- Clean condenser coil/tubes
- Check cooling tower for scale or buildup
- Check contactors condition
- Check evaporator condition
- Check low-pressure controls
- Check high-pressure controls
- Check filter, replace as needed
- Check belt, replace as needed
- Check crankcase heater operation
- Check economizer operation

Algorithms

kWh_{SAVED} = Nominal Capacity x $IPLV_{BASE}$ x $EFLH_{COOL}$ x MF_E

kW_{SAVED} = Nominal Capacity x FLV_{BASE} x CF x MF_D

Where:

$EFLH_{COOL}$ = the equivalent full load hours of cooling per zone from Table 2 per building type

Capacity = the nominal rating of the cooling capacity of the energy efficient chiller (tons)

Chiller efficiencies = because existing chiller efficiency typically cannot be determined without extensive testing, code minimum efficiencies are recommended for base efficiency.

$IPLV_{BASE}$ = Integrated part load efficiency of the baseline chiller (kW/ton), $IPLV_{BASE}$ = $IPLV_{AHRI}$ per Table 1. Alternatively, actual efficiency may be used if verified via testing.

FLV_{BASE} = Full load efficiency of the baseline chiller (kW/ton), FLV_{BASE} = FLV_{AHRI} per Table 1. Alternatively, actual efficiency may be used if verified via testing.

CF = Coincidence factor = 0.9(Ref. 3)

MF_E = Maintenance energy saving factor, MF_E = 5 % (Ref. 4)

MF_D = Maintenance demand saving factor, MF_D = 2.5 % (Ref. 4)

Example:

Tune up of a 200 ton air cooled chiller serving community college in Zone 2:

kWh_{SAVED} = 200 x 0.94 x 782 x 0.05 = 7,351 kWh

kW_{SAVED} = 200 x 1.26 x 0.9 x 0.025 = 5.67 kW

Deemed Input Tables

Table 1. Deemed Full Load and Integrated Part Load Baseline Efficiencies per AHRI 550/590 (Ref. 5)

Equipment	PATH A*		PATH B**	
	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)
Water Cooled Scroll or Screw Chiller < 75 tons	0.780	0.630	0.800	0.600
Water Cooled Scroll or Screw Chiller ≥ 75 and < 150 tons	0.775	0.615	0.790	0.586
Water Cooled Scroll or Screw Chiller ≥ 150 and < 300 tons	0.680	0.580	0.718	0.540
Water Cooled Scroll or Screw Chiller ≥ 300 tons	0.620	0.540	0.639	0.490
Water Cooled Centrifugal Chiller < 150 tons	0.634	0.596	0.639	0.450
Water Cooled Centrifugal Chiller ≥ 150 and < 300 tons	0.634	0.596	0.639	0.450
Water Cooled Centrifugal Chiller ≥ 300 and < 600 tons	0.576	0.549	0.600	0.400
Water Cooled Centrifugal Chiller ≥ 600 tons	0.570	0.539	0.590	0.400

Equipment	PATH A*		PATH B**	
	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)
Air Cooled Chiller with Condenser < 150 tons	1.255	0.96	NA	NA
Air Cooled Chiller with Condenser ≥ 150 tons	1.255	0.94	NA	NA

* Path A is for traditional applications and where the intended applications are expected to have significant operating times at full load conditions, typically a non VFD controlled unit.

** All Path B chillers must be equipped with demand limiting controls or VFD controlled units.

Table 2. Equivalent Full Load Hours of cooling ($EFLH_{Cool}$) per zone in Minnesota by building type (Ref. 6)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	647	825	986
Education - Community College/University	682	782	785
Education – Primary	289	338	408
Education – Secondary	484	473	563
Health/Medical – Clinic	558	738	865
Health/Medical – Hospital	663	1089	1298
Lodging	401	606	754
Manufacturing	347	472	589
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Methodology and Assumptions

Measurements and corrections must be performed with standard industry tools and practices, and the results tracked by the efficiency program.

$EFLH_{Cool}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

References

1. Wisconsin Public Service Commission equipment useful life database, 2013
2. State of Wisconsin Public Service Commission, Focus on Energy Evaluation, Business Programs: Incremental Cost Study, 2009. This study is compile program project cost data. An average value from chiller types and sizes is roughly $5/ton the range is roughly $2 to 8$/ton

3. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, and primary data has not been identified.
4. United States Department of Energy, Building Technologies Program: Hospitals Benefit by Improving Inefficient Chiller systems white paper, August 2011. The paper found that coil cleaning, the primary savings measure associated with this cooling tune-up measure, reduces annual cooling energy consumption by 5-7%. Demand savings are conservatively assumed to be on half this, or 2.5%.
5. 2015 Minnesota Energy Code, Table C.403.2.3 (7), Minimum Efficiency Requirements: Water Chilling Packages. https://codes.iccsafe.org/public/document/code/357/5880017
6. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	11/12/15
2.0	Updated FLV and IPLV values	Cadmus	10/2018

C/I HVAC - Computer Room Air Conditioner (CRAC)

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers with data centers or server rooms
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	New CRAC cooling medium, rated net sensible cooling capacity, rated seasonal coefficient of performance (SCOP)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	$750 per ton may be assumed (Ref. 4). Actual CRAC costs vary widely in practice

Measure Description

This measure analyzes the space cooling savings potential for the replacement or new commissioning of a computer room air conditioner (CRAC). CRACs are installed to meet cooling requirements for computers, servers, and other electronic components.

Algorithms

kWh_{SAVED} = Size * LF * ($12/SEER_{BASE}$ – $12/SEER_{EE}$) * EFLH

kW_{SAVED} = Size * LF * ($12/SEER_{BASE}$ – $12/SEER_{EE}$) * CF

Where:

Size	=	the nominal rating of the cooling capacity of the energy efficient chiller (tons). 1 ton = 12,000 Btu/h
LF	=	Cooling Load Factor = 0.65 (Ref. 5)
CF	=	Coincidence factor = 1 (Default for data centers)
$SEER_{BASE}$	=	3.412 * $SCOP_{BASE}$, minimum seasonal energy efficiency ratio.
$SCOP_{BASE}$	=	minimum rated seasonal coefficient of performance. See Table 1.
$SEER_{EE}$	=	3.412 * $SCOP_{EE}$, seasonal energy efficiency ratio of the energy efficient CRAC.
$SCOP_{EE}$	=	rated seasonal coefficient of performance (SCOP) for the energy efficient CRAC.
EFLH	=	Equivalent full load hour of cooling, 8760 hours (Default for data centers, Ref. 2)

Example:

Installation of a glycol-cooled downflow CRAC with a rated SCOP of 3.00 and net sensible cooling capacity of 48,000 Btu/h (4 tons).

From Table 1, baseline SCOP efficiency equals 2.50.

$SEER_{BASE}$ is calculated as 3.412 * 2.50 = 8.53

$SEER_{EE}$ is calculated as 3.412 * 3.00 = 10.24

kWh_{SAVED} = 4 * 0.65 * (12/8.53 – 12/10.24) * 8760 = 5,354 kWh

kW_{SAVED} = 4 * 0.65 * (12/8.53 – 12/10.24) * 1 = 0.61 kW

Deemed Input Tables

Table 1. Baseline SCOP efficiency by cooling medium type and unit type (downflow or upflow) (Ref. 3)

Cooling Medium	Net Sensible Cooling Capacity	Minimum SCOP Efficiency	
		Downflow Units	Upflow Units
Air-Cooled	<65,000 Btu/h	2.20	2.09
	≥65,000 Btu/h and <240,000 Btu/h	2.10	1.99
	≥240,000 Btu/h and <760,000 Btu/h	1.90	1.79
Water-Cooled	<65,000 Btu/h	2.60	2.49
	≥65,000 Btu/h and <240,000 Btu/h	2.50	2.39
	≥240,000 Btu/h and <760,000 Btu/h	2.40	2.29
Water-Cooled with a Fluid Economizer	<65,000 Btu/h	2.55	2.44
	≥65,000 Btu/h and <240,000 Btu/h	2.45	2.34
	≥240,000 Btu/h and <760,000 Btu/h	2.35	2.24
Glycol-Cooled	<65,000 Btu/h	2.50	2.39
	≥65,000 Btu/h and <240,000 Btu/h	2.15	2.04
	≥240,000 Btu/h and <760,000 Btu/h	2.10	1.99
Glycol-Cooled with a Fluid Economizer	<65,000 Btu/h	2.45	2.34
	≥65,000 Btu/h and <240,000 Btu/h	2.10	1.99
	≥240,000 Btu/h and <760,000 Btu/h	2.05	1.94

Methodology and Assumptions

$EFLH_{Cool}$ was determined on prototype operating modules from universal market segment hours for data centers (Ref. 2).

References

1. ASHRAE, 2007, Applications Handbook, Ch. 36, table 4, Comparison of Service Life Estimates
2. Commercial Buildings Energy Consumption Survey, 2003 referenced in Xcel Energy Cooling Efficiency DEPACC Technical Assumptions, Deemed Savings, Nov. 2013.

3. Code of Federal Regulations, Title 10, Chapter II, Subchapter D, Part 431, Subpart F, §431.97 http://www.ecfr.gov/cgi-bin/text-idx?SID=a69096e892b13c204bbe6da3a92f8111&mc=true&node=se10.3.431_197&rgn=div8 , accessed 12/4/2016.
4. Franklin Energy Services workpaper FES-H15 for Michigan programs, referencing cost data provided by a local Liebert distributor showing an average incremental cost of $750/ton or $62.50/MBTUH. CRAC costs vary greatly in practice.
5. Chapter 4. Energy Use Characterization, Technical Support Document to Final Rule: Standards, Federal Register, 77 FR 28928:28994-5, May 16, 2012. https://www.regulations.gov/document?D=EERE-2011-BT-STD-0029-0039, accessed 12/4/2016.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	12/4/2016

C/I HVAC - Condensing Furnaces

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Input Btu/h of new unit, project location (county), AFUE of the new equipment, building type
Version No.	1.1
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	See Table 2

Measure Description

This measure includes installation of gas-fired high efficiency, condensing residential-style forced air furnaces in commercial/industrial buildings.

Algorithms

Unit Dth Savings per Year = Btuh_in x Load_Factor x $EFLH_{Heat}$ x Eff_High x (1/Eff_Base – 1/Eff_high) / 1,000,000

Where:

Btuh_in	=	the nominal rating of the input capacity of the new furnace or boiler in Btu/h
Load_Factor	=	the load factor, assumed to be 0.77 (implies 30% oversizing) (Ref. 2)
$EFLH_{Heat}$	=	Effective Full Load Hours of Heating, see Table 1
Eff_base	=	80%, efficiency (AFUE) of the baseline, i.e., standard replacement, equipment. (Ref. 4)
Eff_high	=	Efficiency (AFUE) of the new furnace or boiler, supplied by customer/contractor.
1,000,000	=	Conversion from Btu to Dth

Example:

Retrofit furnace installed in a low-rise office building in Climate Zone 3. Input btu/h = 60,000, AFUE = 95%.

Unit Dth Savings per Year = 60,000 x 0.77 x 1,610 x 0.95 x (1/0.80 - 1/0.95) / 1,000,000 = 13.9 Dth

Deemed Input Tables

Table 1. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 3)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1,887	1,699	1,546
Education - Community College/University	1,972	1,776	1,616
Education – Primary	2,394	2,156	1,961
Education – Secondary	2,561	2,306	2,098
Health/Medical – Clinic	2,234	2,012	1,830
Health/Medical – Hospital	2,508	2,258	2,054
Lodging	2,361	2,126	1,934
Manufacturing	1,397	1,258	1,144
Multifamily	2,324	2,092	1,904
Office - Low Rise	1,966	1,770	1,610
Office - Mid Rise	2,189	1,971	1,793
Office - High Rise	2,149	1,935	1,760
Restaurant	1,868	1,681	1,530
Retail - Large Department Store	1,763	1,587	1,444
Retail - Strip Mall	1,701	1,531	1,393
Warehouse	1,872	1,685	1,533
Other/Miscellaneous	2,123	1,911	1,739

Table 2. Incremental Costs (Ref. 5)

Equipment Type	Incremental Cost ($/unit)
New furnace, AFUE ≥ 90% and < 92%	$1,254
New furnace, AFUE ≥ 92% and < 94%	$1,342
New furnace, AFUE ≥ 94% and < 96%	$1,429
New furnace, AFUE ≥ 96%	$1,517

Methodology and Assumptions

Assumes dedicated exhaust installation for furnaces and chimney liner for water heaters.

Notes

On May 1, 2013, federal standards prohibiting the sale or import of non-weatherized furnaces with AFUEs of less than 90 percent were set to take effect in the Northern Region (including MN).This standard has been postponed.

$EFLH_{Heat}$ were determined from Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{65,MN} / HDD_{65,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 3. Heating Degree Days and Design Temperature Differences

Geography	HDD65	DTD
Chicago, IL	6,339	73.5
MN Zone 1	9,833	92
MN Zone 2	8,512	86.5
MN Zone 3	7,651	84.5

AFUE does not include any electrical power savings.

References

1. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, Inc. June 2007 http://www.ctsavesenergy.org/files/Measure%20Life%20Report%202007.pdf
2. PA Consulting, KEMA, Focus on Energy Evaluation, Business Programs: Deemed Savings ManualV1.0, March 22, 2010. This factor implies that boilers are 30 percent oversized on average.
3. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
4. US Department of Energy federal minimum efficiency. https://www.ecfr.gov/cgi-bin/text-idx?SID=a9921a66f2b4f66a32ec851916b7b9d9&mc=true&node=se10.3.430_132&rgn=div8
5. Xcel Energy 2017-2019 CIP Triennial (Docket No. E,G002/CIP-16-115). https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Regulatory%20Filings/2017-2019%20CIP%20Triennial%20Plan.pdf

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	9/19/2017
1.1	Updated incremental costs	Cadmus	10/2018

C/I HVAC - Destratification Fan

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	All areas with less than a 50' ceiling height where stratification has been observed to be a problem
Actions	New Construction (addition on new or existing building)
Required from Customer/Contractor	Ceiling height, area being destratified, project location (county) Optional: Heat transfer coefficient for roof, area being destratisfied in square feet, hours per day of fan operation in heating season, heating system efficiency
Version No.	1.2
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 years (Ref. 1)
Unit Participant Incremental Cost	See Table 1 (Ref. 2)

Measure Description

This measure analyzes the heating savings potential of destratification fans in new and existing buildings. This measure includes High Volume Low Speed and High Volume High Speed fans.

Algorithms

Unit Dth Savings per Year = (U x A x ΔT_C x HH x HrsPerDay/24) / η / 1,000,000

Where:

A	=	Area served by destratification fan. If unknown see Table 1. (ref 3)
HrsPerDay	=	Hours/day of operation. If unavailable assume 12. (ref.4)
HH	=	Heating Hours in season below 65°F. See Table 2. (Ref. 5)
ΔT_C	=	Difference in ceiling air temperature (°F) in stratified and unstratified spaces. If unknown see Table 2 (Ref. 6).
U	=	Average heat transfer coefficient for the roof (BTU / h · ft ^2 · °F). If unknown see Table 2. (Ref. 7)
η	=	Efficiency of heating equipment. If unknown use 0.8 (Ref. 8)
1,000,000	=	Conversion factor for BTU to Dth

Example:

Install destratification fan per 1000 sq. ft. in 108,000 sq. ft. manufacturing facility operating on average 20 hours per day. The ceiling height is 25 ft. The building is located in Zone 3.

Dth Savings per Year = (0.08 x 1,000 x 10 x 20/24 x 6242) / 0.8 / 1,000,000 = 5.2 Dth per fan

108 fans total, 5.2 x 108 = 561.6 Dth per year total.

Table 1. Default square footages for fan applications and incremental costs

Ceiling Height (ft)	Destratification Area (ft^2) (Ref. 3)	Incremental Cost / sq. ft. (Ref. 2)
10 – 30	1000	$1.09
31 – 50	750	$1.45

Table 2. Ceiling Temperature differences, hours and U values

Zone #	ΔT_C (°F) (Ref. 6)	Heating Hours (Ref. 5)	U (Ref. 7) BTU/h·ft^2·°F
Northern: #1	10	7066	0.08
Central: #2	10	6643	0.08
Southern: #3	10	6242	0.08

Methodology and Assumptions

Assumed a noticeable stratification temperature is 10 °F or more.

Applicable to High Volume Low Speed and High Volume High Speed fans.

Assumes whole area is covered by stratification fans.

Notes

ASHRAE Advanced Design Guide for Manufacturing Facilities recommends destratification fans for ASHRAE zones 5-8.

There is a kW and kWh penalty not addressed in these calculations.

References

1. "Measured Life Report Residential and Commercial/Industrial Lighting and HVAC Measures", June 2007, by GDS Associates, Inc.pg. 1-3, modified to fan application and engineering judgment
2. ”Technology Evaluation of Thermal Destratifiers and Other Ventilation Technologies", by Joel C Hughes, Naval Facilities Engineering Center, pg. 8, average of examples
3. "Technology Evaluation of Thermal Destratifiers and Other Ventilation Technologies", by Joel C. Hughes, Naval Facilities Engineering Center, pg. 3, rounded values
4. Average number of occupied hours in day, FES.
5. National Climate Data Center - National Oceanic and Atmospheric Administration 1981-2010 Normals. Weather data for Duluth and International Falls was averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3.

6. "Technology Evaluation of Thermal Destratifiers and Other Ventilation Technologies", by Joel C. Hughes, example 1 of measured ceiling temperatures normalized for HDD, FES
7. Composite U value for Deer Manufacturing Model modified to reflect lower U values, FES
8. Assumed standard combustion efficiency of heating equipment, FES

Revision History

Version	Description	Author	Date
1.0	New savings specification for retrofit/incorporation of destratification fans.	Franklin Energy Services	8/1/2012
1.1	Changed statement "Assumed a noticeable stratification temperature is 5° or more" to "10° or more" per FES comment response, changed measure name, made some inputs optional per variable definitions, minor revisions	Joe Plummer	2/12/2013
1.2	Corrected typos in algorithm, added heating system efficiency to optional inputs	Joe Plummer	4/2/2014

C/I HVAC - ECM Blower Motors

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial or industrial buildings with residential-style forced-air furnaces. Measure applies to replacements of single-speed PSC motors only
Actions	Replace Working, Modify
Required from Customer/Contractor	Central AC present (yes/no), furnace AFUE
Version No.	1.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	9 years (Ref. 6)
Unit Participant Incremental Cost	$475 (Ref. 3)

Measure Description

This measure is the retrofit of a less efficient (PCS) motor to a 2 stage BPM or ECM motor in an existing furnace. The target age range for existing furnaces is 10-12 years. This measure characterizes only the electric savings associated with the fan.

Savings improve when the blower is used for cooling as well and when it is used for continuous ventilation, but only if the non-ECM motor would have been used for continuous ventilation too.

New standards for residential furnace blower motor fans, also applicable to residential-style forced-air furnaces in commercial or industrial buildings (Ref. 8), require the incorporation of ECMs, thereby making ECMs the baseline. Accordingly, this measure does not apply to new construction or replace on fail actions.

Algorithms

kWh_{SAVED} = Heating Savings + Cooling Savings + Shoulder Season Savings

kW_{SAVED} = Cooling Watts Savings * CF / 1000

$Therm_{SAVED}$ = -Heating Savings * 0.003412 / AFUE

Where:

Heating Savings = 126 kWh (Ref. 4)

Cooling Savings = 68 kWh if AC is present (Ref. 5), = 0 if no AC is present

Shoulder Season Savings = 54 kWh (Ref. 7)

Cooling Watts Savings = Cooling Watts Saved = 220 if retrofit of single speed PSC motor and AC is present (Ref. 3), = 0 if no AC is present

CF	=	Coincidence factor = 0.9 (Ref. 2)
0.003412	=	Converts kWh to Dth
AFUE	=	Efficiency of Furnace provided by customer. If unknown assume 80%

Example:

An ECM blower is installed in place of an existing single speed PSC motor in a building where central AC is present and AFUE of furnace is unknown.

kWh_{SAVED} = 126 + 68 + 54 = 248 kWh

kW_{SAVED} = 220 * 0.9/1000 = 0.198 kW

$Therm_{SAVED}$ = -126 * 0.003412 / 0.8 = -0.54 Dth

Methodology and Assumptions

Methodology, assumptions, and savings are consistent with the Residential ECM Blower Measure. All the assumptions were made based on furnaces analysis in Wisconsin described in study "PA Consulting Group/Patrick Engineering Residential Deemed Savings Review for Focus on Energy, 2009" (Ref. 1) and the values were adapted for Minnesota.

References

1. PA Consulting Group/Patrick Engineering Residential Deemed Savings Review for Focus on Energy, 2009
2. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.
3. "Evaluation of Retrofit Variable-Speed Furnace Fan Motors", R. Aldrich and J. Williamson, Consortium for Advanced Residential Buildings, January 2014
4. Ibid. The Evaluation referenced noted a difference of 126 Watts. Over the course of 1000 hour heating system, "Electricity Savings from Variable-Speed Furnaces in Cold Climates", Scott Pigg, Energy Center of Wisconsin and Tom Talerico, Glacier Consulting Group, the kWH savings = 126 Watts* 1000 hrs / 1000 W/KW = 126 KWh.
5. Ibid. The Evaluation referenced noted a difference of 220 Watts. Over the course of 310 hour cooling system, "State of Wisconsin Public Service Commission, Focus on Energy Evaluation, Residential Programs: CY09 Deemed Savings Review", March 26, 2010, the kWH savings = 220 Watts* 310 hrs / 1000 W/KW = 68 KWh.
6. Massachusetts Common Assumption: The early replacement measure life of 9 years was determined by subtracting the estimated target age range of existing equipment between 10 and 12 years old from the 20 year measure life for new equipment.
7. Modified by the ratio of Watt savings 422 watts (Ref. 7) / 400 watts (Ref. 3) x 51 kWh = 54 kWh.
8. Electronic Code of Federal Regulations. Title 10, Chapter II, Subchapter D, Part 430, Subpart C, §430.32. https://www.ecfr.gov/cgi-bin/text-idx?SID=a9921a66f2b4f66a32ec851916b7b9d9&mc=true&node=se10.3.430_132&rgn=div8

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	9/25/16
1.1	Removed replace on fail and new construction actions, consistent with new federal standards	Cadmus	10/2018

C/I HVAC - ECM Circulators

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Pumps
Applicable To	Commercial facilities with domestic hot water and space heating/cooling circulation pumps
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Motor wattage, motor application
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$6 per Watt (Ref. 2)

Measure Description

Electronically commutated (EC) circulators (pumps) are high-efficiency brushless DC motors. They are typically fractional horsepower motors that enjoy several benefits over the more common permanent split capacitor (PSC) fractional horsepower motor.

Algorithms

$kWh_{SAVED} = kW_{BASE} * t_{BASE} - kW_{ECM} * t_{PROPOSED}$

$kW_{SAVED} = (kW_{BASE} - kW_{ECM}) * CF$

Where:

kW_{BASE} = kW_{ECM} / 18% (Ref. 3)

kW_{ECM} = 0.050 kW, 0.250 kW, 0.700 kW (Ref. 4)

t_{BASE} = See Table 1

$t_{PROPOSED}$ = See Table 1

CF_{DHW} = 1.0 (Ref. 5)

CF_{CW} = 0.299 (Ref. 6)

CF_{HW} = 0

Example:

A customer installed a new 250W ECM pump on their domestic hot water heater.

kWh_{SAVED} = 0.250 kW / 18% * 4,000 hours - 0.250 kW * 2,190 hours = 5,008 kWh

kW_{SAVED} = (0.250 kW / 18% - 0.250 kW) * 1.0 = 1.140 kW

Deemed Input Tables

Table 1. Annual Operating Hours

Annual Hours	DHW Circulator (Ref. 7, 8)	Heating Water Circulator (Ref. 9)	Cooling Water Circulator (Ref. 10)
Baseline	4,000	2,582	1,191
Proposed	2,190	2,582	1,191

Table 2. Coincident Peak Impact

EC Motor Size	DHW Circulator	Heating Water Circulator	Cooling Water Circulator
< 100 W	0.228 kW	0.000 kW	0.068 kW
100 - 500 W	1.139 kW	0.000 kW	0.341 kW
500 - 750 W	3.189 kW	0.000 kW	0.953 kW

Table 3. Estimated Energy Savings

EC Motor Size	DHW Circulator	Heating Water Circulator	Cooling Water Circulator
< 100 W	1,002 kWh	588 kWh	271 kWh
100 - 500 W	5,008 kWh	2,941 kWh	1,356 kWh
500 - 750 W	14,023 kWh	8,234 kWh	3,798 kWh

Methodology and Assumptions

- Pump motor must be EC, DC brushless, or permanent magnet style
- Pump motor must be capable of variable speed operation
- Motor must include integrated “smart” controls that will modulate flow based on demand
- Motor must be < 1 hp

References

1. Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems. January 2001. Page 4. Accessed 6/11/14. https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/pumplcc_1001.pdf
2. These values are based on $29/gpm for ECM pumps and $12/gpm for PSC pumps. Costs are found in Wilo's Price Book - Pumps and systems for Building Services and Groundwater. Accessed 6/10/2014. http://www.wilo-usa.com/fileadmin/us/Price_Pages/2014_Wilo_Price_Book_BS.GW_20-44-004-0614.pdf.
3. The Cadmus Group, Inc. Impact Evaluation of the 2011–2012 ECM Circulator Pump Pilot Program. October 18, 2012. Table 2. Pump Spot Measurements.
4. General sizes chosen to represent given size ranges.

5. Assumes baseline pump would be operating during the peak period. Franklin Energy Services.
6. Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 2.0, June 7, 2013, page 235.
7. Estimate based on EPRI Report Assessment of New Energy Efficient Circulator Pump Technology (40%*8,760 hr = 3,504 hr) and recommendation by Grundfos representatives (60%*8,760 hr = 5,256 hr).
8. Hours of use for pumps with an aqua-stat control in multi-family applications (6 hr/d * 365 d = 2,190 hr). DHW Recirculation System Control Strategies, Final Report 99-1. NYSERDA, January 1999. Page 3-30. http://www.emra.com/NYSERDA%20DHW%20Report%2099-1%20(Recirc%20Control)%20(a5-0).pdf.
9. Estimated based on an average of HDD65. Hours = HDD65*24/(70°F-Design Temps).
10. Estimated based on an average of CDD65. Hours = CDD65*24/(Design Temps-70°F).

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	11/10/2015

C/I HVAC - ECM Fan Motors

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial buildings for space heating and cooling applications
Actions	Motors < 1/12 hp: Replace on Fail, Replace Working, New Construction Motors ≥ 1/12 hp and < 1 hp: Replace Working only
Required from Customer/Contractor	Design CFM, building type, climate zone
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	$120 (Ref. 2) for Replace on Fail, New Construction, Modify Full cost of new motor for Replace Working

Measure Description

This measure includes efficiency gains for an electronically commutated motor (ECM) < 1 horsepower being applied within fan-powered terminal boxes, fan coils, and HVAC supply fans on small unitary equipment. Motors ≥ 1 horsepower should employ the C/I Motors measure.

Note that Minnesota state energy code as of March 31, 2020 (Ref. 3) follows 2018 IECC standards (Ref. 4). These standards require that motors equal to or larger than 1/12 hp (82 W) and less than 1 hp (746 W) must be ECMs or have an efficiency of 70%. Therefore the application of this measure for motors in this range shall be Replace Working only.

Algorithms

kWh_{SAVED} = Heating kWh Savings + Cooling kWh Savings

kW_{SAVED} = Cooling kW Savings * CF

$Therm_{SAVED}$ = -(Heating kWh Savings) * 0.003412 / $Heat_{EFF}$

Where:

Cooling kWh Savings = (Design CFM) * (Box Size Factor) * LF * $EFLH_{COOL}$ / 1000

Cooling kW Savings = (Design CFM) * (Box Size Factor) * LF / 1000

Heating kWh savings = (Design CFM) * (Box Size Factor) * LF * $EFLH_{HEAT}$ / 1000

Design CFM = Design airflow of fan in cubic feet per minute

Box Size Factor = Savings factor in watts/CFM (Ref. 5)

Design CFM < 1000, Box Size Factor = 0.32 Watts/CFM

Design CFM ≥ 1000, Box Size Factor = 0.21 Watts/CFM

$Heat_{EFF}$ = 80% or use actual if known.

CF = 0.9; electric peak coincidence factor (Ref. 8)

LF = 0.9; load factor (Ref. 9)

Example:

An ECM blower is installed into a 1,000 CFM VAV box in a manufacturing facility located in MN Climate Zone 2, over an existing working PSC motor.

VAV Box Size Factor = 0.21 watts/CFM

$EFLH_{COOL}$ = 472 hrs

$EFLH_{HEAT}$ = 1258 hrs

$kWh_{SAVED\ COOLING}$ = 1000 * 0.21 watts/CFM /1000 * 0.9 * 472 hrs = 89 kWh

$kW_{SAVED\ COOLING}$ = 1000 * 0.21 watts/CFM /1000 * 0.9 * 0.9 = 0.17 kW

$kWh_{SAVED\ HEATING}$ = 1000 * 0.21 watts/CFM /1000 * 0.9 * 1258 hrs = 238 kWh

Unit kW_{SAVED} = 0.17 kW

Unit kWh_{SAVED} = 238 + 89 kWh = 327 kWh

Deemed Input Tables

Table 1. Equivalent Full Load Hours of cooling per zone in Minnesota by building type (Ref. 6)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	647	825	986
Education - Community	682	782	785
Education - Primary	289	338	408
Education - Secondary	484	473	563
Health/Medical - Clinic	558	738	865
Health/Medical - Hospital	663	1089	1298
Lodging	401	606	754
Manufacturing	347	472	589
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Table 2. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 7)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Methodology and Assumptions

The annual energy and power savings for ECMs are site-specific and can be determined on a case-by-case basis. Use the residential ECM HVAC profile for dwellings only.

Notes

Effective full load hours were not developed for multifamily central cooling plants. Select Lodging as the building type to approximate EFLH for multifamily central cooling.

References

1. Measure Life Study, Prepared for the Massachusetts Joint Utilities. Energy & Resource Solutions, 2005. Table 1-1.
2. *Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment.* US Department of Energy, 2013. Table 4.10. https://www.energy.gov/sites/prod/files/2014/02/f8/Motor%20Energy%20Savings%20Potential%20Report%202013-12-4.pdf
3. U.S. Department of Energy Building Energy Codes Program. Minnesota. https://www.energycodes.gov/adoption/states/minnesota
4. 2018 International Energy Conservation Code. Chapter 4 section C403.8.4. https://codes.iccsafe.org/content/iecc2018/chapter-4-ce-commercial-energy-efficiency
5. Massachusetts Technical Reference Manual: 2013-2015 Program Years – Plan Version, October 2012. Savings factors based on engineering analysis developed at National Grid.
6. FES calculated EFLH from energy models based on California DEER study prototypes modified by Illinois field data with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone 3) 2012.
7. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
8. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.
9. An assumed load factor of 0.9 reflects that motors are not typically 100% loaded.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	9/24/2016
2.0	Limited to Replace Working for most sizes	Cadmus	10/2020

C/I HVAC - Heat Pump Systems

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and Industrial customers where heat pump unitary equipment can be installed
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Equipment size (tons); IEER, SEER or EER of new equipment; IEER, SEER or EER of existing equipment (if program includes early replacements); HSPF or COP of new equipment; HSPF or COP of existing equipment (if program includes early replacements); existing equipment condition (working or failed, if program includes early replacements); building type (see Table 1), project location (county)
Version No.	3.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 years (Ref. 1)
Unit Participant Incremental Cost	See Table 3 (Ref. 2) or Table 4 (Ref. 3)

Measure Description

This measure includes replacement of non-working and working unitary air source heat pump (ASHP), ground water source heat pump (GWSHP), ground source heat pump (GSHP), and packaged terminal heat pump (PTHP) equipment. This measure analyzes the heating and cooling savings potential of the installation of higher efficiency packaged and split system heat pump equipment.

The incremental cost is associated with base equipment cost and does not include any installation costs.

Algorithms

For ASHP units < 5.5 tons:

kWh_{SAVED} = Size x 12 x [$EFLH_{COOL}$ x (1 / $SEER_{BASE}$ – 1 / $SEER_{EE}$) + $EFLH_{HEAT}$ x (1/$HSPF_{BASE}$ – 1/$HSPF_{EE}$)]

For all other units:

kWh_{SAVED} = Size x [$EFLH_{COOL}$ x 12 x (1 / $IEER_{BASE}$ – 1 / $IEER_{EE}$) + $EFLH_{Heat}$ x 3.52 x (1 / COP_{BASE} – 1 / COP_{EE})]

kW_{SAVED} = Size * 12 x (1 / EER_{BASE} – 1 / EER_{EE}) x CF

Where:

CF = Deemed coincidence factor, equal to 0.9 (Ref. 4)

COP_{BASE} = Heating coefficient of performance for baseline or existing equipment, provided by customer/contractor. If unknown see Tables 3 and 5 (Ref. 5)

COP_{EE}	=	Heating coefficient of performance for efficient equipment, provided by customer/contractor
EER_{BASE}	=	Energy efficiency ratio of the baseline equipment, based on the 2015 Minnesota Energy-coded minimal efficiency ratings. See Tables 3 and 5 (Ref. 5)
EER_{EE}	=	Energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor. If unknown, use EER = 0.875 * SEER or EER = 0.875 * IEER (Ref. 7)
$EFLH_{COOL}$	=	Equivalent full load cooling hours based on the building type. See Table 1. (Ref. 7)
$EFLH_{HEAT}$	=	Equivalent full load heating hours based upon the building type. See Table 2. (Ref 8)
$HSPF_{BASE}$	=	Heating system performance factor of baseline or existing equipment, provided by customer/contractor or use $HSPF_{BASE}$ = 7.7 if unknown (Ref. 5)
$HSPF_{EE}$	=	Heating system performance factor of efficient ASHP, provided by customer/contractor
Size	=	Nominal Cooling capacity in tons of the new equipment (1 ton = 12,000 btu/h) $IEER_{BASE}$ = Integrated energy efficiency ratio of the baseline equipment, based on the 2015 Minnesota Energy Code requirements. See Table 3 (Ref. 5)
$IEER_{EE}$	=	Integrated energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor.
$SEER_{BASE}$	=	Seasonal energy efficiency ratio of the baseline equipment, based on the 2015 Minnesota Energy Code requirements. See Table 3 (Ref. 5)
$SEER_{EE}$	=	Seasonal energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor.

Example:

New ASHP packaged rooftop installed in midrise office, 7.5-ton cooling capacity, IEER 14 and COP of 3.4, Climate Zone 3.

kWh_{SAVED} = 7.5 x [651 x 12 x (1 / 12 - 1 / 14) + 1793 x 3.52 x (1 / 3.3 - 1 / 3.4)] = 1,119 kWh

kW_{SAVED} = 7.5 x 12 x [1 /11 - 1 / (14 x 0.875)] x 0.9 = 0.75 kW

Deemed Input Tables

Table 1. Equivalent Full Load Hours of cooling, per zone, in Minnesota by building type (Ref. 7)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	647	825	986
Education - Community College/University	682	782	785
Education - Primary	289	338	408
Education - Secondary	484	473	563
Health/Medical - Clinic	558	738	865
Health/Medical - Hospital	663	1,089	1,298
Lodging	401	606	754
Manufacturing	347	472	589
Office - Low Rise	257	359	446
Office - Mid Rise	373	529	651
Office - High Rise	669	1,061	1,263
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Table 2. Equivalent Full Load Hours of heating, per zone, in Minnesota by building type (Ref. 8)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1,887	1,699	1,546
Education - Community College/University	1,972	1,776	1,616
Education - Primary	2,394	2,156	1,961
Education - Secondary	2,561	2,306	2,098
Health/Medical - Clinic	2,234	2,012	1,830
Health/Medical - Hospital	2,508	2,258	2,054
Lodging	2,361	2,126	1,934
Manufacturing	1,397	1,258	1,144
Office - Low Rise	2,324	2,092	1,904
Office - Mid Rise	1,966	1,770	1,610
Office - High Rise	2,189	1,971	1,793
Restaurant	2,149	1,935	1,760
Retail - Large Department Store	1,868	1,681	1,530
Retail - Strip Mall	1,763	1,587	1,444
Warehouse	1,701	1,531	1,393
Other/Miscellaneous	1,872	1,685	1,533

Table 3. Deemed baseline efficiency for heating and cooling, incremental costs

Equipment	$SEER_{BASE}$	$IEER_{BASE}$	EER_{BASE}	$HSPF_{BASE}$	COP_{BASE}	Incremental Cost
ASHP Units less than or equal to 5.4 tons (Split System)	14.0 (Ref. 9)	-	11.4 (Ref. 5)	8.2 (Ref. 12)	-	See Table 4
ASHP Units less than or equal to 5.4 tons (Packaged System)	14.0 (Ref. 9)	-	11.4 (Ref. 5)	8.0 (Ref. 12)	-	See Table 4
ASHP Units 5.5-11.3 tons*	-	12.2 (Ref. 9)	11.0 (Ref. 14)	-	3.3 (Ref. 5)	$100/ton (Ref. 15)
ASHP Units 11.4-19.9 tons*	-	11.6 (Ref. 9)	10.6 (Ref. 14)	-	3.2 (Ref. 5)	$100/ton (Ref. 15)
ASHP Units 20-63.3 tons	-	10.6 (Ref. 9)	9.5 (Ref. 14)	-	3.2* (Ref. 5)	$100/ton (Ref. 15)
GSHP Units (closed loop)**	-	15.3 (Ref. 10)	13.4 (Ref. 5)	-	3.1 (Ref. 5)	$150/ton (Ref. 2)
GWSHP Units (open loop)***	-	18.5 (Ref. 10)	16.2 (Ref. 5)	-	3.6 (Ref. 5)	$150/ton (Ref. 2)

*COP based upon 47°F DB and 43°F WB outdoor air temperature.

** EER based upon 77°F entering water; COP based on 32°F entering water.

*** EER based upon 59°F entering water; COP based on 50°F entering water.

Table 4. ASHP units 5.4 tons or less incremental cost (Ref. 3)

Efficiency Level	Incremental Cost
SEER 14	$137/ton
SEER 15	$274/ton
SEER 16	$411/ton
SEER 17	$548/ton
SEER 18	$685/ton

Table 5. PTHP minimum efficiencies and incremental costs (Ref. 11 and Ref. 13)

Equipment	Cooling Capacity (Btu/h)	EER_base*	COP_base*	Incremental Cost
PTHP, Standard Size (used for New Construction)	< 7,000	11.9	3.3	$250/ton
	7,000-15,000	14-(0.3*Cap/1000)	3.7-(0.052*Cap/1000)	$250/ton
	> 15,000	9.5	2.9	$250/ton
PTHP, Non-Standard Size (used for Replacements** Only)	< 7,000	9.3	2.7	$250/ton
	7,000-15,000	10.8 – (0.213*Cap/1000)	2.9 – (0.026*Cap/1000)	$250/ton
	> 15,000	7.6	2.5	$250/ton

* Cap = cooling capacity in Btu/h at 95°F, outdoor dry-bulb temperature

** Replacement unit shall be factory labeled as follows: "MANUFACTURED FOR REPLACEMENT APPLICATIONS ONLY; NOT TO BE INSTALLED IN NEW CONSTRUCTION PROJECTS". Replacement efficiencies apply only to units with existing sleeves less than 16 inches (406mm) in height and less than 42 inches (1067 mm) in width.

Methodology and Assumptions

$EFLH_{Cool}$ were determined from based prototypes building models on the California DEER study prototypes, modified Illinois field data, and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

$EFLH_{Heat}$ were determined from based prototypes building models on the California DEER study prototypes, modified Illinois field data, and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,\,MN} / HDD_{55,\,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 6. Heating Degree Days and Design Temperature Differences

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

Assumed ventilation rates complied with the requirements of ASHRAE standard 62.1 - 2004.

Notes

Baseline ground source heat pump SEER is based on an entering temperature of 59°F entering water temperature.

References

1. "Measure Life Report, Residential and Commercial/Industrial Lighting, and HVAC Measures", by GDS Associates, Inc. June 2007, pg. 6.
2. Comparison of Electric/Gas Fired Unitary equipment costs from DEER 2008 Database Technology and Measured Cost Data and Electric/Gas Fired Unitary and Heat Pump equipment costs from RSMeans Mechanical Cost Data.
3. DEER 2008 Database Technology and Measure Cost Data (www.deeresources.com).
4. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9; primary data has not been identified.
5. Minnesota 2015 Energy Code - TABLE C403.2.3(2) MINIMUM EFFICIENCY REQUIREMENTS: ELECTRICALLY OPERATED UNITARY AND APPLIED HEAT PUMPS.
6. ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment.
7. FES calculated EFLH from energy models based on California DEER study prototypes modified by Illinois field data with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) 2012.
8. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
9. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment. https://www.ecfr.gov/cgi-bin/text-idx?SID=ded1dbd4f1450bfd666ff67a75d7aba8&mc=true&node=pt10.3.431&rgn=div5 Table 3 to §431.97
10. IEER approximated as IEER = EER/0.875.
11. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment. https://www.ecfr.gov/cgi-bin/text-idx?SID=ded1dbd4f1450bfd666ff67a75d7aba8&mc=true&node=pt10.3.431&rgn=div5 Table 5 to §431.97
12. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment. https://www.ecfr.gov/cgi-bin/text-idx?SID=ded1dbd4f1450bfd666ff67a75d7aba8&mc=true&node=pt10.3.431&rgn=div5 Table 4 to §431.97
13. PTHP incremental costs assumed to be approximately equal to PTAC incremental costs; see C/I HVAC – Unitary and Split Systems.
14. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment. https://www.ecfr.gov/cgi-bin/text-idx?SID=ded1dbd4f1450bfd666ff67a75d7aba8&mc=true&node=pt10.3.431&rgn=div5 Table 1 to §431.97

15. Illinois Energy Efficiency Stakeholder Advisory Group. *Illinois Statewide Technical Reference Manual for Energy Efficiency. Version 6.0. Volume 2.* February 8, 2017. Page 165. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_2_C_and_I_020817_Final.pdf

Revision History

Version	Description	Author	Date
1.0	New deemed savings specification replacing/utilizing Heat Pump Units	Franklin Energy Services	
1.1	Corrected table references, Required Inputs	Joe Plummer	6/6/14
2.0	Changed from Heating Degree Days to EFLHHeat. Updated Table 2 to include building types, Added Other/Miscellaneous building type for EFLHCool. Correct reference to COPs, Changed base line to 2015 Minnesota Energy Code.	Franklin Energy Services	11/12/15
2.1	Updated minimum efficiencies according to new federal standards, Updated GSHP and GWSHP efficiencies to align with test conditions used in AHRI listings, Added packaged terminal heat pumps, Updated example calculation.	Franklin Energy Services	9/15/17
3.0	Streamlined equations, added split vs. packaged variations for < 5.4 ton baselines, updated costs for air source systems.	Cadmus	10/2018

C/I HVAC - High Volume Low Speed Fans

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial, industrial, or agricultural customers that currently use non HVLS fans
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Size (diameter) of HVLS fans being installed, facility use type
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 years (Ref. 1)
Unit Participant Incremental Cost	Refer to Table 3

Measure Description

This measure applies to the installation of large horizontally mounted high volume low speed (HVLS) fans to replace multiple smaller, non HVLS fans in commercial, industrial, or agricultural facilities.

Algorithms

Unit kWh Savings per Year = (kW_base - kW_EE) x Hrs x HVAC_cooling_kWhsavings_factor

Unit Peak kW Savings = (kW_base - kW_EE) x CF x HVAC_cooling_kWsavings_factor

Unit Dth Savings per Year = (kW_Base - kW_EE) x Hrs x HVAC_heating_penalty_factor

Where:

kW_Base = Qty_Base x kW_Base_per_Fan

kW_EE = Qty_HVLS x kW_HVLS_per_Fan

Qty_HVLS = the quantity of HVLS fans being installed. The default value is 1 (per unit basis). Qty_Base = the quantity of baseline fans that would be replaced with HVLS fans. Assumed to be 5 standard fans per HVLS fan. (Ref. 3)

kW_HVLS_per_Fan = The rated input Wattage of each HVLS fan, assumed to be 1.0 kW (Ref. 4)

kW_Base_per_Fan = The rated input Wattage of each non-HVLS fan, assumed to be 1.0 kW (Ref. 4)

Hrs = Assumed annual operating hours of fans (Refer to Table 1)

HVAC_cooling_kWhsavings_factor = Cooling system energy savings factor resulting from reduction in fan energy (see Table 2). Reduction in fan energy results in a reduction in cooling energy, if the customer has air conditioning.

HVAC_cooling_kWsavings_factor = Cooling system demand savings factor resulting from reduction in fan power (see Table 2). Reduction in fan power results in a reduction in cooling demand, if the customer has air conditioning.

HVAC_heating_penalty_factor = Heating system penalty factor resulting from reduction in fan energy (see Table 2).

CF = Peak coincidence factor = 0.9 (Ref. 5)

Example:

A 20-foot HVLS fan is installed to replace five standard fans, used to provide air circulation in an air conditioned manufacturing facility.

kW_Base = 5 x 1.0 = 5.0 kW

kW_EE = 1.0 = 1.0 kW

Electric Energy Savings (kWh/yr) = (5.0 kW – 1.0 kW) x 5,200 x 1.095 = 22,776 kWh

Electric Peak Demand Savings (kW) = (5.0 kW – 1.0 kW) x 0.9 x 1.254 = 4.5 peak kW

Heating Penalty = (5.0kW – 1.0kW) x 5,200 x -0.0023 = -47.8 Dth

Deemed Input Tables

Table 1. Annual Operating Hours by Building Type (Ref. 6)

Building Type	Annual Operating Hours
Office	4,439
Restaurant	3,673
Retail	4,719
Grocery/Supermarket	5,802
Warehouse	4,746
Elementary School	2,422
Secondary School	4,311
College	3,540
Health	5,095
Hospital	6,038
Hotel/Motel	3,044
Manufacturing	5,200
Other/Misc.	4,576
24-Hour Facility	8,760

Table 2. HVAC Interactive Factors by HVAC System (Ref. 7)

Space Type	HVAC Cooling kW Savings Factor		HVAC Cooling kWh Savings Factor		HVAC Heating Penalty Factor (Dth/kWh)
	HVAC System: Heating Olny	HVAC System: Heating & Cooling	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only or Heating & Cooling
Conditioned	1.00	1.254	1.00	1.095	-0.0023
Unconditioned Space	1.00	1.00	1.00	1.00	0

Table 3. Incremental cost of HVLS Fans by Size (Ref. 2)

HVLS Fan Size (Diameter, feet)	Incremental Cost
20 feet	$4,150
22 feet	$4,180
24 feet	$4,225

Notes

There are currently no Federal energy efficiency standards in place for high velocity low speed fans.

References

1. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values, October 10, 2008. EUL value for this measure was assumed to be the same as HVAC Fan Motors.
2. ActOnEnergy, Program Year Three Technical Reference Manual No. 2010-4. Costs are based on the comparison of the prices of seven small (48" diameter) industrial low-speed fans and one HVLS fan. Average costs from three different manufacturers were analyzed.
3. D.W. Kammel, M.E, Raabe, J. J. Kappelman: Design of High Volume Low Speed Fan
4. Supplemental Cooling System in Dairy Free Stall Barns
5. Manufacturer data from Rite Hite, Macro-Air, Big Ass Fans, and laboratory testing data for 48" fans from BESS labs showed that the difference in average input wattage for HVLS and standard fans is negligible. Average input wattage was shown to be around 1.0 kW. (http://bess.illinois.edu/) last accessed 08/31/12
6. 0.9 is a typical value used for central HVAC equipment in many programs. The range is 0.74 to
7. 1.0 with most being very close to 0.9, primary data has not been identified.
8. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 pg 139. The Illinois TRM summarizes recent studies including: DEER 2005, DEER 2008, ComEd FY1 and FY2 evaluations, Ameren Missouri Final Report:

Evaluation of Business Energy Efficiency Program Custom and Standard Incentives, and Focus on Energy Evaluation, ACES Deemed Savings Desk Review, November 2010.

9. HVAC cooling and heating interactive factor data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes (see http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf), and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/1/2012
2.0	Added HVAC Cooling kWh and kW savings and Heating penalty factors	Franklin Energy Services	11/12/15

C/I HVAC - Infrared Heater

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial customers with natural gas fired forced air heating systems
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	New infrared heater input Btu/h, project location (county)
Version No.	2.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$1,716 (Ref. 2)

Measure Description

This measure includes replacement of failed or working furnaces and unit heaters in existing buildings with natural gas fired infrared heaters, as well as installation of infrared heaters in new buildings.

Algorithms

Unit Dth Savings per Year = Pre_Annual_Consumption x (1 - Load_Reduction_Factor)

Where:

Pre_Annual_Consumption = Btuh_In x Load_Factor x $EFLH_{Heat}$ / ConversionFactor

Load_Reduction_Factor = (HDD45 / (55°F - T_design)) / (HDD55 / (65°F - T_design))

Btuh_In = the nominal rating of the input capacity of the new infrared heater in Btu/h Load_Factor = load factor, assumed to be 77% (Ref. 3)

$EFLH_{Heat}$ = the heating equivalent full load hours. See Table 2.

HDD55 = the heating degree-days of the climate zone with a 55 degree base. See Table 1. HDD45 = the heating degree-days of the climate zone with a 45 degree base. See Table 1.

T_design = the equipment design temperature of the climate zone, see Table 1

ConversionFactor = 1,000,000 Btu/Dth

Example:

A 300 Mbtuh infrared heater is installed to replace a furnace of the same size in an existing Manfacturing building in Climate Zone 1.

Pre_Annual_Consumption = 300,000 x 0.77 x 1397 /1,000,000 = 323 Dth

Unit Dth Savings per Year = 323 x [1 - (4429 / (55 - (-22))) / (6956 / (65 - (-22)))] = 90.6 Dth

Deemed Input Tables

Table 1. Heating Degrees Days (HDD) and Heating Design Temperature per zone in Minnesota

	Zone 1 (Northern MN)	Zone 2 (Central MN)	Zone 3 (Southern MN/Twin Cities)
HDD55 (Ref. 5)	6,956	5,888	5,233
HDD45	4,429	3,864	3,317
T_design (Ref. 6)	-22 °F	-16.5 °F	-14.5 °F

Table 2. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 4)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

$EFLH_{Heat}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 3. Heating Degree Days and Design Temperature Difference

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

Methodology and Assumptions

The calculation methodology for this measure assumes that the space temperature can be dropped 10°F while maintaining occupant comfort levels.

Notes

There are currently no existing Minnesota state-wide or federal efficiency standards for infrared heaters.

References

1. Focus on Energy Evaluation, Business Programs: Measure Life Study, August 25, 2009.
2. Nicor Gas Energy Efficiency Plan 2011-2014. Revised Plan Filed Pursuant to Order Docket 10-0562, May 27, 2011
3. Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that heating systems are 30% oversized on average.
4. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
5. National Climate Data Center - National Oceanic and Atmospheric Administration 1981-2010
6. Normals. Weather data for Duluth and International Falls was averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3.
7. *2009 ASHRAE Fundamentals Handbook Table 1A Heating and Wind Design Conditions, Heating DB 99.6%*

Revision History

Version	Description	Author	Date
1.0	Original doucment	Franklin Energy Services	7/30/2012
1.1	Added Industrial to Market Segments, corrected use of Btu/Dth conversion factor in algorithm, changed measure name	Joe Plummer	2/12/2013
2.0	Changed from Heating Degree Days to EFLHHeat. Updated Table 2 to include building types	Franklin Energy Services	11/12/2015

C/I HVAC - Mini Split Ductless Systems A/C Only and Heat Pump

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers with < 65,000 Btu/hr cooling systems where mini-split ductless equipment (both cooling-only and heat pump versions) can be installed
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	(1) Existing HVAC system type (air-source heat pump, electric heat with split system, or other thru-the-wall air conditioner), (2) mini-split system size, (3) furnace system size (if applicable), (4) proposed system heating HSPF, (5) proposed system cooling SEER
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	Actual costs should be used. For planning purposes, an averaged full installed cost was determined to be $2,500 per ton (Ref. 2)

Measure Description

This measure includes replacing non-working and working air-source heat pump equipment, electric resistance heating systems with split system air conditioning systems, and electric resistance heating with mini-split ductless air conditioner or heat pump systems.

Systems functioning as the primary heating and cooling systems are applicable for savings and rebates. Back-up heating systems are not applicable. In circumstances where the mini-split heating system is installed in conjunction with an existing heating or cooling systems, the existing system must be controlled as the back-up heating or cooling.

Algorithms

Air-source heat pump or electric resistance heat with air conditioner baseline

Unit kWh Savings per Year = Cap_{COOL} x 12 x $EFLH_{COOL}$ x (1 / $SEER_{BASE}$ - 1 / $SEER_{EE}$) + Cap_{HEAT} x 12 x $EFLH_{HEAT}$ x (1 / $HSPF_{BASE}$ – 1 / $HSPF_{EE}$)

Unit Peak kW Savings = Cap_{COOL} x 12 x (1 / EER_{BASE} - 1 / EER_{EE}) x CF

Electric resistance heat only baseline

Unit kWh Savings per Year = Cap_{HEAT} x 12 x $EFLH_{HEAT}$ x (1 / $HSPF_{BASE}$ - 1 / $HSPF_{EE}$) - Cap_{COOL} x 12 x $EFLH_{COOL}$ / $SEER_{EE}$

Unit Peak kW Savings = -Cap_{COOL} x 12 / EER_{EE} x CF

Where:

Cap_{COOL}	=	Mini-split ductless cooling capacity in tons (1 ton = 12,000 Btu/h)
Cap_{HEAT}	=	Mini-split ductless heating capacity in tons (1 ton = 12,000 Btu/h)
12	=	Unit conversion, EER to kW/ton
$EFLH_{COOL}$	=	Equivalent full-load cooling hours, see Table 3 (Ref. 6)
$SEER_{BASE}$	=	SEER in cooling mode for the baseline HVAC system, see Table 2
$SEER_{EE}$	=	Actual SEER of mini-split ductless system, from AHRI database (Ref. 9)
$EFLH_{HEAT}$	=	Equivalent full-load heating hours, see Table 4 (Ref. 7)
$HSPF_{BASE}$	=	HSPF in heating mode for the baseline HVAC system, see Table 1
$HSPF_{EE}$	=	Actual HSPF in heating mode for proposed heat pump, from AHRI database (Ref. 9)
EER_{BASE}	=	EER of baseline system (= $SEER_{BASE}$ x 0.875)
EER_{EE}	=	EER of proposed system (= actual, or $SEER_{EE}$ x 0.875)
CF	=	0.90, coincidence factor (Ref. 8)

Example:

Assume a 2.5-ton air-source heat pump being replaced by a mini-split system in a low-rise office building in climate zone 1. Assume that two 1-ton mini-splits and one 1/2-ton mini-split will be installed.

Unit kWh Savings per Year = 2.5 x 12 x [213 x (1 / 14 - 1 / 20) + 2,280 x (1 / 8.5 - 1 / 11)] = 1,966 kWh

Unit Peak kW Savings = 2.5 x 12 x (1 / (14 x 0.875) - 1 / (20 x 0.875)) x 0.9 = 0.66 kW

Deemed Input Tables

Table 1. Baseline HSPF

Baseline Heating System	$HSPF_{BASE}$	Reference
Existing Commercial Air-Source Heat Pump	8.5	Ref. 4, Ref. 10
Existing Electric Resistance	3.412	Assumed (= 100% efficient)
Thru-the-Wall Heat Pump	8.5	See Notes

Table 2. Baseline SEER

Baseline Cooling System	$SEER_{BASE}$	Reference
Existing Commercial Air-Source Heat Pump	14	Ref. 4, Ref. 10
Existing Commercial Split System Air Conditioner	13.0	Ref. 4, Ref. 10
Thru-the-Wall Air Conditioner	14	See Notes

Table 3. Equivalent Full-Load Hours for Cooling

Building Type	Zone 1 (Northern MN)	Zone 2 (Central MN)	Zone 3 (Southern MN)
Convenience Store	647	825	986
Education - Community College/University	682	782	785
Education - Primary	289	338	408
Education - Secondary	484	473	563
Health/Medical - Clinic	558	738	865
Health/Medical - Hospital	663	1,089	1,298
Lodging	401	606	754
Manufacturing	347	472	589
Office - Low Rise	257	359	446
Office - Mid Rise	373	529	651
Office - High Rise	669	1,061	1,263
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Table 4. Equivalent Full-Load Hours for Heating

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1,887	1,699	1,546
Education - Community College/University	1,972	1,776	1,616
Education - Primary	2,394	2,156	1,961
Education - Secondary	2,561	2,306	2,098
Health/Medical - Clinic	2,234	2,012	1,830
Health/Medical - Hospital	2,508	2,258	2,054
Lodging	2,361	2,126	1,934
Manufacturing	1,397	1,258	1,144
Multifamily	2,324	2,092	1,904
Office - Low Rise	1,966	1,770	1,610
Office - Mid Rise	2,189	1,971	1,793
Office - High Rise	2,149	1,935	1,760
Restaurant	1,868	1,681	1,530
Retail - Large Department Store	1,763	1,587	1,444
Retail - Strip Mall	1,701	1,531	1,393
Warehouse	1,872	1,685	1,533
Other/Miscellaneous	2,123	1,911	1,739

Notes

For new construction, it is recommended that the air-source heat pump baselines be used. However, if it can be documented that electric resistance heat is common for the region, a hybrid baseline may be used.

$EFLH_{COOL}$ was determined from prototypes building models based on the California DEER study prototypes with modified Illinois field data and scaled with Minnesota weather data for Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis–St. Paul (Zone3).

$EFLH_{HEAT}$ was determined from prototypes building models based on the California DEER study prototypes with modified Illinois field data and scaled with Minnesota weather data Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis–St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 5. Heating Degree Days and Design Temperature Difference

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

Proposed mini-split ductless should meet ENERGY STAR minimum requirements (14.5 SEER, 8.2 HSPF).

Multi-head system capacity is the minimum of the total indoor unit capacity and outdoor unit capacity.

Through-the-wall units in a commercial scenario are assumed to be packaged terminal units. As packaged terminal air conditioners and packaged terminal heat pumps are rated differently than mini-split heat pumps, conservative assumptions are used, deemed equal to split systems.

References

1. GDS Associates, Inc. *Measure Life Report - Residential and Commercial/Industrial Lighting and HVAC Measures*. June 2007. http://library.cee1.org/sites/default/files/library/8842/CEE_Eval_MeasureLifeStudyLights&HVACGDS_1Jun2007.pdf
2. Swift, Joseph R, and Rebecca A. Meyer, The Connecticut Light and Power Company. *Ductless Heat Pumps for Residential Customers in Connecticut*. 2010 ACEEE Summer Study on Energy Efficiency in Buildings (2-292).
   NEEP. *Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report*. January 2014.
3. Title 10, Code of Federal Regulations, Part 430 - Energy Conservation Program for Consumer Products, Subpart C, Section 430.32. January 1, 2013. http://www.gpo.gov/fdsys/pkg/CFR-2013-title10-vol3/pdf/CFR-2013-title10-vol3-sec430-32.pdf
4. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment, Subpart F - Commercial Air Conditioners and Heat

Pumps. January 1, 2010. http://www.ecfr.gov/cgi-bin/text-idx?SID=683dd820ec02f5e7beaa862cd5239790&mc=true&node=pt10.3.431&rgn=div5

5. U.S. Department of Energy. http://buildingsdatabook.eere.energy.gov/ChapterIntro7.asp Though the federal minimum efficiency is 78%, there are very few models available at this efficiency; a review of AHRI shows that most low efficiency units are 80%.
6. Franklin Energy Services. 2012.
Calculated EFLH from energy models based on California DEER study prototypes modified by Illinois field data with Minnesota weather data for Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis–St. Paul (Zone3).
7. Franklin Energy Services scaled EFLH from those provided in the *Illinois Technical Reference Manual* based on Minnesota weather data. EFLH for the *Illinois Technical Reference Manual* were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
8. 0.9 is a typical value used for central HVAC equipment in many programs. The range is 0.74 to 1.0, with most being very close to 0.9. Primary data has not been identified.
9. Air-Conditioning, Heating, & Refrigeration Institute. "AHRI Directory of Certified Product Performance." www.ahridirectory.org
10. International Code Council. IECC 2012. Washington DC.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	7/31/2015
2.0	Streamlined equations, removed furnace baseline, clarified requirements for back-up systems, updated and clarified baselines	Cadmus	11/2018

C/I HVAC - Parking Garage Exhaust Fan CO Control and Heating

Measure Detail	Measure Value
Target Market Segments	We envision this measure to be used by Assembly, Big Box Retail, Grocery, Large Office, and Industrial customers. This measure applies to both Commercial and Industrial retrofit projects.
Target End Uses	HVAC
Applicable To	Commercial and industrial customers
Actions	Modify, New Construction
Required from Customer/Contractor	Motor size, efficiency, heating type
Version No.	1.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$800/HP (Ref. 2)

Measure Description

The proposed measure would allow for demand-controlled ventilation in enclosed parking garages by monitoring CO levels. By modulating airflow based on need rather than running at constant volume, the system will save energy, increase fan belt life, and increase motor life. If the parking garage is also heated, this reduction in airflow will lead to energy savings from a lower heating load.

ASHRAE 90.1-2010 requires that enclosed garages have systems that automatically detect contaminant levels and stage fans or modulate fan airflow rates to 50% or less of design capacity, with exceptions (see Methodology and Assumptions).

Algorithms

Unit kWh Savings per Year = $(HP \times LF \times UF \times C_1 \times t \times SF) / \eta_{motor}$

Unit Peak kW Savings = $(HP \times LF \times UF \times C_1 \times CF) / \eta_{motor}$

Heating kWh Savings per Year (if Electric) = $(HP \times C_2 \times t_{heating} \times (T_{set} - T_{cold}) \times C_3 \times SF) / (C_4 \times \eta_{heating})$

Unit Dth Savings per Year = $(HP \times C2 \times t_{heating} \times (T_{set} - T_{cold}) \times C_3 \times SF) / (C_4 \times \eta_{heating})$

Where:

HP	=	Unit motor horsepower of a typical ventilation fan, 1.0 HP
LF	=	Motor Load Factor, 0.70 (Ref. 3)
UF	=	Motor Usage Factor, 1.00 (Ref. 3)
t	=	Annual operating hours, typically 8760
SF	=	Annual reduction in operating hours, 33% (Ref. 3)

CF	=	Coincidence Factor of 0.88[2] (Ref. 3)
$t_{heating}$	=	Annual hours of heating, 4043 (Ref. 4)
T_{cold}	=	Average outdoor temperature when the temperature is below Tset, 20.1°F (Ref. 5)
T_{set}	=	Temperature below which the parking garage is heated, 40°F (Ref. 6)
C_1	=	0.746 kW/HP
C_2	=	1,000 CFM/HP
C_3	=	1.08 Btu / (hr·CFM·°F)
C_4	=	Electric: 3,412 Btu / kWh, Gas: 1.0 x10^6 Btu / Dth
η_{motor}	=	Motor efficiency for typical motor, 91.0% (Ref. 7)
$\eta_{heating}$	=	Electric: 100%, Gas: 80% (Ref. 8)

Example:

A customer installed a new demand-controlled parking garage ventilation system. The size of the motor is 1 HP and its nominal efficiency is 91.0%. The parking garage is heated by natural gas.

Unit kWh Savings per Year = [1 HP x 0.70 x 1.00 x 0.746 kW/HP x 8760 x (33%)] / 0.91 = 1,660 kWh

Unit Peak kW Savings = 1 HP x 0.7 LF x 0.746 kW/HP x 0.88 CF / 91.0% Eff = 0.505 kW

Heating Dth Savings per Year = [1 HP x 1,000 CFM/HP x 4043 hrs x (33%) x (40 - 20.1) °F x 1.08 Btu/(hr·CFM·°F)] / (1.0x 10^6 Btu/Dth x 80%) = 35.8 Dth

Methodology and Assumptions

Enclosed parking garage ventilation systems shall automatically detect contaminant levels and stage fans or modulate fan airflow rates to 50% or less of design capacity provided acceptable contaminant levels are maintained. Exceptions:

- Garages less than 30,000 ft2 with ventilation systems that do not utilize mechanical cooling or mechanical heating.
- Garages that have a garage area to ventilation system motor nameplate hp ratio that exceeds 1500 ft2/hp and do not utilize mechanical cooling or mechanical heating.
- Where not permitted by the authority have jurisdiction. (Ref. 9)

[2] Comparing Ref. 3 with 2015 ASHRAE Handbook the coincidence factor matches up with what was shown in the Enclosed Vehicular Facilities section for the Profile 3 scenario of an on/off system during peak hours.

References

1. Michigan Energy Measures Database, Demand Control Ventilation (DCV) 2015 MEMD Master with Weather-Sensitive Weighting Tool (Zipped File), Measure: W-CO-HV-100036-C-WR-WR-WR-WR-01. Accessed 07/24/15. http://www.michigan.gov/mpsc/0,4639,7-159-52495_55129---,00.html
2. Based on a survey of DCV case studies provided by Nagle Energy and AirTest, project cost averaged out to approximately $1,000 per controlled horsepower. These projects all included the installation of VSDs, so the presumed cost of the VSD ($200/hp) was removed from the estimate. See accompanying calculation file for more details.
3. KEMA workpaper for 'Demand Control Ventilation – Parking Garage', Source: Manufacturer Data.
4. 4,043 hours is the average total number of hours that the temperature is below 40°F. National Solar Radiation Data Base. Cities used: Duluth, International Falls, Minneapolis / St. Paul, Rochester. Accessed 07/28/15. http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/
5. 20.1°F is the average annual temperature below 40°F. National Solar Radiation Data Base. Cities used: Duluth, International Falls, Minneapolis / St. Paul, Rochester. Accessed 07/28/15. http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/
6. ENERGY STAR Technical Reference - Parking and the ENERGY STAR Score. Page 3. Accessed 07/28/15. http://www.energystar.gov/sites/default/files/buildings/tools/ENERGY%20STAR%20Score%20for%20Parking.pdf
7. Consortium for Energy Efficiency Premium-Efficiency Motors Initiative, 2007. 7.5 HP, Open Drip-Proof, 1800 RPMs (Page 16 of 18). Accessed 07/24/15. http://library.cee1.org/sites/default/files/library/4928/CEE_IndMMS_guidancespec_Jun2007.pdf
8. Franklin Energy Services (FES) Estimate
9. ASHRAE 90.1-2010 6.4.3.4.5

Revision History

Version	Description	Author	Date
1.0	Created standalone specifications for parking garage exhaust fan CO controls and heating	Franklin Energy Services	11/12/15
1.1	Corrected constant in Dth Savings algorithm	Franklin Energy Services	11/30/15

C/I HVAC - Steam Trap

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC, Industrial Process
Applicable To	Commercial customers with natural gas fired low-pressure (≤ 15 psig) steam boilers used for space heating, industrial customers with process steam systems
Actions	Replace on Fail
Required from Customer/Contractor	Orifice diameter in inches, steam system pressure in psig, project location (county), trap installed cost OR steam system type, steam pressure control (see Table 4) Optional inputs from customer/contractor: Efficiency of steam boiler
Version No.	3.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	6 (Ref. 1)
Unit Participant Incremental Cost	Use actual or refer to Table 4 if unavailable

Measure Description

This measure includes the replacement of leaking steam traps that are part of a HVAC steam distribution system, or an industrial process steam system.

Algorithms

Unit Dth Savings per Year = Rate_Loss x h_fg x Loss_Factor x $EFLH_{Heat}$ x CCF_Space Heating / (Heat_Eff x 1,000,000)

Where:

Rate_Loss = rate of steam loss, determined by steam gage pressure and steam trap orifice diameter, determined using Grashof's Equation: lb/hr = 0.70 x 0.0165 x 3600 x A x $p^{0.97}$ (Ref. 2).

A = the area of the steam trap orifice in square inches = $\pi d^2/4$, d = diameter of steam trap orifice in inches

P = system pressure in pounds per square inch absolute (psia), psia = psig (gauge pressure) + 14.7 psi at sea level

h_fg = latent enthalpy of vaporization at specified conditions, from Table 3

Loss_Factor = A factor to account for the percentage of the orifice that is open. Assumed to be 50%

$EFLH_{Heat}$ = equivalent full load hours of heating, from Table 2. For process traps use hours provided by customer. If unknown use 8760.

CCF_Space_Heating = valve control correction factor determined by type of piping leg equipment control serving steam supplied to trap, see Table 1 (Ref. 3) Applicable to space heating traps only.

Heat_Eff = efficiency of the steam boiler. If unknown, use typical value of 80%

1,000,000 = Conversion from Btu to Dth

Example:

Replace a leaking 1/8" HVAC steam trap that is part of a 5 psig heating system in a High Rise Office in Climate Zone 1. The heating system incorporates a heat timer.

Rate_Loss = 0.70 x 0.0165 x 3600 x (π x (1/8)^2/4) x $(14.7 + 5)^{0.97}$ = 9.2 lb/hr

Dth Savings per Year = 9.2 lb/hr x 960 x 50% x 2149 x 1.0 / 80% / 1,000,000 = 11.9 Dth

Deemed Input Tables

Table 1. Control Correction Factor

Space Heating Control Type - Examples	CCF (Ref. 3)
Uncontrolled, By-Pass Damper on Air Handler Heating Coil	3.5
TRV, Modulating, Heat Timer	1.0
Manual Control Valves, Unknown Control Type	2.25

Table 2. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 4)

Building Type - Application	Zone 1	Zone 2	Zone 3
Production End-use (Ref. 7)	4567	4567	4567
Convenience Store	1887	1699	1546
Education - Community College/University	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Table 3. Latent Heat of Vaporization for Various Pressures (Ref. 5)

PSIG	Latent Enthalpy of Vaporization (h_fg) (BTU/lb)
2	966
5	960
10	953
15	946
25	934
50	912
75	895
100	880
125	868
150	857
200	837
250	820
300	805

Table 4. Cost Per Steam Trap for Various System Types (Ref. 6)

Steam System Type	Cost per Trap
Commercial Dry Cleaners	$77.00
Commercial Heating , low pressure steam	$77.00
Industrial Medium Pressure >15 psig psig < 30 psig	$180.00
Steam Trap, Industrial Medium Pressure ≥30 <75 psig	$223.00
Steam Trap, Industrial High Pressure ≥75 <125 psig	$276.00
Steam Trap, Industrial High Pressure ≥125 <175 psig	$322.00
Steam Trap, Industrial High Pressure ≥175 <250 psig	$370.00
Steam Trap, Industrial High Pressure ≥250 psig	$418.00
Steam Trap, Industrial Medium Pressure ≥30 <75 psig	$223.00
Steam Trap, Industrial High Pressure ≥75 <125 psig	$276.00
Steam Trap, Industrial High Pressure ≥125 <175 psig	$322.00
Steam Trap, Industrial High Pressure ≥175 <250 psig	$370.00
Steam Trap, Industrial High Pressure ≥250 psig	$418.00

Notes

$EFLH_{Heat}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 5. Heating Degree Days and Design Temperature Difference

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

References

1. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values, October 10, 2008
2. Barney L. Capehart, Wayne C. Turner, William J. Kennedy, "Guide To Energy Management, 6 Ed," The Fairmont Press, Inc., 2008
3. FES determined. The correction factor corrects heating usage as a function of sequence of operation of controls maintaining steam supply in piping system serviced by the steam trap as determined by FES. When the CCF = 1, this is equivalent to utilization comparable to the EFLH. When the CCF = 3.5, this is approximately equal to utilization for all hours below 55°F or balance point of the building. When the CCF = 2.25, this is an average utilization for other two utilization rates.
4. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
5. Keenan, J.H., Keyes, F. G., Hill, P. G., and Moore, J. G. "Steam Tables." John Wiley & Sons, 1969
6. Illinois Statewide Technical Reference Manual-6.4.15 Steam Trap Replacement or Repair, July 18, 2012

Revision History

Version	Description	Author	Date
1.0	Original from Nexant with extraneous tabs hidden	Nexant	
1.1	Changed measure life and measure life source	Franklin Energy Services	7/31/2012
1.2	Changed incremental cost and cost source	Franklin Energy Services	7/31/2012
1.3	Updated HDD65 and design temperatures based on new 30-year averages.	Franklin Energy Services	7/31/2012
1.4	The references for HDD65, design temperatures, and tune-up savings were changed.	Franklin Energy Services	7/31/2012
1.5	Changed EFLH assumptions and sources	Franklin Energy Services	7/31/2012
1.6	Changed algorithm	Franklin Energy Services	7/31/2012
1.7	Added the variables Oversize_Factor, Conversion_Factor, and Loss_Factor	Franklin Energy Services	7/31/2012

Version	Description	Author	Date
2.0	Specified that low pressure is ≤ 15 psig in Applicable To, changed incremental cost to specify that actual may be used, entered required and optional inputs, minor revisions	JP	3/4/2013
3.0	Changed to EFLHheat algorithm. Added Table 1	Franklin Energy Services	11/12/2015

C/I HVAC - Pipe Insulation

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC, DHW
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Modify
Required from Customer/Contractor	Length of pipe insulation, number of joining components insulated, piping system type, pipe location (indoors or outdoors), project location (county), facility type
Version No.	1.0
Unit Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See Algorithm
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	See Table 8 (Ref. 2)

Measure Description

This measure includes installation of ≥ 1" or ≥ 2" fiberglass, foam, calcium silicate or other types of insulation with similar insulating properties to existing bare pipe on straight piping as well as other pipe components such as elbows, tees, valves, and flanges for commercial applications. Default per linear foot savings estimates are provided for exposed indoor and above ground outdoor piping distributing hot water or steam, heated from natural gas fired systems. System types include:

- Hydronic heating systems. These may or may not have outdoor reset controls. These may have no recirculation (do not circulate water around a central loop and operate upon demand from a thermostat), or they may have recirculation only during the heating season, or they may have year-round recirculation.
- Domestic hot water
- Low- and high-pressure steam systems. These also may have no recirculation, heating season recirculation, or year-round recirculation.

The minimum pipe diameter is 1". Indoor piping must have at least 1" of insulation. Outdoor piping must have 2" of insulation and an all-weather protective jacket. Savings are derived from the measure in the Illinois TRM (Ref. 2), with modification for the Minnesota climate.

Algorithms

Unit Dth Savings per Year = $(L_{PIPE} + L_{COMP}) \times (Q_{BASE} - Q_{INSUL}) \times EFLH \times TRF / (Eff * 1{,}000{,}000)$

Where:

Q_{BARE} = Heat loss from bare piping, Btu/h per foot. See Table 1.

Q_{INS} = Heat loss from insulated pipe, Btu/h per foot. See Table 1.

L_{PIPE}	=	Length of straight straight pipe to be insulated, feet. User input.
L_{COMP}	=	Equivalent length of joining components, i.e., elbows, joints, valves, tees, etc., in feet. See See Table 2, Table 3, and Table 4.
Eff	=	Efficiency of the boiler being used to generate the hot water or steam. User input or assume 80%.
HOU	=	Hours of use. For heating, use EFLH values in Table 5. For year round recirculation use 8,760. For heating season recirculation, use hours with outside air temperature below 55°F in Table 6.
1,000,000	=	Conversion from Btu to Dth
TRF	=	Thermal regain factor, varies by space type (Table 7)

Example:

A customer in Zone 3 installed an aluminum insulation jacket on two feet of outdoor uninsulated hot water pipe with no outdoor temperature reset.

Unit Dth Savings per Year = 2 x (464 - 15) x 8760 x 1 / (0.80 x 1,000,000) = 9.8 Dth

Deemed Input Tables

Table 1. Q_{BARE}, Q_{INS} and their Input Assumptions for Various Install Scenarios (Ref. 2, see Notes)

Location		Indoor Piping						Outdoor Piping				
System Type		Hot water			5 psi steam	65 psi steam	Domestic Hot Water	Hot water			5 psi steam	6 psi steam
Insulation thickness		1			2	2.5	1	3			3.5	4
Outdoor Temp Reset		No	Yes	Yes	n/a	n/a	n/a	No	Yes	Yes	n/a	n/a
Recirculation		Any	Heating season	All year	n/a	n/a	n/a	Any	Heating season	All year	n/a	n/a
Ambient T		75°F						Zone 1, Duluth: 41°F Zone 2, St. Cloud: 44°F Zone 3, MSP: 48°F				
Fluid in Pipe T, °F		170	145	130	225	312	125	170	145	130	225	312
Q_{BARE}, Btu/h per foot	**Zone 1**	**114**	**78**	**58**	**232**	**286**	**52**	**489**	**386**	**325**	**754**	**1001**
	Zone 2							**478**	**377**	**318**	**736**	**978**
	Zone 3							**464**	**367**	**309**	**716**	**951**
Q_{INS}, Btu/h per foot	**Zone 1**	**22**	**16**	**12**	**23**	**32**	**13**	**16**	**13**	**11**	**22**	**30**
	Zone 2							**16**	**13**	**11**	**21**	**29**
	Zone 3							**15**	**12**	**10**	**21**	**28**

Table 2. 90 Degree Elbow and Straight Tee Equivalent Length

Nominal Pipe Diameter (in)	Equivalent Length of Other Components (ft)	
	90° Elbow (Ref. 3)	Straight Tee (Ref. 4)
1	0.3	0.38
2	0.66	0.63
3	1.01	0.84
4	1.4	1.03
5	1.76	1.22
6	2.13	1.41
8	2.91	1.75
10	3.65	2.13
12	4.44	2.5

Table 3. Valve Equivalent Length, L_{COMP} (Ref. 2)

ANSI Class (psi)	Equivalent Length of Other Components (ft)			
	1" Valve	2" Valve	3" Valve	4" Valve
150	2	3.56	3.67	3.98
300	5.22	4.73	4.79	5.15
600	5.22	4.73	5.11	6.49
900	6.96	8.37	7.09	7.96

Table 4. Flange Equivalent Length, L_{COMP} (Ref. 2)

ANSI Class (psi)	Equivalent Length of Other Components (ft)			
	1" Flange	2" Flange	3" Flange	4" Flange
150	1.04	1.14	1.16	1.22
300	1.04	1.35	1.44	1.56
600	1.16	1.42	1.48	1.9
900	3.57	2.48	2.02	2.24

Table 5. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 5)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Table 6. HOU for Heating Season Recirculation (Ref. 2, see Notes)

Geography	Hours
MN Zone 1	5995
MN Zone 2	5445
MN Zone 3	5046

Table 7. Thermal Regain Factors (Ref. 2)

Pipe Location	Assumed Regain	Thermal Regain Factor
Outdoor	0%	1
Indoor, heated space	85%	0.15
Indoor, semi- heated, (unconditioned space with heat transfer to conditioned space, e.g., boiler room, ceiling plenum, basement, crawlspace, wall)	30%	0.7
Indoor, unheated, (no heat transfer to conditioned space)	0%	1
Location not specified	85%	0.15
Custom	Custom	1 – assumed regain

Deemed Measured Costs

Actual costs should be used if known. Otherwise, the deemed measure cost below may be used. Pipe insulation type are all calciu silicate insulation, PVC jackets for indoor, and aluminum jacket for outdoor. The following table summarizes the estimated costs for this measure per foot added and include installation costs.

Table 8. Incremental Costs (Ref. 2)

Insulation thickness	Total Cost per foot (Indoor)	Total Cost per foot (Outdoor)
1.0”	$16.35	$18.20
1.5”	$22.43	$25.00
2.0”	$26.93	$29.50
2.5”	$31.28	$33.85
3.0”	$35.62	$38.19
3.5”	$40.02	$42.59
4.0”	$44.40	$46.97

Notes

Savings are calculated based on a bare pipe baseline. This measure is not generally valid for new construction applications. Required pipe insulation thickness for new buildings is generally 1” or greater (Ref. 6).

Values for Q_{BASE} and Q_{INS} were derived using 3E Plus v4.0 software (Ref. 7) in the Illinois TRM. These models assumed 2” piping. Q_{BASE} and Q_{INS} values for indoor piping are unaltered. However their values for outdoor piping were weather-normalized to reflect the mean outdoor temperature of Minnesota climate zones, and the corresponding change in mean temperature difference between the pipe fluid and the pipe exterior.

The algorithm described above can be used for prescriptive pipe insulation savings for scenarios meeting the criteria outlined in the Measure Description section. For custom scenarios such as larger diameter pipes, thicker insulation, or exotic insulation materials, 3E Plus Version 4.1 software may be used to calculate Q_{BARE} and Q_{INS}. Pipe type, pipe base metal, pipe size, insulation type, jacket material, process temperature, and ambient temperature can all be specified on the Energy tab of the software, and the Calculation Type can be set to Heat Loss Per Hour. Process and ambient temperatures as specified in Table 1 should be used. For outdoor installations, a wind speed of 5 miles per hour should be specified. Once the inputs are specified, selecting Calculate reveals heat loss values for bare pipe (Q_{BARE}) and for various thicknesses of insulation (Q_{INS}). A report can then be exported specifying the input assumptions and output heat loss values. For more information, consult the 3E Plus manual (Ref. 8).

References

1. Measured Life Report, Residential and Commercial/Industrial Lighting and HVAC measures, GDS Associates, June 2007. Value for Pipe Wrap measure. https://library.cee1.org/system/files/library/8842/CEE_Eval_MeasureLifeStudyLights%2526HVACGDS_1Jun2007.pdf
2. Illinois Stakeholder Advisory Group. *2021 Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 9.0, Volume 2: Commercial and Industrial Measures*. September 25, 2020. https://ilsag.s3.amazonaws.com/IL-TRM_Effective_010121_v9.0_Vol_2_C_and_I_09252020_Final.pdf
3. Based on the dimensions for diameter, long radius, and short radius given by ANSI/ASME 36.19.
4. Based on the center to face and diameter dimensions given by ANSI/ASME B36.19.
5. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
6. 2020 Minnesota Energy Code with ANSI/ASHRAE/IES Standard 90.1. https://codes.iccsafe.org/content/MNEC2020P1/chapter-4-ce-commercial-energy-efficiency#MNEC2020P1_CE_Ch04_SecC403.3.2
7. North American Insulation Manufacturer's Association. 3E Plus Software. https://insulationinstitute.org/tools-resources/free-3e-plus/
8. North American Insulation Manufacturer's Association. 3E Plus User Guide Version 4.1. August 2012. https://insulationinstitute.org/wp-content/uploads/2016/03/3E-Plus-V4-Users-Manual.pdf

Revision History

Version	Description	Author	Date
1.0	Initial version	Cadmus	9/2021

C/I HVAC - Unitary and Split Systems

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and Industrial customers where DX unitary equipment can be installed
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	New equipment type, new equipment nominal cooling capacity in tons, new equipment EER/SEER, building type (refer to Table 1), project location (county)
Version No.	2.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 years (Ref. 1)
Unit Participant Incremental Cost	See Tables 2 and 3

Measure Description

This measure includes installation of electric DX packaged, split, and condensing units, and PTACs in replacement and new construction applications. This measure analyzes the cooling savings potential of the installation of higher efficiency air-conditioning equipment. This measure is applicable to DX cooling only, DX cooling and electric heat, and DX cooling and gas heat units. The incremental cost is associated with base equipment cost and does not include any installation costs.

Algorithms

For packaged, split units less than or equal to 5.4 tons, and PTAC units:

Unit kWh Savings per Year = Size x (12/SEER_base - 12/SEER_EE) x EFLH_cool

For packages and split units greater than 5.4 tons:

Unit kWh Savings per Year = Size x (12/IEER_base - 12/IEER_EE) x EFLH_cool

Unit Peak kW Savings = Size x (12/EER_base - 12/EER_EE) x CF

Where:

Size = Nominal cooling capacity in tons of the new equipment (1 ton = 12,000 btu/h)

SEER_base = Seasonal energy efficiency ratio of the baseline equipment, based on federal manufacturing requirements. See Table 2 for DX Packaged, Split and Condensing Units; see Table 3 for PTAC units, SEER_base = EER_base/0.875

SEER_EE	=	Seasonal energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor. If unknown, use SEER = EER / 0.875 (Ref. 2)
IEER_base	=	Integrated energy efficiency ratio of the baseline equipment, based on federal manufacturing requirements. See Table 2 for DX Packaged, Split and Condensing Units
IEER_EE	=	Integrated energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor
EFLH_cool	=	Effective full-load cooling hours based on the building type. See Table 1
EER_base	=	Energy efficiency ratio of the baseline equipment, based on federal manufacturing requirements. See Table 2 for DX Packaged, Split, and Condensing Units; see Table 3 for PTAC units
EER_EE	=	Energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor. If unknown, use EER = .875 x SEER (Ref. 2)
CF	=	Deemed coincidence factor, equal to 0.9 (Ref. 3)

Example 1:

Retrofit packaged rooftop installed in Medical Clinic, 7.5-ton cooling capacity, EER 12.0, IEER 13.0, Climate Zone 3.

IEER_base = 12.7

IEER_EE = 13.0

EER_base = 11.0

EER_EE = 12.0

Unit kWh Savings per Year = 7.5 x (12 / 12.7 - 12 /13.0) x 865 = 141 kWh

Unit Peak kW Savings per Year = 7.5 x (12 /11.0 - 12 /12.0) x 0.9 = 0.539 kW

Example 2:

Replacement PTAC unit installed in motel, 9,000 Btu/hr cooling capacity, EER 13.0, Climate Zone 2.

EER_base = 10.9 - (0.213 x 9,000/1,000) = 8.96

EER_EE = 13.0

SEER_base = 8.96/0.875 = 10.24

SEER_EE = 13/0.875 = 14.86

Unit kWh Savings per Year = 9,000/12,000 x (12/10.24 – 12/14.86) x 606 = 165.76 kWh

Unit Peak kW Savings per Year = 9,000/12,000 x (12/8.96 – 12/13.0) x 0.9 = 0.28 kW

Deemed Input Tables

Table 1. Equivalent full load hours of cooling, per zone, in Minnesota by building type (Ref. 4)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	647	825	986
Education - Community College/University	682	782	785
Education - Primary	289	338	408
Education - Secondary	484	473	563
Health/Medical - Clinic	558	738	865
Health/Medical - Hospital	663	1,089	1,298
Lodging	401	606	754
Manufacturing	347	472	589
Office - Low Rise	257	359	446
Office - Mid Rise	373	529	651
Office - High Rise	669	1,061	1,263
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Table 2. Deemed baseline efficiency and incremental costs for DX Packaged, Split, and Condensing Units (Refs. 5, 6, 7, 9, 10)

Equipment	SEER_base or IEER_base*	EER_base*	Incremental Cost
DX Condensing Units > 11.3 Tons (>135 MBH)	14.0	10.5	$100/ton
DX Packaged Units < 5.4 Tons (<65 MBH)	14	N/A	$165/ton
DX Split Units < 5.4 Tons (<65 MBH)	13	N/A	$165/ton
DX Packaged and Split Units >=5.5 and < 11.4 Tons (>=65 MBH and < 135 MBH)	12.7	11.0	$150/ton
DX Packaged and Split Units 11.4 - 19.9 Tons (>=135 MBH and < 240 MBH)	12.2	10.8	$140/ton
DX Packaged and Split Units >=20.0 < 63.3 Tons (>=240 MBH and < 760 MBH)	11.4	9.8	$125/ton
DX Packaged and Split Units >= 63.3 Tons (>=760 MBH)	9.6	9.5	$110/ton

* Efficiency values for units with gas heating, for units with no heating or electric resistance heating, add 0.2 to the above values.

Table 3. Deemed baseline efficiency and incremental costs for PTAC Units (Ref. 5, 7, 9)

Equipment	Cooling Capacity (Btu/h)	EER_base	Incremental Cost
PTAC, Standard Size (used for New Construction)	< 7,000	11.9	$250/ton
	7,000-15,000	14.0 - (0.300* Cap/1000)	$250/ton
	> 15,000	9.5	$250/ton
PTAC, Non-Standard Size (used for Replacements* only)	< 7,000	9.4	$250/ton
	7,000-15,000	10.9 - (0.213* Cap/1000)	$250/ton
	> 15,000	7.7	$250/ton

*Replacement unit shall be factory labeled as follows "MANUFACTURED FOR REPLACEMENT APPLICATIONS ONLY; NOT TO BE INSTALLED IN NEW CONSTRUCTION PROJECTS". Replacement efficiencies apply only to units with existing sleeves less than 16 inches (406mm) in height and less than 42 inches (1067 mm) in width.

Methodology and Assumptions

EFLH_Cool data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Assumed ventilation rates complied with the requirements of ASHRAE standard 62.1 - 2004.

Notes

Table 4. Criteria for ENERGY STAR-Certified Light Commercial Air Conditioners (Ref. 8)

Equipment Type	Cooling Capacity	Heating Section Type	Minimum Energy Efficiency Criteria
Small Air-Cooled Central	≥ 65,000 Btu/h –	Electric Resistance (or None)	12.2 EER; 14.0 IEER
Air Conditioner	< 135,000 Btu/h	All other	12.0 EER; 13.8 IEER
Large Air-Cooled Central	≥ 135,000 Btu/h –	Electric Resistance (or None)	12.2 EER; 13.2 IEER
Air Conditioner	< 240,000 Btu/h	All other	12.0 EER; 13.0 IEER

Table 5. Criteria for ENERGY STAR-Certified Light Commercial Heat Pumps (Ref. 8)

Equipment Type	Cooling Capacity	Heating Section Type	Minimum Energy Efficiency Criteria
Small Air-Cooled	≥ 65,000 Btu/h –	Electric Resistance (or None)	11.8 EER; 12.8 IEER; 3.4 COP at 47°F; 2.4 COP at 17°F
Heat Pump	< 135,000 Btu/h	All other	11.6 EER; 12.6 IEER; 3.4 COP at 47°F; 2.4 COP at 17°F
Large Air-Cooled	≥ 135,000 Btu/h –	Electric Resistance (or None)	10.9 EER; 12.0 IEER; 3.3 COP at 47°F; 2.1 COP at 17°F
Heat Pump	< 240,000 Btu/h	All other	10.7 EER; 11.8 IEER; 3.3 COP at 47°F; 2.1 COP at 17°F

References

1. ASHRAE Owning and Operating Equipment Data Base - Equipment Life/Maintenance Cost Survey
2. ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment
3. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified
4. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012
5. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Industrial Equipment, Energy Conservation Standards for Small, Large, and Very Large Air-Cooled Commercial Package Air Conditioning and Heating Equipment and Commercial Warm Air Furnaces. January 15, 2016
6. Xcel MN Workpapers 2010
7. Based on a review of TRM incremental cost assumptions from Vermont, Wisconsin, and California. This assumes that baseline shift from IECC 2006 to IECC 2009 carries the same incremental costs

8. ENERGY STAR Program Requirement Product Specification for Light Commercial HVAC, Version 3.1, Rev. March 20, 2017
9. Minnesota 2015 Commercial Energy Code, Table C403.2.3(1) Minimum Efficiency Requirements: Electrically Operated Unitary Air Conditioners and Condensing Units

Revision History

Version	Description	Author	Date
2.0	Updated to energy code, including IEER efficiencies, included Other/Miscellaneous building type	Franklin Energy Services	11/12/15
2.1	Updated minimum equipment efficiencies. Added ENERGY STAR Program Requirements Version 3.1 equipment efficiencies	Franklin Energy Services	7/31/17

C/I HVAC - Air Conditioner Tune-ups

Measure Detail	Measure Value
Target Market Segments	Commercial and Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers
Actions	O&M
Required from Customer/Contractor	Nameplate SEER or IEER, Nameplate Capacity, Tune-up Component, Location, (if refrigerant charge correction is conducted) what fraction low or high the original refrigerant charge was
Version No.	1.0
Unit kWh Savings per Year	Varies
Unit Peak kW Savings	Varies
Unit Dth Savings per Year	0
Measure Lifetime (years)	3 (Ref. 1)
Unit Participant Incremental Cost	$35/ton (Ref. 2)

Measure Description

Tune up non-residential unitary or split air conditioners using any or all of procedures outlined, including a condenser coil cleaning, evaporator cleaning, and refrigerant charge correction.

Algorithms

Unit kWh Savings per Year = CAP * $EFLH_{Cool}$ / (SEER * (1 – SF)) * SF

Unit kW Savings per Year = CAP * CF / (EER * (1 – SF)) * SF

Where:

CAP	=	Actual capacity of unit in kBtu/h
$EFLH_{Cool}$	=	Full load cooling hours, varies by building type and zone, see Table 2
SEER	=	Actual nameplate SEER (or IEER) of equipment
SF	=	Savings factor for different tune-up actions, see Table 3
EER	=	Actual nameplate EER of equipment, or SEER * 0.875
CF	=	Coincidence factor = 0.9

Example:

A customer with a 13 SEER, 60 kBtu/h rooftop air conditioner in a low-rise office located in zone 1 receives a tune-up that includes both condenser cleaning and evaporator cleaning.

kWh_{SAVED} = 60 * 257 / (13 * (1 – 6.32%)) * 6.32% = 80.02 kWh

kW_{SAVED} = 60 * 0.9 / (13 * 0.875 * (1 – 6.32%)) * 6.32% = 0.32 kW

Deemed Input Tables

Table 1. $EFLH_{Cool}$ per zone in Minnesota by Building Type (Ref. 3)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	647	825	986
Education - Community College/University	682	782	785
Education – Primary	289	338	408
Education – Secondary	484	473	563
Health/Medical – Clinic	558	738	865
Health/Medical – Hospital	663	1089	1298
Lodging	401	606	754
Manufacturing	347	472	589
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Table 2. Savings Factor (SF) per Tune-Up Component (Ref. 3)

Tune-Up Component	SF
Condenser Cleaning	6.10%
Evaporator Cleaning	0.22%
Refrigeration Charge Off. ≤20%	0.68%
Refrigeration Charge Off. >20%	8.44%

References

1. DEER2014 EUL Table. http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EUL-table-update_2014-02-05.xlsx
2. Illinois Energy Efficiency Stakeholder Advisory Group. *Illinois Statewide Technical Reference Manual, Version 6.0, Volume 2: Commercial and Industrial Measures.* Accessed 10/31/2018: http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_2_C_and_I_020817_Final.pdf.
3. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	The Cadmus Group	10/31/2018

C/I HVAC - Unitary Equipment Economizer Addition or Repair

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers where air unitary equipment has been installed, or has failed closed
Actions	Modify
Required from Customer/Contractor	Existing equipment type, existing equipment nominal cooling capacity in tons, existing equipment EER/SEER, building type (refer to Table 1), project location (county)
Version No.	3.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 years (Ref. 1)
Unit Participant Incremental Cost	For economizer addition, see Table 2 (Ref. 2) For economizer repair, use actual cost

Measure Description

This measure includes the retro-fit of existing equipment or the optional addition of an air side economizer on new equipment where not required by code. This measure analyzes the cooling savings potential of the installation of an air side economizer on unitary equipment. This measure is applicable to dx and water cooled air systems.

This measure also includes the repair of economizers that have failed closed, or been manually disabled in a closed position. This is a common occurrence that often costs less to rectify than installing a new economizer, while providing the same savings as that action. This measure does not apply to economizers that have failed open, cases of which are generally noticed and rectified soon after onset.

Algorithms

Unit kWh Savings per Year = Size x (12/SEER_EE) x $EFLH_{cool}$ x SF x SM Unit

Where:

Size	=	Nominal Cooling capacity in tons of the new equipment (1 ton = 12,000 btu/h)
$EFLH_{Cool}$	=	Equivalent full load cooling hours based on the building type. See Table 1. (Ref. 3)
SEER_EE	=	Energy efficiency ratio of the existing equipment, provided by the customer. If unknown, use SEER = EER/0.875 (Ref. 4) Assume SEER = 10.9 if unavailable. (Ref. 5)

SF	=	Deemed savings factor based upon zone. See Table 2. (Ref. 6)
SM	=	Deemed System Multiplier. SM = 1 for Constant Air Volume (CAV) Systems and SM = 1.4 for Variable Air Volume (VAV) systems. (Ref. 7)

Example:

Install an economizer by retrofitting a packaged rooftop installed in a Health Care Clinic, 20 ton cooling capacity, SEER 14.4, VAV system, Climate Zone 1.

Unit KWh Savings per Year = 20 * (12 / 14.4) * 558 * 0.24 *1.4 = 3,125 KWh

Deemed Input Tables

Table 1. Equivalent Full Load Hours of cooling ($EFLH_{Cool}$) per zone in Minnesota by building type (Ref. 3)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	647	825	986
Education - Community College/University	682	782	785
Education - Primary	289	338	408
Education - Secondary	484	473	563
Health/Medical - Clinic	558	738	865
Health/Medical - Hospital	663	1089	1298
Lodging	401	606	754
Manufacturing	347	472	589
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Table 2. Deemed Savings Factor for Zone and incremental costs

Equipment	Savings Factor (Ref. 6)			Incremental
	Zone 1	Zone 2	Zone 3	Cost** (Ref. 2)
Units* less than or equal to 10 tons	0.240	0.130	0.100	$1,500
Units* 11-20 tons	0.240	0.130	0.100	$1,900
Units* 21-30 tons	0.240	0.130	0.100	$2,100
Units* 31-60 tons	0.240	0.130	0.100	$2,500
Units* 61-100 tons	0.240	0.130	0.100	$4,000

* Units include packaged and built up air-handler units.

** An additional $1000 should be included when retro-fitting existing units.

Methodology and Assumptions

$EFLH_{Cool}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Assumed ventilation rates complied with the requirements of ASHRAE standard 62.1 - 2004.

Methodology assumes 30% savings for VAV over CV systems. Savings were derived through energy modeling using fixed dry bulb control with a high temperature limit of 65˚F.

Incremental costs include controls and programming and assume similar cost between dx and water cooled equipment.

Savings assume economizer is given preference over demand control ventilation strategy.

Notes

Current code requires incorporation of economizer on all cooling systems 2.75 tons and greater for all three Minnesota weather zones with exceptions (Ref 8):

1. Where more than 25 percent of the air designed to be supplied by the system is to spaces that are designed to be humidified above 35°F (1.7 °C) dew-point temperature to satisfy process needs.
2. Systems expected to operate less than 20 hours per week.
3. Where the use of *outdoor air* for cooling will affect supermarket open refrigerated casework systems.

References

1. "Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures", by GDS Associates, Inc. June 2007, pg. 6
2. "Economizers for Packaged Air Systems", Energy Efficiency Office, Department of Natural Resources, Canada
3. Calculated through energy modeling by FES 2012
4. "ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment"
5. "Small Commercial HVAC, Surveying the Frontier of Energy Efficiency", by Lee DeBallie, PE – Energy Center of Wisconsin
6. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012

7. Calculated from the inverse of 0.7. Typical energy consumption of VAV systems are 70% of CV systems. Multiplier verified through energy modeling by FES 2012 and modeling results verified by "Energy Cost and IAQ Performance of Ventilation Systems and Controls - Project Report#2: Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies", pg. 7, by Indoor Environmental Division, EPA, January 2000
8. 2015 Minnesota Energy Code, Section C403.3.1 Economizers.

Revision History

Version	Description	Author	Date
1.0	New savings specification for retrofit/incorporation of air economizer on air systems.	Franklin Energy Services	
1.1	Minor Edits	Joe Plummer	
1.2	Changed Action Type from Replace Working to Modify	Joe Plummer	6/6/2014
2.0	Added/Updated economizer code requirements	Franklin Energy Services	11/12/2015
3.0	Added option for economizer repair	Cadmus	10/2018

C/I HVAC - Variable Speed Drives

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial for space heating and cooling applications
Actions	Modify, Replace Working (Retrofit), New Construction (limited sizes, see Notes)
Required from Customer/Contractor	Horsepower, application type, motor efficiency, annual operating hours
Version No.	3.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	See Table 1 (Ref. 2)

Measure Description

This measure applies to variable speed drives installed on HVAC systems including:

- HVAC Fans - supply fans, return fans, and cooling tower fans
- HVAC Pumps - hot water heating and chilled water cooling pumps

The VSD will vary the speed of the motor in a HVAC application with a diversified load.

In the applicable HVAC applications the power of the motor is approximately proportional to the cube of the speed, providing significant energy savings.

Measure Cost

Actual costs should be used, if known. For smaller motors (< 20 HP), default project costs are given in the following table (Ref. 2). VSDs installed on larger motors must use actual costs.

Table 2. Incremental Cost by Motor Horsepower (Ref. 2)

HP	Cost
1 - 5 HP	$ 1,330
7.5 HP	$ 1,622
10 HP	$ 1,898
15 HP	$ 2,518
20 HP	$ 3,059

Algorithms

$$\text{Annual kWh Savings} = \left(0.746 \times \text{HP} \times \frac{\text{LF}}{\text{Eff}}\right) \times \text{Hours} \times \text{ESF}$$

Where:

0.746	=	Conversion from HP to kW
HP	=	Rated Motor horsepower. Actual value.
LF	=	Motor load factor at the pump or fan design flow rate. Use actual value if known. If unknown, use default value of 65% (Ref. 3)
Eff	=	Efficiency of motor. Use actual value if known. If unknown, use default NEMA premium efficiency rating by size and type of motor found in Table 4 (Ref. 4)
Hours	=	Annual operating hours. Actual run hours must be used; justification for run hours assumption must be included in project documentation.
ESF	=	Energy Savings Factor. ESF is the sum product of DutyCycle and PLR_{BASE} across all flow rates, minus the sum product of DutyCycle and PLR_{EFF} across all flow rates. See Table 5 below for example ESF values.
	=	$\sum_{0\%}^{100\%} (\text{DutyCycle} \times PLR_{BASE}) - \sum_{0\%}^{100\%} (\text{DutyCycle} \times PLR_{EFF})$
DutyCycle	=	Percent of motor runtime at each flow rate. At generation facilities, it is expected that a duty cycle will be known with a reasonable degree of accuracy. Duty Cycle should be in the form of Table 2 below. See Table 3 for an example Duty Cycle.

Table 2. Duty Cycle Format

Flow Rate (Percent of design flow)	Duty Cycle (Percent of motor runtime at each flow rate)
0% to 10%	
10% to 20%	
20% to 30%	
30% to 40%	
40% to 50%	
50% to 60%	
60% to 70%	
70% to 80%	
80% to 90%	
90% to 100%	

PLR_{BASE} = Part Load Ratio for the baseline control strategy. The ratio of percent of peak power draw that occurs at each flow rate percentage. Consult Table 6 to find PLR_{BASE} values depending on the existing control strategy.

PLR_{EFF} = Part Load Ratio for the VSD. The ratio of percent of peak power draw that occurs at each flow rate percentage. Consult Table 6 to find PLR_{EFF} values. They should either be the Pump VSD or Fan VSD values.

Example:

A 100 HP boiler feedwater pump currently using a throttling valve is retrofitted with a VSD. The pump runs for 3,000 hours per year, the motor load factor is 90% and the motor efficiency is 95%. The motor duty cycle is found in Table 3 below.

ESF is calculated using example the duty cycle in Table 3, PLR_{BASE} (from Table 6 – pump throttling valve values), and PLR_{EFF} (from Table 6 – pump VSD values).

Table 3. Example ESF Calculation (Ref. 6)

Flow Rate (Percent of design flow)	Example Duty Cycle (Percent of motor runtime at each flow rate)	PLR_{BASE} (Throttling Valve)	PLR_{EFF} (VSD)
10% to 20%	6%	0.67	0.06
20% to 30%	11%	0.73	0.09
30% to 40%	13%	0.78	0.12
40% to 50%	17%	0.82	0.18
50% to 60%	24%	0.87	0.27
60% to 70%	17%	0.90	0.39
70% to 80%	9%	0.94	0.55
80% to 90%	2%	0.97	0.75
90% to 100%	1%	1.00	1.00

ESF = [(0.06 x 0.67) + (0.11 x .73) +(0.13 x 0.78) + (0.17 x 0.82) + (0.24 x 0.87) + (0.17 x 0.90) + (0.09 x 0.94) + (0.02 x 0.97) + (.01 x 1.0)] – [(0.06 x 0.06) + (0.11 x 0.09) + (0.13 x 0.12) + (0.17 x 0.18) + (0.24 x 0.27) + (0.17 x 0.39) + (0.09 x 0.55) + (0.02 x 0.75) + (0.01 x 1)] = 0.8371 – 0.2653 = 0.5718

Unit kWh Savings per Year = (0.746 x 100 x 0.90 / 0.95) x 3,000 x 0.5718 = 121,234 kWh

Deemed Input Tables

Table 4. Default NEMA Premium Motor Efficiencies (Ref. 4)

Size HP	Open Drip Proof (ODP)			Totally Enclosed Fan-Cooled (TEFC)		
	# of Poles			# of Poles		
	6	4	2	6	4	2
	Speed (RPM)			Speed (RPM)		
	1200	1800 Default	3600	1200	1800	3600
1	0.825	0.855	0.770	0.825	0.855	0.770
1.5	0.865	0.865	0.840	0.875	0.865	0.840
2	0.875	0.865	0.855	0.885	0.865	0.855
3	0.885	0.895	0.855	0.895	0.895	0.865
5	0.895	0.895	0.865	0.895	0.895	0.885
7.5	0.902	0.910	0.885	0.910	0.917	0.895
10	0.917	0.917	0.895	0.910	0.917	0.902
15	0.917	0.930	0.902	0.917	0.924	0.910
20	0.924	0.930	0.910	0.917	0.930	0.910
25	0.930	0.936	0.917	0.930	0.936	0.917
30	0.936	0.941	0.917	0.930	0.936	0.917
40	0.941	0.941	0.924	0.941	0.941	0.924
50	0.941	0.945	0.930	0.941	0.945	0.930
60	0.945	0.950	0.936	0.945	0.950	0.936
75	0.945	0.950	0.936	0.945	0.954	0.936
100	0.950	0.954	0.936	0.950	0.954	0.941
125	0.950	0.954	0.941	0.950	0.954	0.950
150	0.954	0.958	0.941	0.958	0.958	0.950
200	0.954	0.958	0.950	0.958	0.962	0.954
250	0.954	0.958	0.950	0.958	0.962	0.958
300	0.954	0.958	0.954	0.958	0.962	0.958
350	0.954	0.958	0.954	0.958	0.962	0.958
400	0.958	0.958	0.958	0.958	0.962	0.958
450	0.962	0.962	0.958	0.958	0.962	0.958
500	0.962	0.962	0.958	0.958	0.962	0.958

Table 5. Example Energy Savings Factors (using example Duty Cycle from Table 3)

Baseline Control Type	ESF
Pump – No Control	0.73
Pump - Bypass Valve	0.67
Pump - Throttling Valve	0.60
Fan - No Control or Bypass Damper	0.71
Fan - Discharge Dampers	0.50
Fan - Outlet Damper, Backward Inclined & Airfoil Fans	0.47
Fan - Inlet Damper Box	0.41
Fan - Inlet Guide Vane, Backward Inclined & Airfoil Fans	0.34
Fan - Inlet Vane Dampers	0.24
Fan - Outlet Damper, Forward Curved Fans	0.22
Eddy Current Drives	0.19
Inlet Guide Vane, Forward Curved Fans	0.10

Table 6. Part Load Ratio for Flow rate bins Based on Control Types for Pumps (Ref. 5) and Fans (Ref. 6)

Control Type	Flow rate (percentage of design flow)								
	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Pump Baseline values ($PLR_{Baseline}$)									
No Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bypass Valve	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Throttling Valve	0.67	0.73	0.77	0.82	0.87	0.90	0.94	0.97	1.00
Pump VSD value (PLR_{EFF})									
VSD – pump	0.06	0.09	0.12	0.18	0.27	0.39	0.55	0.75	1.0
Fan Baseline values ($PLR_{Baseline}$)									
No Control or Bypass Damper	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Discharge Dampers	0.55	0.63	0.7	0.77	0.83	0.88	0.93	0.97	1.00
Outlet Damper, Backward Inclined & Airfoil Fans	0.53	0.57	0.64	0.72	0.80	0.89	0.96	1.02	1.05
Inlet Damper Box	0.60	0.62	0.64	0.66	0.69	0.74	0.81	0.92	1.07
Inlet Guide Vane, Backward Inclined & Airfoil Fans	0.56	0.57	0.59	0.60	0.62	0.67	0.74	0.85	1.00
Inlet Vane Dampers	0.40	0.42	0.44	0.48	0.53	0.60	0.70	0.83	0.99
Outlet Damper, Forward Curved Fans	0.26	0.30	0.37	0.45	0.54	0.65	0.77	0.91	1.06
Eddy Current Drives	0.20	0.25	0.32	0.41	0.51	0.63	0.76	0.90	1.04
Inlet Guide Vane, Forward Curved Fans	0.22	0.23	0.26	0.31	0.39	0.49	0.63	0.81	1.04
Fan VSD value (PLR_{EFF})									
Fan - VSD	0.10	0.11	0.15	0.20	0.29	0.41	0.57	0.76	1.01

Notes

Speed or capacity control is required by the 2015 Minnesota energy code by size and application; for VAV fan units greater than or equal to 7.5 Hp without variable pitch fan blades, non-multi-stage hydronic pumping systems with a design output greater than 300,000 Btu/h, heat rejection fans greater than or equal to 7.5 HP.

It is generally accepted that VSDs provide this capacity control for these sizes, and should be considered the baseline for New Construction

Operation below 30% of design speed is not recommended.

References

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3. U.S. Department of Energy. *Improving Motor and Drive System Performance; A Sourcebook for Industry*. 2008. Page 18. https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_sourcebook_web.pdf
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6. Del Balso, Ryan Joseph. "Investigation into the Reliability of Energy Efficiency/Demand Side Management Savings Estimates for Variable Frequency Drives in Commercial Applications". A project report submitted to the Faculty of the Graduate School of the University of Colorado, 2013.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/1/2012
1.1	Minor revisions	Joe Plummer	2/12/2013
1.2	Added annual operating hours as an optional input from customer/contractor, clarified Required Inputs	Joe Plummer	1/6/2014
2.0	Updated energy code requirements for new construction	Franklin Energy Services	11/12/2015
3.0	Updated calculation approach and default values, requiring custom hours of use	Cadmus	11/2018

Commercial HVAC - Adjustment of Programmable Thermostats for Small Commercial Buildings

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Commercial customers in businesses noted in Table 1 with commercial unitary type air-conditioning equipment controlled by thermostats. Gas must be the primary heating source to use this measure and building automation systems must not be incorporated.
Actions	Modify
Required from Customer/Contractor	Confirmation of gas or electric heating, business type (see Table 2), location (county), heating size (Btu/h Input) or (kW Input), cooling size (tons), existing hours of setback, existing degrees of setback, proposed hours of setback, proposed degrees of setback
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	8 (Ref. 1)
Unit Participant Incremental Cost	$181 (Ref. 2)

Measure Description

This measure includes adjustment of new or existing programmable thermostat schedules in existing small commercial businesses where the current HVAC operating schedule does not align with the building occupancy. An estimate is provided for cooling and heating energy consumption through temperature set-back during unoccupied times. Savings make no other assumptions regarding adjustments during occupied periods or sequence of operations incorporated into the programmable thermostat. Among sequence savings not considered are optimal start, outside air damper control, or other potential energy savings measures associated with occupancy.

Algorithms

Unit kWh Savings per Year = ECc x CSP x ISR + HCel x HSP X ISR

Unit Dth Savings per Year = HCgas x HSP x ISR

Where:

ECc	=	Electrical consumption for cooling and ventilation, kWh
ECc	=	$EFLH_{Cool}$ x Size x (12/EffC_e)
$EFLH_{Cool}$	=	Equivalent Full Load Hours of cooling, See Table #1. (Ref. 3)
Size	=	Nominal cooling capacity in tons of the controlled equipment (1 ton = 12,000 btu/h), if unknown assume 5 tons (Ref.4)

EffC_e = SEER or IEER rating of controlled equipment, provided by customer. If unknown, assume 12.1 (Ref.5). Note SEER = EER / 0.875

CSP = SFC x ((Hours_Ca x Degrees_Ca) - (Hours_Ce x Degrees_Ce)), Cooling Savings Percentage, %

SFC = Savings Factor for cooling consumption, % per Degree-Hour, See Table 2 (Ref. 6)

Hours_Ce = Existing hours per week of cooling setback, Hours, provided by customer

Hours_Ca = New hours per week of cooling setback, Hours, provided by customer

Degrees_Ce= SP_Ceo – SP_Ceu, existing cooling setback degrees (°F)

SP_Ceo = Existing occupied temperature cooling set point, °F, provided by customer

SP_Ceu = Existing unoccupied temperature cooling set point, °F, provided by customer

Degrees_Ca= SP_Cao – SP_Cau, adjusted cooling setback degrees, °F

SP_Cao = New occupied temperature set point, °F, provided by customer

SP_Cau = New unoccupied temperature set point, °F, provided by custom

ISR = In-Service Rate, the percentage of units installed and programmed effectively, Table 3. (Ref. 7)

HCel = Heating consumption for electrically heated businesses, kWh

HCel = $EFLH_{Heat}$ x kW_H x Load_Factor_H

$EFLH_{Heat}$ = Equivalent Full Load Hours heating, See Table 1. (Ref. 8)

kW_H = Nominal Heating capacity in kW of the equipment. Capacity, kW, provided by customer/contractor or use = 23.9 kWh if unknown. (Ref. 9)

Load_Factor_H = the heating load factor, assumed to be 0.5 (implies 50% oversizing) (Ref. 10)

HSP = SFH x ((Hours_Ha x Degrees_Ha) - (Hours_He x Degrees_He)), Heating Savings Percentage, %

SFH = Savings Factor for heating consumption, % per Degree-Hour, See Table 2 (Ref. 6)

Hours_He = Existing hours per week of heating setback, Hours, provided by customer

Hours_Ha = New hours per week of heating setback, Hours, provided by customer

Degrees_He = Existing setback degrees, °F

Degees_He = SP_Heo – SP_Heu

SP_Heo = Existing occupied temperature set point, °F, provided by customer

SP_Heu = Existing unoccupied temperature set point, °F, provided by customer

Degrees_Ha = Adjusted setback degrees, °F

Degees_Ha = SP_Hao – SP_Hau

SP_Hao = Adjusted occupied temperature set point, °F, provided by customer

SP_Hau = Adjusted unoccupied temperature set point, °F, provided by customer

ECgas = Heating consumption for gas heated businesses, Dth

HCgas = $EFLH_{Heat}$ x BTUH_IN x Load_Factor_H /Conversion_Factor

Btuh_In = Nominal Heating capacity in btu/h of the equipment. Capacity, btu/h, provided by customer/contractor or use = 100,000 if unknown. (Ref. 11)

Conversion_Factor = 1,000,000 Btu/Dth

Examples:

Adjust the schedule for a programmable thermostat in a gas heated strip mall retail store Climate Zone 1, via a direct installation program delivery.

Current Occupied Set Points: 70 Cooling /68 Heating

Current Unoccupied Set Points: 75 Cooling /65 Heating

Current Hours of Setback per week: 75

Proposed Occupied Set Points: 70 Cooling /68 Heating

Proposed Unoccupied Set Points: 80 Cooling /58 Heating

Proposed Hours of Setback per week: 80

ECc = 307 x 5 x 12 / 12.1 = 1,522 kWh

CSP = 0.0040% x (80 x (80 -70) – 75 x (75 – 70)) = 1.5 %

HCel = 0

Unit kWh Savings per Year = 1,522 kWh x 1.5% x 1.0 + 0 = 22.83 kWh

HCgas = 1,701 x 100,000 x 0.5 / 1,000,000 = 85.05 Dth

HSP = 0.0139% x (80 x (68 – 58) – (75 x (68 – 65)) = 8%

Unit Dth Savings per Year = 85.05 x 8% x 1.0 = 6.8 Dth

Deemed Input Tables

Table 1. Equivalent Full Load Hours of cooling ($EFLH_{Cool}$) per zone in Minnesota by building type (Ref. 3)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	647	825	986
Office - Low Rise	257	359	446
Restaurant	347	535	652
Retail - Large Department Store	462	588	686
Retail - Strip Mall	307	441	574
Other/Miscellaneous	443	612	729

Table 2. Cooling and Heating Savings Factor per degree of setback per hour unoccupied per zone in Minnesota by building type (Ref. 6)

Building Type	SFC	SFH
Convenience Store	0.0054%	0.0072%
Office - Low Rise	0.0050%	0.0164%
Restaurant	0.0059%	0.0072%
Retail - Large Department Store	0.0040%	0.0072%
Retail - Strip Mall	0.0040%	0.0139%
Other/Miscellaneous	0.0040%	0.0072%

Table 3. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 8)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1,887	1,699	1,546
Office - Low Rise	1,966	1,770	1,610
Restaurant	1,868	1,681	1,530
Retail - Large Department Store	1,763	1,587	1,444
Retail - Strip Mall	1,701	1,531	1,393
Other/Miscellaneous	2,123	1,911	1,739

Table 4. In-Service Rates (Ref. 7)

Program Delivery	ISR
Direct Install	1.0
Other, or unknown	0.56

Methodology and Assumptions

EFLH_Cool data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

$EFLH_{Heat}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 5. Heating Degree Days and Design Temperature Difference

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

Demand savings are assumed to be minimal, as it is assumed that demand savings for HVAC measures are defined as summer peak hour savings.

Savings are calculated based upon a constant speed baseline operation.

References

1. Table 1, HVAC Controls, Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, 2007.
2. Nicor Rider 30 Business EER Program Database, Paid Rebates with Programmable Thermostat Installation Costs, Program to Date as of January 11, 2013.
3. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012.
4. Utilizing nominal square footage noted in DTE and CE C&I Programmable Thermostat Savings Analysis: Preliminary Findings, Navigant Energy, June 17, 2014 and assumption of 400 square feet per ton of cooling capacity results in 5-ton cooling unit.
5. Commercial and Industrial Programmable Thermostats, Navigant Energy, June 16, 2015, pg. 33.
6. Utilizing the savings results from the Table 4-1 MEMD Calibration Research – Commercial and Industrial Programmable Thermostats, Navigant Energy, June 16, 2015 and dividing these results from the nominal weighted setbacks recorded in Appendix E of the Commercial Rooftop Units in Minnesota Characteristics and Performance, Final Report, Minnesota Department of Commerce Department of Energy Resources, March 2017 and the prototype DEER modeling unoccupied hours for each building type.
7. "Programmable Thermostats. Report to KeySpan Energy Delivery on Energy and Cost Effectiveness," GDS Associates, Marietta, GA. 2002.
8. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on

California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.

9. Utilizing nominal square footage noted in DTE and CE C&I Programmable Thermostat Savings Analysis: Preliminary Findings, Navigant Energy, June 17, 2014 and assumption of 400 square feet per ton of cooling capacity results in 5-ton cooling unit. This result was then utilized to determine the heating input for rooftop units in this size from the three largest manufacturers. This value was then converted to KW assuming electrical resistance heating and 100 percent efficiency.
10. Commercial Rooftop Units in Minnesota Characteristics and Performance, Final Report, Minnesota Department of Commerce Department of Energy Resources, March 2017, Pg. 85.
11. Utilizing nominal square footage noted in DTE and CE C&I Programmable Thermostat Savings Analysis: Preliminary Findings, Navigant Energy, June 17, 2014 and assumption of 400 square feet per ton of cooling capacity results in 5-ton cooling unit. This result was then utilized to determine the heating input for rooftop units in this size from the three largest manufacturers.

Revision History

Version	Description	Author	Date
1.0	New Measure	Franklin Energy Services	09/01/2017

Commercial HVAC - Boiler Modifications, Space Heating Only

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC, Industrial Process
Applicable To	Commercial and industrial customers with HVAC boilers
Actions	Operations & Maintenance, Modify
Required from Customer/Contractor	Modification type, nominal pre-modification Btu/h input, project location (county), facility type
Version No.	4.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	See Table 2
Unit Participant Incremental Cost	Unit Participant Incremental Cost: Use actual cost of modification. Table 2 figures may be used for planning estimates

Measure Description

This measure describes retrofit opportunities to increase boiler efficiency. This includes cut-out controls, modulating burners, reset controls, oxygen controls, stack dampers, boiler tune-ups, and turbulators. Applies only to natural gas boilers in space heating applications.

To qualify for the boiler tune-up modification measure the facility must, as applicable, complete the tune-up requirements[3] listed below, by approved technician:

- Measure combustion efficiency using an electronic flue gas analyzer
- Adjust airflow and reduce excessive stack temperatures
- Adjust burner and gas input, manual or motorized draft control
- Check for proper venting
- Complete visual inspection of system piping and insulation
- Check safety controls
- Check adequacy of combustion air intake
- Clean fireside surfaces.
- Inspect all refractory. Patch and wash coat as required.
- Inspect gaskets on front and rear doors and replace as necessary.
- Seal and close front and rear doors properly.
- Clean low and auxiliary low water cut-off controls, then re-install using new gaskets.

[3] Act on Energy Commercial Technical Reference Manual No. 2010-4, 9.2.2 Gas Boiler Tune-up

- Clean plugs in control piping.
- Remove all hand hole and man hole plates. Flush boiler with water to remove loose scale and sediment.
- Replace all hand hole and man hole plates with new gaskets.
- Open feedwater tank manway, inspect and clean as required. Replace manway plate with new gasket.
- Clean burner and burner pilot.
- Check pilot electrode and adjust or replace.
- Clean air damper and blower assembly.
- Clean motor starter contacts and check operation.
- Make necessary adjustments to burner for proper combustion.
- Perform all flame safeguard and safety trip checks.
- Check all hand hole plates and man hole plates for leaks at normal operating temperatures and pressures.
- Troubleshoot any boiler system problems as requested by on-site personnel

Algorithms

Unit Dth Savings per Year = (Percent Savings) x (Pre-Annual Consumption)

Where:

Pre-Annual Consumption (Dth/yr) = BTUH_In x Load_Factor x $EFLH_{Heat}$ / ConversionFactor

BTUH_In = the nominal rating of the input capacity of the boiler in Btu/h

Load_Factor = boiler load factor, assumed to be 77% (Ref. 1)

$EFLH_{Heat}$ = the heating equivalent full load hours. See Table 1.

ConversionFactor = 1,000,000 Btu/Dth

Percent Savings = percent of the pre-modification annual consumption saved. See Table 2.

Example:

For a 1000 kBtuh boiler tune-up in Zone 2 in a Mid-Rise Office:

Pre-Annual Consumption (Dth/yr) = 0.77 x 1,000,000 x 1971 / 1,000,000 = 1517.7 Dth

Gas Energy Heating Savings (Dth/yr) = 0.022 x 1517.7 = 33.39 Dth

Deemed Input Tables

Table 1. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 12)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Table 2. Modification Savings and Incremental Costs

Modification Type	Percent Savings	Approximate Cost	Measure Life
Cut-out Control	1.7% (Ref. 2)	$141 per boiler (Ref. 2)	5 years (Ref. 7)
Fully Modulating Burner	3% (Ref. 3)	$2.53 per kBtu/h input (Ref. 4)	15 years (Ref. 4)
Outdoor Reset Control	3.8% (Ref. 2)	$600 per boiler (Ref. 2)	5 years (Ref. 7)
Oxygen Control	2% (Ref. 5)	$27,000 per boiler (Ref. 6)	5 years (Ref. 7)
Stack Damper	5% (Ref. 5)	$3.125 per nominal pre-modification kBtu/h input (Ref. 2)	5 years (Ref. 7)
Tune-up	2.2% (Ref. 8)	$0.83/kBtu/h input (Ref. 9)	2 years (Ref. 10)
Turbulators	3% (Ref. 11)	$1,375 per boiler (Ref. 2)	20 years (Ref. 2)

Notes

There are currently no existing Minnesota state-wide or federal efficiency standards for aftermarket boiler retrofit measures.

$EFLH_{Heat}$ were determined from prototypes building models based on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as

follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 3. Heating Degree Days and Design Temperature Difference

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

References

1. PA Consulting, KEMA, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that boilers are 30% oversized on average.
2. CenterPoint Energy, Triennial CIP/DSM Plan 2010-2012, June 1, 2009
3. Xcel Energy, 2010/2011/2012 Triennial Plan, Minnesota Electric and Natural Gas Conservation Improvement Program, E,G002/CIP-09-198
4. Franklin Energy Services review of PY2/PY3 costs for custom People's and Northshore high turndown burner projects, used in Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 3.0, February 14, 2014.
5. United States EPA, Climate Wise: Wise Rules for Industrial Efficiency, July 1998
6. California Utilities Statewide Codes and Standards Team, CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE): PROCESS BOILERS, October 2011
7. Focus on Energy Evaluation, Business Programs: Measure Life Study, August 25, 2009..
8. FES determined by collection of results from approximately 25 projects completed through a Midwest energy project.
9. Illinois Statewide Technical Reference Manual, Sections 6.4.3 and 6.4.4, July 18, 2012. This source used data from a work paper provided by Resource Solutions Group that is not available publicly.
10. How to Select, Prioritize, & Justify Economically Viable Energy Projects, Eileen Westervelt, U of I Business Innovation Services, 10-30-2012
11. United States DOE, Industrial Technologies Program, Steam Fact Sheet #25, January 2012
12. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.

Revision History

Version	Description	Author	Date
3.6	Changed to EFLH heating and revised boiler tune-up efficiency	FES	11/12/2015

Commercial HVAC - Boilers, Space Heating Only

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Commercial customers with HVAC boilers
Actions	New Construction, Replace on Fail, Replace Working
Required from Customer/Contractor	New boiler input Btu/h, new boiler efficiency at actual operating conditions, new boiler type (steam, steam except natural draft, hot water), existing boiler type (steam, steam except natural draft, hot water), project location (county), facility type
Version No.	5.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 1)
Unit Participant Incremental Cost	See Table 2

Measure Description

This measure includes replacement of failed or working HVAC boilers in existing commercial buildings with high efficiency steam or hot water boilers, as well as installation of high efficiency steam or hot water boilers in new commercial buildings.

Algorithms

Unit Dth Savings per Year = BTUH_In x Load_Factor x $EFLH_{Heat}$ x Eff_High x (1/Eff_Base - 1/Eff_High) / ConversionFactor

Where:

BTUH_In = the nominal rating of the input capacity of the boiler in Btu/h

Load_Factor = boiler load factor, assumed to be 77% (Ref. 2)

$EFLH_{Heat}$ = the heating equivalent full load hours. See Table 1.

Eff_Base = Efficiency of the baseline boiler. See Table 2.

Eff_High = Efficiency of the new high efficiency boiler.

ConversionFactor = 1,000,000 Btu/Dth

Example:

A 1,000 kBtuh hot water boiler is replaced with a 1,000 kBtuh 88% efficient hot water boiler in Zone 2 in Mid-Rise Office:

Unit Dth Saving Per Year = 1,000,000 x 0.77 x 1971 x 0.88 x (1/0.80 – 1/0.88) / 1,000,000 = 151.8 Dth/yr

Deemed Input Tables

Table 1. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 3)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Table 2. Incremental Costs and Baseline Efficiency (Ref. 4, 5, 6, 7, 8, 9)

High Efficiency Replacement Boiler Type	High Efficiency Boiler Efficiency Range*	Baseline Efficiency*	Incremental Cost ($ / kBtuh)
Steam, < 300 kBtu/h	82+% AFUE	80% AFUE	$3.30
Steam except natural draft, 300-2500 kBtu/h	83-85% TE	79% TE	$1.44
Steam, natural draft, 300-2500 kBtu/h	83-85% TE	77% TE	$1.44
Steam except natural draft, > 2500 kBtu/h	83-85% CE	79% TE	$1.02
Steam, natural draft, > 2500 kBtu/h	83-85% CE	77% TE	$1.02
Mid-Efficiency Hot Water, < 300 kBtu/h	84.5-88%AFUE	82% AFUE	$5.88
Mid-Efficiency Hot Water, 300-2500 kBtu/h	85-88% TE	80% TE	$4.97
Mid-Efficiency Hot Water, > 2500 kBtu/h	85-88% CE	82% CE	$2.50
High Efficiency Hot Water, < 300 kBtu/h	≥ 88% AFUE	82% AFUE	$9.14
High Efficiency Hot Water, 300-2500 kBtu/h	≥ 88% TE	80% TE	$9.12
High Efficiency Hot Water, > 2500 kBtu/h	≥ 88% CE	82% CE	$7.25

* AFUE = Annual Fuel Utilization Efficiency, CE = Combustion Efficiency, TE = Thermal Efficiency

Notes

Incremental material cost should be confirmed with manufacturer and project data.

$EFLH_{Heat}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 3. Heating Degree Days and Design Temperature Differences

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

There are currently federal efficiency standards in place for HVAC boiler systems. They are as follows:

Table 4. Federal Efficiency Standards for Products Manufactured On or After March 2, 2012 (Ref. 6)

Boiler Type	Size (Btu/hr)	Efficiency Requirement
Gas-fired, hot water	≥300,000 and ≤2,500,000	80% thermal efficiency
Gas-fired, hot water	>2,500,000	82% combustion efficiency
Oil-fired, hot water	≥300,000 and ≤2,500,000	82% thermal efficiency
Oil-fired, hot water	>2,500,000	84% combustion efficiency
Gas-fired except natural draft, steam	≥300,000 and ≤2,500,000	79% thermal efficiency
Gas-fired except natural draft, steam	>2,500,000	79% thermal efficiency
Gas-fired-natural draft, steam	≥300,000 and ≤2,500,000	77% thermal efficiency
Gas-fired-natural draft, steam	>2,500,000	77% thermal efficiency
Oil-fired, steam	≥300,000 and ≤2,500,000	81% thermal efficiency
Oil-fired, steam	>2,500,000	81% thermal efficiency

Table 5. Federal Efficiency Standards for Products Manufactured On or After March 2, 2022 (Ref. 6)

Boiler Type	Size (Btu/hr)	Efficiency Requirement
Gas-fired natural draft, steam	≥300,000 and ≤2,500,000	79% thermal efficiency
Gas-fired natural draft, steam	>2,500,000	79% thermal efficiency

References

1. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values, October 10, 2008
2. Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that boilers are 30% oversized on average.

3. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
4. 2008 Database for Energy-Efficient Resources, Revised DEER Measure Cost Summary, June 2, 2008. All incremental cost values assume replacement on failure.
5. Xcel Energy, 2010/2011/2012 Triennial Plan, Minnesota Electric and Natural Gas Conservation Improvement Program, June 1, 2009
6. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment, Subpart E - Commercial Packaged Boilers. https://www.ecfr.gov/cgi-bin/text-idx?SID=06bb5275babde5c3b0d48497ae00764f&mc=true&node=pt10.3.431&rgn=div5#sp10.3.431.e
7. Franklin Energy Services review of boiler manufacturer data and past projects - December, 2012.
8. ASHRAE Standard 90.1-2004 as adopted by MN Commercial Energy Code (MN Rules Ch. 1323)
9. Title 10, Code of Federal Regulations, Part 430 – Energy Conservation Program For Consumer Products, Subpart C - Energy and Water Conservation Standards. https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=06bb5275babde5c3b0d48497ae00764f&mc=true&n=sp10.3.430.c&r=SUBPART&ty=HTML

Revision History

Version	Description	Author	Date
4.0	Changed from Heating Degree Days to $EFLH_{Heat.}$ Updated Table 1 to include building types	Franklin Energy Services	11/12/2015
5.0	Updated baseline efficiencies to follow code, updated costs	Cadmus	10/2018

Commercial HVAC - Condensing Unit Heaters

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Commercial customers
Actions	New Construction, Replace on Fail, Replace Working
Required from Customer/Contractor	Input capacity of the new condensing unit heater, project location, thermal efficiency
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$676 (Ref. 2)

Measure Description

This measure applies to a gas fired condensing unit heater installed in a commercial application.

Algorithms

Unit Dth Savings per Year = BTUH_in x Load_Factor x $EFLH_{Heat}$ x Eff_High x (1/Eff_Base – 1/Eff_High) / Conversion_Factor

Where:

Btuh Input = Nominal rating of the input capacity of the new condensing unit heater in Btu/h

Load_Factor = Load factor, assumed to be 0.77 (Ref. 3)

$EFLH_{Heat}$ = the equivalent full load hours, see Table 1

Eff Base = Efficiency of the baseline, standard is 80% (Ref. 5)

Eff High = Thermal efficiency of the new condensing unit heater, supplied by customer/contractor, if unsure use 90% (Ref. 6)

Conversion_Factor = 1,000,000 Btuh/Dth

Example:

Replacing an 80% efficient 280,000 Btuh unit heater in an average Minneapolis building with a 280,000 Btuh condensing unit heater.

Unit Dth Savings per Year = 280,000 Btuh x .77 x 1739 EFLH x 80% x (1/80% - 1/90%) / 1,000,000 Btuh/Dth = 41.7 Dth

Deemed Input Tables

Table 1. Equivalent Full Load Hours of Heating per zone in Minnesota by building type (Ref. 4)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

$EFLH_{Heat}$ were determined from prototypes building models based on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone 3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 2. Heating Degree Days and Design Temperature Difference

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

References

1. Database for Energy Efficient Resources (DEER) 2008
2. ENERGY STAR and CEE do not currently provide calculators for this type of equipment therefore deemed values from Nicor Gas were used. Nicor Gas Energy Efficiency Plan 2011-2014. Revised Plan Filed Pursuant to Order Docket 10-0562, May 27, 2011

3. Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that heating systems are 30% oversized on average.
4. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on the California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
5. ASHRAE 90.1 2007, Heating, Ventilating, and Air Conditioning, Table 6.8.1E
6. Illinois Statewide Technical Reference Manual for Energy Efficiency (Effective 6-1-15) Measure 4.4.5 Condensing Unit Heaters
7. National Climate Data Center - National Oceanic and Atmospheric Administration 1981-2010 Normals. Weather data for Duluth and International Falls was averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3.
8. 2013 ASHRAE Handbook - Fundamentals, Table 1A Climate Design Information, Minnesota Heating DB 99.6%.

Revision History

Version	Description	Author	Date
1.0	Created standalone Specifications for Condensing Unit Heaters	Franklin Energy Services	11/10/2015

Commercial HVAC - Demand Control Ventilation

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers where air unitary equipment has been/could be installed
Actions	Replace Working (addition on working equipment)
Required from Customer/Contractor	Existing equipment type, existing equipment nominal cooling capacity in tons, existing equipment EER/SEER, building type (refer to Table 1), project location (county)
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	See Table 2 (Ref. 2)

Measure Description

This measure includes the retro-fit of existing constant volume equipment or the optional addition of demand control ventilation. This measure analyzes the heating and cooling savings potential of the installation of demand control ventilation on unitary equipment. This measure is applicable to DX and water cooled air systems with natural gas heating.

The incremental cost is associated with CO2 sensor equipment cost and programming, the incremental cost does not include any damper actuator installation costs.

Algorithms

Unit kWh Savings per Year = (4.5 x CFM_pre x Δh) x ($EFLH_{Cool}$ x 1 / SEER) x SF_C /1000

Unit Dth Savings per Year = [(1.08 x CFM_pre)/η x HDD65 x Hours] / 1,000,000 x SF_H

Where:

CFM_pre = Constant outside air flow in cubic feet per minute, for systems with supply and exhaust fans the supply fan flow shall be used, Provided by customer/contractor.

Δh = Difference in enthalpy (Btu/lbm) between the design day outside air conditions (Ref. 3) and the return air conditions (Ref.4) See Table 1.

$EFLH_{Cool}$ = Equivalent full load cooling hours based on the building type. See Table 2. (Ref. 5)

EER	=	Energy efficiency ratio of the existing equipment, provided by the customer. If unknown, use SEER = EER/0.875 (Ref. 6) Assume EER = 10.9 in unavailable. (Ref. 7)
Hours	=	Average hours per day of operation. Provided by customer.
HDD65	=	Heating Degree Days See Table 1. (Ref. 8)
SF_C	=	Deemed cooling savings factor based upon building type. See Table 2. (Ref. 9)
SF_H	=	Deemed Heating savings factor based upon building type. See Table 2. (Ref. 9)
η	=	Efficiency of heating equipment. Assume 0.8 (Ref. 12) unless different efficiency is provided by owner.
1.08	=	Conversion factor for flow rate and specific volume of air
4.5	=	Conversion factor for BTU, flow rate and specific volume
1,000,000	=	Conversion factor for BTU to Dth

Example:

Install a CO2 senor in the return duct for a 10.5 EER packaged rooftop installed on a low rise office building open on average 12 hours per day in Climate Zone 3. OA supply existing is 1500 cfm.

Unit KWh Savings per Year = (4.5 x 1500 x (36.55 – 29.07)) x (446 x 1 / (10.5/.875)) x 0.15 / 1000= 368 KWh

Unit Dth Savings per Year = ((1.08 x 1500) / 0.8 x 7651 x 12) / 1,000,000 x 0.28= 52 Dth

Deemed Input Tables

Table 1. Enthalpies, heating degree days and incremental costs

Zone	Design Cooling h (Btu/lbm) (Ref. 3)	Cooling Return h (Btu/lbm) (Ref. 4)	HDD65 (°F-days) (Ref. 8)	Incremental Cost ($/CFM) (Ref. 2)
Northern: #1	32.40	28.36	9,833	1.32
Central: #2	35.55	28.36	8,512	1.32
Southern: #3	36.55	28.36	7,651	1.32

Table 2. Cooling and Heating Savings Factors and Equivalent Full Load Hours of cooling per zone (Ref. 5) in Minnesota by building type

Building Type	SF_C (Ref. 9)	SF_H (Ref. 9, Ref. 13)	EFLH		
			Zone 1	Zone 2	Zone 3
Convenience Store	0.34	0.63	647	825	986
Education - Community College/University	0.34	0.63	682	782	785
Education - Primary	0.34	0.63	289	338	408
Education - Secondary	0.34	0.63	484	473	563

Building Type	SF_C (Ref. 9)	SF_H (Ref. 9, Ref. 13)	EFLH		
			Zone 1	Zone 2	Zone 3
Health/Medical - Clinic	0.29	0.34	558	738	865
Health/Medical - Hospital	0.34	0.40	663	1,089	1,298
Lodging	0.15	0.18*	401	606	754
Manufacturing	0.29	0.53	347	472	589
Office-Low Rise	0.15	0.28	257	359	446
Office-Mid Rise	0.15	0.28	373	529	651
Office-High Rise	0.15	0.28	669	1,061	1,263
Restaurant	0.34	0.62	347	535	652
Retail - Large Department Store	0.34	0.62	462	588	686
Retail - Strip Mall	0.34	0.62	307	441	574
Warehouse	0.31	0.36	164	343	409
Other/Miscellaneous	0.30	0.51	443	612	729

* Value is applicable to Common Areas and Conference Rooms and not to sleeping areas

Methodology and Assumptions

$EFLH_{Cool}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Assumed ventilation rates complied with the requirements of ASHRAE standard 62.1 - 2004. Incremental costs include controls and programming and assume similar cost between dx and water cooled equipment.

Savings assume constant volume air system.

Assumes existing economizer operation and economizer operation is given preference over demand control ventilation strategy.

Assumes savings in hospitals and clinics is limited to those areas not having code required ACH of fresh air.

Gas savings algorithm is derived from the following:

Energy = Design Heating Load / η x $EFLH_{HEAT}$ x conversion

Where:

Design Heating Load = (1.08 x CFM x ΔT),

$EFLH_{HEAT}$ = HDD65 x 24 / ΔT x Hours/24

ΔT = Difference in temperature (°F) between the return air conditions (Ref. 5) and the design day outside air conditions

Unit Dth Savings per Year = [(1.08 x CFM x ΔT)/η x (HDD65 x Hours /ΔT)] / 1,000,000 x SF_H

Unit Dth Savings per Year = [(1.08 x CFM_pre)/η x HDD65 x Hours] / 1,000,000 x SF_H

Notes

The 2015 Minnesota Energy Code generally requires Demand Controlled Ventilation be provided for spaces larger than 500 square feet (50 m2) and with an average occupant load of 25 people per 1000 square feet (93 m2) of floor area. Please reference Section C403.2.5.1 Demand controlled ventilation of the 2015 Minnesota Energy Code for specific requirements.

References

1. Assumed Service life limited by controls and control life referenced from "Demand Control Ventilation Using CO2 Sensors", pg. 19, by US Department of Energy Efficiency and Renewable Energy
2. "Demand Control Ventilation Using CO2 Sensors", pg. 2, by US Department of Energy Efficiency and Renewable Energy and with an assumed zone size of 1500 Outside Air CFM
3. Psychometric Calculator, by KW Engineering and from ASHRAE 2009. Cooling DB/MCWB @ 1.0% for each TRM weather zone.
4. Assumed cooling set point of 74°F and 50% relative humidity with a 2°F temperature rise in the return plenum, FES
5. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012
6. "ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment"
7. "Small Commercial HVAC, Surveying the Frontier of Energy Efficiency", by Lee DeBallie, PE – Energy Center of Wisconsin
8. National Climate Data Center - National Oceanic and Atmospheric Administration 1981-2010 Normals. Weather data for Duluth and International Falls was averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3.
9. Calculated through energy modeling by FES with certain building type SF modified based upon economizer operation hours. Savings where limited to 40% based upon professional experience due to concerns for negative building pressurization and minimum outside air requirements per sq. ft of occupied facility. Higher values may be obtained, but custom calculations would be required.
10. Assumed heating set point of 70°F, FES
11. 2009 ASHRAE Handbook HVAC Fundamentals

12. Assumed standard combustion efficiency of heating equipment, FES
13. Seventhwave. Energy Savings from Implementing and Commissioning Demand Control Ventilation. July 2015. http://mn.gov/commerce-stat/pdfs/card-report-energy-savings-demand-control-ventilation.pdf
    Indicates heating savings factors should be increased by 56%.

Revision History

Version	Description	Author	Date
2.0	Added 2015 Minnesota Energy Code Information. Updated EFLHCool format and description and added other category.	Franklin Energy Services	11.12.15
3.0	Updated equation, updated heating savings factors based on CARD study,	Cadmus	11/2018

Commercial HVAC - Energy Recovery Ventilator

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers where energy recovery equipment could be installed
Actions	Replace on Fail, Replace Working, Modify
Required from Customer/Contractor	ERV type, outside air cfm, building hours of operation, project location (county), cooling system type
Version No.	3.1
Unit kWh Savings per Year	0 (Ref. 11)
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	See Table 4 (Ref. 2)

Measure Description

This measure includes the optional addition of energy recovery on existing air side equipment. This measure analyzes the heating savings potential of an energy recovery ventilator on air side equipment. This measure is applicable to all gas-fired heated air systems.

Algorithms

Unit Peak kW Savings = ((4.5 x CFM x Δh_cooling) x (1 / EER x ERV_E)/1000 – (CFM x PD / 6356 / Eff_Motor / Eff_Fan x 0.746) x CF

Unit Dth Savings per Year = ((4.5 x CFM x Δh_heating) / η x ((HDD65 x 24) / (T_indoor – T_design)) x (Hours / 24)) / 1,000,000 x ERV_E x 0.75

Where:

CF	=	Coincidence Factor = 0.9 (Ref. 8)
CFM	=	Outside Air Flow in cubic feet per minute
EER	=	Provided by customer. If SEER provided, SEER x 0.875 (Ref. 10). If value not provided use default values in Table 4. (Ref. 9).
Eff_Fan	=	Efficiency of Fan. Provided by customer. If value not provided assume 0.705 (Ref. 13)
Eff_Motor	=	Efficiency of Motor. Provided by customer. If value not provided assume 0.855 (Ref. 14)
ERV_E	=	Total Energy Effectiveness of ERV. Provided by manufacturer/customer *If values are not provided use default values in Table 4. (Ref. 7)

Hours	=	Hours of operation, per day. Provided by customer. If none provided, assume 12. (Ref. 15)
HDD65	=	Heating Degree Days See Table 1. (Ref. 3)
PD	=	Additional Pressure Drop through heat exchanger, inches of Water Column per CFM. Provided by customer. If value is not provided see values in Table 4. (Ref. 7)
T_indoor	=	Customer provided indoor heating conditioned space temperature in °F. See Table 1 for default values if not provided.
T_design	=	the equipment design heating temperature of the climate zone. See Table 1. (Ref. 4)
η	=	Efficiency of heating equipment. Assume 0.8 (Ref. 6) unless different efficiency is provided by customer.
Δh_cooling	=	Difference in enthalpies (btu/lb) between the design day cooling enthalpy and exhaust air heat exchanger inlet enthalpy. See Table 2 for default values if not provided.
Δh_heating	=	Difference in enthalpies (btu/lb) between the exhaust air heat exchanger inlet enthalpy and design day heating enthalpy. See Table 1 for default values if not provided.
4.5	=	Conversion factor for flow rate and specific volume of air at standard room conditions and minutes to hours (0.075 lb/cubic foot at 1 atm and 68 degrees F x 60 min/hr = 4.5)
6,346	=	Conversion factor for ft-lb/min to horsepower, and psi to inches of water (33,013 ft-lb/min divided by 5.202 inches of water per pound/square foot = 6,346)
1,000	=	Conversion factor of watts per kWh
1,000,000	=	Conversion factor for BTU to Dth
0.75	=	factor to account for prevention of freezing of condensate. Control strategies incorporate full air flow by-pass or other strategies that reduce the number of hours of operation at lower temperatures, multiply ERE_E by 0.75 if not adjusted by manufacturer or customer. (Ref. 15)

*If heat recovery control strategy uses full air flow by-pass for operation at temperatures causing freezing of condensate, multiply ERE_E by 0.75 if not adjusted by manufacturer or customer.

Example:

Install a heat recovery wheel on a low-rise office building in Climate Zone 3. The outside air existing supply rate is 1500 cfm, and the building is open on average 12 hours per day. The cooling system utilizes an Air-Cooled Chiller.

Unit peak kW Savings = (((4.5 x 1500 x (36.55– 28.36)) x1 / 15 x 0.647)/1000 - (1,500 x 0.00012 / 6356 / 0.705 / 0.855 x 0.746)) x 0.9 = 2.15 kW

Unit Dth Savings per Year = ((4.5 x 1500 x (25.34 – (-3.29)) / 0.8) x (7,651 x 24) / (70.0 – (-14.5)) x 12 / 24) / 1,000,000 x 0.647 x 0.75 = 127.4 Dth

Deemed Input Tables

Table 1. Heating design temperatures, heating enthalpies and heating degree days base 65

Zone #	Design Day Heating Outside Air Conditions		Return Air Conditions Heating		HDD65 (Ref. 9)
	Heating (°F) (Ref. 4)	Enthalpy (Btu/lb) (Ref. 12)	Temp.(°F) (Ref. 5)	Enthalpy (Btu/lb) (Ref. 12)	
Northern: #1	-22.0	-5.16	70.0	25.34	9,833
Central: #2	-16.5	-3.79	70.0	25.34	8,512
Southern/ Twin Cities: #3	-14.5	-3.29	70.0	25.34	7,651

Table 2. Cooling design temperatures and enthalpies

Zone #	Design Day Cooling Outside Air Properties	Return Air Conditions Cooling	
	Enthalpy (Btu/lb) (Ref. 12)	Temp.(°F) (Ref. 5)	Enthalpy (Btu/lb) (Ref. 12)
Northern: #1	32.40	76.0*	28.36
Central: #2	35.55	76.0*	28.36
Southern/ Twin Cities: #3	36.55	76.0*	28.36

* Assuming 74F air at 50% RH with an additional 2F duct temperature rise

Table 3. EER values for various equipment (ref.9)

Equipment Type	EER
Air Cooled Air Conditioner	8.4
Air/Water Cooled Chiller	15.0
Air Cooled Heat Pumps	8.6

Table 4. Energy Recovery Effectiveness Factor, Pressure Drop and Incremental Cost

Energy Recover Type	Total Heating Effectiveness	Pressure Drop /CFM Inches WC/CFM	Incremental Cost** /CFM
	(Ref.7)	(Ref. 7)	(Ref. 2)
Fixed Plate – (Sensible Heat Only)	0.355	0.00035	$6
Fixed Plate – (Sensible and Latent Heat)	0.577	0.00074	$6
Fixed Plate - Unknown	0.466	0.00055	$6
Rotary Wheel	0.647	0.00012	$6
Heat Pipe	0.31	0.00011	$6

*** Cost includes cabinet and controls incorporated into packaged and built up air handler units.*

Methodology and Assumptions

Default efficiencies assume 1-to-1 ratio of fresh vs. exhaust/relief air. Savings do not include any savings from reduced energy for humidification.

Studies have shown that the cooling savings have been offset by the increased fan energy in all areas of MN.

Notes

Table 5. Design Supply Fan Air Flow Rate (CFM)

CLIMATE ZONE	Percent Outdoor Air at Full Design Air Flow Rate					
	≥ 30% and < 40%	≥ 40% and < 50%	≥ 50% and < 60%	≥ 60% and < 70%	≥ 70% and < 80%	≥ 80%
6A (MN)	≥ 5,500	≥ 4,500	≥ 3,500	≥ 2,000	≥ 1,000	> 0
7*	≥ 2,500	≥ 1,000	> 0	> 0	> 0	> 0

*ASHRAE Zone 7 MN counties include: Aitkin, Becker, Beltrami, Carlton, Cass, Clay, Clearwater, Cook, Crow Wing, Grant, Hubbard, Itasca, Kanabec, Kittson, Koochirching, Lake, Lake of the Woods, Mahnomen, Marshall, Mille Lacs, Norman, Otter Tail, Pennington, Pine, Polk, Red Lake, Roseau, St. Louis, Wadena, Wilkin

Code requires Energy Recovery Ventilation for most applications based upon the table above.

The "green code" ASHRAE Standard 189 further reduces outdoor air thresholds requiring ERV and increases minimum ERV effectiveness to 60 percent.

References

1. Assumed service life limited by controls -" Demand Control Ventilation Using CO2 Sensors", pg. 19, by US Department of Energy Efficiency and Renewable Energy.
2. "Map to HVAC Solutions", by Michigan Air, Issue 3, 2006.
3. National Climate Data Center - National Oceanic and Atmospheric Administration 1981-2010 Normals. Weather data for Duluth and International Falls was averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3.

4. 1997 ASHRAE Handbook HVAC Fundamentals.
5. Assumed heating set point of 70°F and cooling set point of 72° F with a 2F temperature rise in the return ducting and 50% relative humidity
6. Assumed standard combustion efficiency of heating equipment, FES.
7. Analysis of AHRI listed devices available 1/1/2016.
8. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to with most being very close to 0.9, primary data has not been identified.
9. ASHRAE Standard 90.1-1989. FES assumed baseline.
10. ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment. This value is given as a SEER and is modified as EER = 0.875 x SEER for single stage equipment.
11. It is assumed cooling savings are equal to the increased fan energy usage.
12. Psychometric Calculator, by kW Engineering and from ASHRAE 2009 Cooling DB/MCWB @ 1.0% for each TRM weather zone
13. Average Fan efficiency for centrifugal fans from the Energy Efficiency Guide Book (2004), Chapter 5, Bureau of Energy Efficiency, Government of India.
14. Assumed average 5 HP Nema EPAct Open Frame motor efficiency.
15. Franklin Energy Services estimate of operational hours.
16. Values calculated using psychrometeric conditions at 1000ft and 50% relative huidity

Revision History

Version	Description	Author	Date
2.0	Added kW Peak savings. Removed gas algorithm derived from notes and added full equation to reduced equation algorithm. Updated code requirements.	Franklin Energy Services	1/1/16
2.1	Changed to total (sensible and latent) energy savings	Franklin Energy Services	1/1/16
2.2	Updated return-air enthalpy to reflect 70F, 50% relative humidity and sea-level altitude. Updated example calculation.	Franklin Energy Services	12/4/17
3.0	Updated equation, broadended measure definition, clarified baselines	Cadmus	11/2018
3.1	Updated and clarified equation inputs and units	Cadmus	10/2020

Commercial HVAC - Exhaust Energy Recovery

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	HVAC
Applicable To	Commercial and industrial customers where energy can be recovered from exhausted air
Actions	Replace Working, New Construction, Modify
Required from Customer/Contractor	Air to liquid or Air to Air heat exchanger type (fixed plate or runaround loop), exhaust air CFM, exhaust air temperature, hours per year of operation, temperature of media being heated
Version No.	2.1
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 years (Ref. 1)
Unit Participant Incremental Cost	See Table 1 (Ref. 2)

Measure Description

This measure includes the addition of energy recovery on new and existing exhaust systems. This measure analyzes the heating savings potential of the heat energy recovery from exhausted air. This analysis assumes there is a requirement of heating capacity greater than the potential for recovery.This measure is applicable to HVAC and process exhaust air systems above 100° F.

Algorithms

Unit kWh Savings per Year = - (CFM x PD / 6356 / Eff_Motor / Eff_Fan x 0.746 x 2 x Hours)

Unit Peak kW Savings = - (CFM x PD / 6356 / Eff_Motor / Eff_Fan x 0.746 x 2)

Unit Dth Savings per Year = 1.08 x CFM x ΔT x Hours x ERV_E / (1,000,000 x η)

Where:

CFM	=	Exhaust Air flow in cubic feet per minute
Eff_Fan	=	Efficiency of Fan. Provided by customer. If value not provide assume 0.69 (Ref. 10)
Eff_Motor	=	Efficiency of Motor. Provided by customer. If value not provide assume 0.855 (Ref. 11)
ERV_E	=	Sensible Energy Effectiveness of ERV. Provided by manufacturer or customer. If value is not provided see Table 1.
Hours	=	Hours of operation per year. Provided by customer.
PD	=	Pressure Drop increase. Provided by customer. If value not provided assume 1” WC. (Ref. 12)

ΔT	=	T_exhaust – T_media Difference in temperature (°F) between the exhaust air heat exchanger inlet and temperature of media being heated.
T_ exhaust	=	Temperature of exhaust (°F). Provided by customer. If value not provided assume 131.4° F. (Ref. 3)
T_media	=	Temperature of media being heated. Provided by customer. If value not provided see table 2 for possible applications.
η	=	Efficiency of heating equipment of media gaining energy. Assume 0.8 (Ref. 4) unless different efficiency is provided by customer.
1.08	=	Conversion factor for flow rate and specific volume of air and minutes to hours
6356	=	Conversion factor for Flow and inches of water column to Horsepower
0.746	=	Conversion Factor for Horsepower to KW
1,000,000	=	Conversion facto for BTU to Dth
2	=	Factor to account for similar power consumption for both sides of heat exchanger (Ref.12)

Example:

Install a runaround loop filters on a kitchen exhaust hood to pre-heat domestic hot water in zone 2. The kitchen hood operates 16 hours a day 360 days per year and exhausts and average of 1000 cfm.

Unit kW Savings = - (1,000 x 1 / 6356 / 0.69 / 0.85 x 0.746 x 2) = - 0.4 kW

Unit kWH Savings = - (1,000 x 1 / 6356 / 0.69 / 0.85 x 0.746 x 2 x 16 x 360) = - 2,292 kWh

Unit Dth Savings per Year = 1.08 x 1,000 x (131.4 – 49.1) x 16 x 360 x 0.60 / (1,000,000 x 0.8) = 384 Dth

Deemed Input Tables

Table 1. Air Heat Exchanger Sensible Effectiveness and Incremental Costs

Energy Recovery Type	Sensible Heating Effectiveness	Incremental Cost (Ref. 2)
Fixed Plate	0.54 (Ref. 5)	$3/CFM
Runaround Loop	0.60 (Ref. 6)	$3/CFM

Table 2. Air Heat Exchanger Application Media Temperatures

Heating Application	Zone 1 Media Temperature °F	Zone 2 Media Temperature °F	Zone 3 Media Temperature °F
Pre-Heat Incoming Domestic Water (Ref.7)	46.5	49.1	51.3
Re-Heat Ventilation Air (Ref.8)	55	55	55
Heat Water Source Heat Pump Loop (Ref.9)	60	60	60

Methodology and Assumptions

Runaround loop costs assume no special coatings and relatively short distance between coils.

References

1. Assumed service life limited by controls -" Demand Control Ventilation Using CO2 Sensors", pg. 19, by US Department of Energy Efficiency and Renewable Energy
2. "Map to HVAC Solutions", by Michigan Air, Issue 3, 2006
3. Kitchen exhaust temperature from picture 33 in article "Heat Load Based Design - Hood Studies", by Foodservice Society Consultants International
4. Assumed standard combustion efficiency of heating equipment, Franklin Energy Services Analysis of AHRI listed devices available 1/1/2016.
5. Laboratories for the 21st Century: Best Practices, Energy Recovery for Ventilation Air in Laboratories, Dept. of Energy, DOE/GO-102003-1774, October 2003.
6. Values are from DOE, 2010 Residential Heating Products Final Rule Technical Support Document, Tables 8.2.13-14, 8.2.16 (http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_ch8.pdf). The values are interpreted with explanation in the "Cost Info" tab of this worksheet.
7. Responsible Energy, Reheat for Commercial Buildings, Madison Gas & Electric, GS1889, 10/28/2015
8. Trane Engineering Newsletter Volume 36-2, Energy Savings Strategies for Water Source Heat Pump Systems, ADM-APN024-EN (May 2007)
9. Average Fan efficiency from the Energy Efficiency Guide Book (2004), Chapter 5, Bureau of Energy Efficiency, Government of India.
10. Assumed average 5 HP Nema EPAct Open Frame motor efficiency.
11. Best design practice noted in Laboratories for the 21st Century: Best Practices, Energy Recovery for Ventilation Air in Laboratories, Dept. of Energy, DOE/GO-102003-1774, October 2003.

Revision History

Version	Description	Author	Date
1.0	New savings specification for retrofit/incorporation of energy recovery.	Franklin Energy Services	8/1/2012
1.1	Changed Table 2 footnote from "reduce efficiency by 75%" to "multiply efficiency by 0.75" to be clear, changed action to replace working, fixed example calculation, changed description from "applicable to all exhaust air systems" to "applicable to HVAC and kitchen hood exhaust air systems", changed days to year from 365 to 365.25 for consistency with other measures	Joe Plummer	3/13/2013
1.2	Added New Construction and Modify to Action Types	Joe Plummer	11/24/13

Version	Description	Author	Date
1.3	Modified equation to be HDD based, instead of temperature based to reflect savings for heating season only. Change exhaust air temperature reference to typical building occupied set point. Changed conversion factor from 1.08 to 4.5 to correct change in equation base. Added heating degree days and enthalpies definitions. Update example. Modified Table 2 to include return air temperature, enthalpies and HHD values. Changed notes. Added references.	Franklin Energy Services	7/18/2014
1.4	Corrected example and typos, added reference for efficiency derating factor.	Joe Plummer	8/1/2014
2.0	Corrected reference numbering. Changed equation format to be consistent with other measures.	Franklin Energy Services	11/12/2014
2.1	Changed to sensible only based equation. Removed EFLH. Added kW and kWH penalties, corresponding references and heating application table.	Franklin Energy Services	1/12/2016

Commercial HVAC - Forced-Air Heating Maintenance

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Commercial customers with natural gas fired, forced-air heating systems
Actions	Operations & Maintenance
Required from Customer/Contractor	Nominal Btu/h input of heating system, project location (county), building type
Version No.	2.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	2 (Ref. 1)
Unit Participant Incremental Cost	$0.83/MBtuh (Ref. 2)

Measure Description

This measure includes the maintenance of forced-air space heating systems in commercial spaces. This includes furnaces, RTUs, unit heaters, and makeup air units, for example. This does not include boiler or infrared heater maintenance.

*Applies to heating equipment in space heating applications only.

Algorithms

Unit Dth Savings per Year = (Percent Savings) x (Pre-Annual Consumption)

Where:

Pre-Annual Consumption (Dth/yr) = Btuh_In x Load_Factor x $EFLH_{Heat}$ / Conversion_Factor

Percent Savings = percent of the pre-modification annual consumption saved. Assumed to be 1.6% on average. (Ref. 5)

Btuh_In = the nominal rating of the input capacity of the heating equipment in Btu/h

Load_Factor = oversizing factor, assumed to be 77% (Ref. 3)

$EFLH_{Heat}$ = the heating equivalent full load hours of heating. See Table 1.

Conversion_Factor = 1,000,000 Btu/Dth

Example:

For maintenance performed on a 150 MBtuh heating unit in Zone 2 on an unknown building type:

Pre-Annual Consumption (Dth/yr) = 150,000 x 0.77 x 1911 /1,000,000 = 221 Dth

Gas Energy Heating Savings (Dth/yr) = 0.016 x 221 = 3.5 Dth

Deemed Input Tables

Table 1. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 4)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Notes

There are currently no existing Minnesota state-wide or federal efficiency standards for heating maintenance.

$EFLH_{Heat}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 2. Heating Degree Days and Design Temperature Difference

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

References

1. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, Inc. June 2007. http://www.ctsavesenergy.org/files/Measure%20Life%20Report%202007.pdf
2. Work Paper – Tune up for Boilers serving Space Heating and Process Load by Resource Solutions Group, January 2012
3. Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that heating systems are 30% oversized on average.
4. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
5. Focus on Energy Evaluation Business Programs: Deemed Savings Manual V1.0, March 22, 2010. Assuming the same savings percentage value as Boiler Tune-Ups.

Revision History

Version	Description	Author	Date
1.0	Original document	Franklin Energy Services	7/30/2012
1.1	Changed name	Joe Plummer	2/11/2013
2.0	Changed from Heating Degree Days to $EFLH_{Heat}$. Updated Table 2 to include building types.	Franklin Energy Services	11/12/2015

Commercial HVAC - Guest Room Energy Management Controls

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Commercial and Public Buildings that serve as a lodging facility and are heated and cooled with PTAC, PTHP, or fan coil HVAC systems
Actions	Modify, Replace Working (retrofit), New Construction
Required from Customer/Contractor	1. Cooling system type (PTAC, PTHP, or chilled water fan coil) 2. Heating type (PTAC/electric resistance, PHTP, hot water PTAC or fan coil) 3. Cooling system size in BTU/hr, heating system size in BTU/hr
Version No.	1.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$260 (Ref. 2)

Measure Description

This measure includes the addition of enhanced guest room heating and cooling controls. Controls are available to minimize energy costs for guestroom HVAC systems. These controls use sensors to determine when a room is occupied. If the room is empty, the controls adjust the room temperature to an “unoccupied” setting. Regular settings are resumed when the guests return to their rooms. These controls are available in multiple forms, two of which are keycard based occupancy sensors and passive infrared occupancy monitors.

Algorithms

Unit kWh Cooling Savings per Year = (Cooling_Size / 1,000) x EFLH_cool x (1 / Cooling_Eff) x GREM_Savings

Unit Peak kW Savings = (Cooling_Size / 1,000) x (1 / Cooling_Eff) x GREM_Savings x CF

If electric heat:

Unit kWh Heating Savings per Year = (Heating_Size / 3,412) x (1 / Heating_Eff) x EFLH_heat x GREM_Savings

If gas heat:

Unit Dth Heating Savings per Year = Heating_Size / 1,000,000 x (1 / Heating_Eff) x EFLH_heat x GREM_Savings

Where:

Cooling_Size = nominal cooling capacity of the cooling system in BTU/hr, use 9,000 Btu/hr if unknown

1,000 = unit conversion, BTU to kBTU

EFLH_cool = cooling equivalent full load hours per Table 1 (Ref. 3)

Table 1. Equivalent Full Load Hours of cooling per zone in Minnesota by building type (Ref. 3)

Building Type	Cooling Equivalent Full Load Hours		
	Zone 1	Zone 2	Zone 3
Lodging	401	606	754

EFLH_heat = heating equivalent full load hours per Table 2 (Ref. 4)

Table 2. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 4)

Building Type	Heating Equivalent Full Load Hours		
	Zone 1	Zone 2	Zone 3
Lodging	2361	2126	1934

Cooling_Eff = cooling efficiency of the HVAC system in units of EER, use actual or select from Table 3

Table 3. Cooling System EER (PTAC/PTHP, Ref. 5; CW Unit, Ref. 6)

HVAC Cooling System	Standard Size	Non-Standard Size
PTAC, < 7,000 BTU	11.9	9.4
PTAC, 7,000-15,000 BTU	14.0 - (0.300 x Cap/1000)	10.9 - (0.213 * Cooling_Size / 1,000)
PTAC, > 15,000 BTU	9.5	7.7
PTHP, < 7,000 BTU	11.9	9.3
PTHP, 7,000-15,000 BTU	14.0 - (0.300 x Cap/1000)	10.8 - (0.213 * Cooling_Size / 1,000)
PTHP, > 15,000 BTU	9.5	7.6
Chilled Water Fan Coil Unit	12.5	N/A

Cap = unit size in BTU/hr

Heating_Size = nominal heating capacity of the heating system in BTU/hr, for PTAC and PTHP units Cooling_Size may be used if heating capacity is unknown

3,412 = unit conversion, BTU per kWh

Heating_Eff = heating efficiency of the HVAC system in units of COP, use actual or select from Table 4

Table 4. Heating System COP (PTAC, See Assumptions; PTHP, Ref. 5; HW Unit, Ref. 7)

HVAC Heating System	Standard Size	Non-Standard Size
PTAC, All Sizes	1.0	1.0
PTHP, < 7,000 BTU	3.3	2.7
PTHP, 7,000-15,000 BTU	3.7 - (0.052 x Cap/1000)	2.9 - (0.026 x Cap/1000)
PTHP, > 15,000 BTU	2.9	2.5
Hot Water PTAC or Fan Coil Unit	0.8	N/A

Cap = unit size in BTU/hr

GREM_Savings = 18.4%, savings fraction for using guest room energy management controls (Ref. 8)

1,000,000 = unit conversion, BTU per decatherm

CF = 0.90, deemed coincidence factor (Ref. 9)

Example 1:

A hotel customer installed a guest room energy management system for a room with a 9,000 BTU cooling / 9,000 BTU heating standard sized PTHP in climate zone 3.

Cooling_Eff = 14.0 - (0.300 * Cap/1,000) = 14.0 - (0.300 * 9,000/1,000) = 11.3

Coolng Savings = (9,000 / 1,000) x 754 x (1 / 11.3) x 0.184 = 110.5 kWh

Demand Savings = (9,000 / 1,000) x (1 / 11.3) x 18.4% x 0.9 = 0.132 kW

Heating_Eff = 3.7 - (0.052 * Cap/1,000) = 3.7 - (0.052 * 9,000/1,000) = 3.23

Heating Savings = (9,000 / 3,412) x (1 /3.23) x 1934 x 0.184 = 290.6 kWh

Total kWh Savings: 401 kWh

Total Peak kW Savings: 0.132 kW

Example 2:

A hotel customer installed a guest room energy management system for a room with a 9,000 BTU cooling / 9,000 BTU heating PTAC in climate zone 2.

Cooling_Eff = 14.0 - (0.300 * Cap/1,000) = 14.0 - (0.300 * 9,000/1,000) = 11.3

Cooling Savings = (9,000 / 1,000) x 606 x (1 / 11.3) x 0.184 =88.8 kWh

Demand Savings = (9,000 / 1,000) x (1 / 11.3) x 18.4% x 0.9= 0.132 kW

Heating Savings = (9,000 / 3412) x (1 / 1.0) x 2126 x 0.184 = 1031.8 kWh

Total kWh Savings: 1120.6 kWh

Total Peak kW Savings: 0.132 kW

Notes

EFLHCool were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

$EFLH_{Heat}$ were determined from prototypes building models based on the California DEER study prototypes modified by using ASHRAE fundamentals weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 5. Heating Degree Days and Design Temperature Differences

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

References

1. DEER 2008 value for energy management systems (used by 2015 Illinois TRM)
2. Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 4.0, February 13, 2015, page 195 (source in IL TRM is actual project data from ComEd Smart Ideas program in program year 1 and 2).
3. FES calculated EFLH from energy models based on California DEER study prototypes modified by Illinois field data with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) 2012.
4. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on the California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
5. Title 10, Code of Federal Regulations, Part 431 – Energy Conservation Program for Consumer Products, Subpart F – Energy and Water Conservation Standards and Their Compliance Dates. https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=8de751f141aaa1c1c9833b36156faf67&mc=true&n=pt10.3.431&r=PART&ty=HTML%20-%20se10.3.431_197#se10.3.431_197
6. ASHRAE Standard 90.1-2010, Energy Standard for Buildings Except Low-Rise Residential Buildings, Table 6.8.1C, average of air cooled chiller (9.562 EER) and ≥75 to <150 ton water cooled chiller (0.775 kW or 15.48 EER).
7. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment, Subpart E - Commercial Packaged Boilers. January 1,

2010. https://www.ecfr.gov/cgi-bin/text-idx?SID=0fc362824764c46ec3f6e2af2a4b1e0f&mc=true&node=sp10.3.431.e&rgn=div6

8. Guest Room HVAC Occupancy-Based Control Technology Demonstration, US DOE Pacific Northwest National Laboratory, September, 2012. http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/creea_guest_room_occupancy-based_controls_report.pdf
9. 0.9 is a typical value used for central HVAC equipment in many programs. The range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	7/30/2015
1.1	Updating NG savings method to EFLH method	Franklin Energy Services	11/16/2015
1.2	Updated cooling efficiencies for standard sized PTACs. Added Cooling and heating efficiencies for non-standard sized PTACs and PTHPs.	Cadmus	11/2018

Commercial HVAC - Programmable Thermostats with Electric Heating

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Commercial customers in businesses noted in Table 1 with commercial unitary type heat pump heating equipment controlled by thermostats. Electricity must be the primary heating source to use this measure and building automation systems must not be incorporated.
Actions	Replace on Fail, Replace Working
Required from Customer/Contractor	Confirmation of electric heating, business type (see Table 1), program delivery type (see Table 2), location (county), size (cooling tons), efficiency (HPSF or COP –Table 3)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	8 (Ref. 1)
Unit Participant Incremental Cost	$181 (Ref. 2)

Measure Description

This measure includes replacement of failed or working manual thermostats in existing commercial businesses with programmable thermostats. New units must have the capability to adjust temperature setpoints according to a schedule without manual intervention. An estimate is provided for reduced heating energy consumption through temperature set-back during unoccupied or reduced demand times. Savings are provided for heating only as a literature review has not shown conclusive cooling savings. Savings make no other assumptions regarding sequence of operations incorporated into the programmable thermostat. Among sequence savings not considered are optimal start, outside air damper control, or other potential energy savings measures associated with occupancy.

Algorithms

Unit kWh Savings per Year = HCelec x HSF x ISR

HCelel = $EFLH_{Heat}$ x Size x Load_Factor x EFF

Where:

HCelec	=	Heating consumption for electrically heated businesses
$EFLH_{Heat}$	=	Equivalent Full Load Hours heating, See Table #1. (Ref. 3)
Size	=	Nominal Cooling capacity in tons of the equipment (1 ton = 12,000 btu/h) Capacity in tons, provided by customer/contractor or use = 5.0 if unknown. (Ref. 4)
Load_Factor	=	boiler load factor, assumed to be 77% (Ref. 5)

EFF = equipment efficiency:

For less than 5.5 tons: Eff = 12 / HSPF, Where HSPF = Heating system performance factor of existing equipment, provided by customer/contractor or use = 7.7 if unknown (Ref. 6)

For 5.5 tons or greater: EFF = 3.52 / COP, Where COP = Heating system performance factor of baseline or existing ASHP, provided by customer/contractor. If unknown see Table 3 (Ref. 6)

If size is unknown assume 5 tons (Ref. 7)

HSF = Heating Savings Factor, assumed fraction reduction in heating energy consumption due to programmable thermostat, HSF = 0.05 (Ref. 8)

ISR = In-Service Rate, the percentage of units installed and programmed effectively, Table 2. (Ref. 9)

Examples:

Retrofit a manual thermostat with a programmable thermostat in an electrically heated strip mall retail store in Climate Zone 1, via a direct installation program delivery.

HCelec = 1701 x 5 x 0.77 x 12 / 7.7 = 10,206 kWh

Unit kWh Savings per Year = 10,206 x 0.05 x 1.0 = 510.3 kWh

Deemed Input Tables

Table 1. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 3)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444

Building Type	Zone 1	Zone 2	Zone 3
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Table 2. In-Service Rates (Ref. 9)

Program Delivery	ISR
Direct Install	1.0
Other, or unknown	0.56

Table 3. Deemed baseline efficiency for heating 5.5 tons and greater

Equipment	COP_base (Ref. 10)
ASHP Units 5.5-11.3 tons*	3.3
ASHP Units 11.4-19.9 tons*	3.2
ASHP Units 20-63.3 tons*	3.2
GSHP Units (closed loop)**	3.1
GWSHP Units (open loop)**	3.6

*HSPF and COP based upon 17°F DB and 15°F WB Outdoor air temperature.

** Heating efficiencies based upon ASHRAE 90.1-2010.

Methodology and Assumptions

$EFLH_{Heat}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 4. Heating degree days and design temperature difference

Geography	HDD55	DTD
Chicago, IL	4,029	73.5
MN Zone 1	6,956	92
MN Zone 2	5,888	86.5
MN Zone 3	5,233	84.5

Demand savings are assumed to be minimal, as it is assumed that demand savings for HVAC measures are defined as summer peak hour savings.

Savings are calculated based upon a constant speed baseline operation.

References

1. Table 1, HVAC Controls, Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, 2007
2. Nicor Rider 30 Business EER Program Database, Paid Rebates with Programmable Thermostat Installation Costs, Program to Date as of January 11, 2013
3. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
4. Utilizing nominal square footage noted in DTE and CE C&I Programmable Thermostat Savings Analysis: Preliminary Findings, Navigant Energy, June 17, 2014 and assumption of 400 square feet per ton of cooling capacity.
5. Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that oversizing on average is 30%.
6. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment, Subpart F - Commercial Air Conditioners and Heat Pumps. January 1, 2010.
7. Utilizing nominal square footage noted in DTE and CE C&I Programmable Thermostat Savings Analysis: Preliminary Findings, Navigant Energy, June 17, 2014 and assumption of 400 square feet per ton of cooling capacity results in 5 ton cooling unit.
8. DTE and CE C&I Programmable Thermostat Savings Analysis: Preliminary Findings, Navigant Energy, June 17, 2014
9. "Programmable Thermostats. Report to KeySpan Energy Delivery on Energy and Cost Effectiveness," GDS Associates, Marietta, GA. 2002
10. ASHRAE 90.1-2010 based upon 17°F DB and 15°F WB Outdoor air temperature.

Revision History

Version	Description	Author	Date
1.0	New Measure	Franklin Energy Services	11/12/2015

Commercial HVAC - Programmable Thermostats with Gas Heating

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Commercial customers in business noted in Table 1 with commercial unitary type heating equipment controlled by thermostats. Gas must be the primary heating source to use this measure and building automation systems must not be incorporated
Actions	Replace on Fail, Replace Working
Required from Customer/Contractor	Confirmation of gas heating, business type (see Table 2), program delivery type (see Table 3), location (county), heating size (Btu/h Input)
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	8 (Ref. 1)
Unit Participant Incremental Cost	$181 (Ref. 2)

Measure Description

This measure includes replacement of failed or working manual thermostats in existing commercial businesses with programmable thermostats. New units must have the capability to adjust temperature setpoints according to a schedule without manual intervention. An estimate is provided for reduced heating energy consumption through temperature set-back during unoccupied or reduced demand times. Savings are provided for heating only as a literature review has not shown conclusive cooling savings. Savings make no other assumptions regarding sequence of operations incorporated into the programmable thermostat. Among sequence savings not considered are optimal start, outside air damper control, or other potential energy savings measures associated with occupancy.

Algorithms

Unit Dth Savings per Year = HCgas x HSF x ISR

Where:

HCgas = Heating consumption for gas heated businesses, see Table 1. (Ref. 3)

HCgas = $EFLH_{Heat}$ x BTUH_IN x Load_Factor / Conversion_Factor

$EFLH_{Heat}$ = Equivalent Full Load Hours heating, See Table #1. (Ref. 3)

Btuh_In = Nominal Heating capacity in btu/h of the equipment. Capacity, btu/h, provided by customer/contractor or use = 100,000 if unknown. (Ref. 4)

Load_Factor = the load factor, assumed to be 0.77 (implies 30% oversizing) (Ref. 5)

Conversion_Factor = 1,000,000 Btu/Dth

HSF = Heating Savings Factor, assumed fraction reduction in heating energy consumption due to programmable thermostat, HSF = 0.05 (Ref. 6)

ISR = In-Service Rate, the percentage of units installed and programmed effectively, Table 2. (Ref. 7)

Example:

Retrofit a manual thermostat with a programmable thermostat in a gas heated strip mall retail store Climate Zone 1, via a direct installation program delivery.

HCgas = 1701 x 100,000 x 0.77 / 1,000,000 = 131.0 Dth

Unit Dth Savings per Year = 131.0 x 0.05 x 1.0 = 6.55 Dth

Deemed Input Tables

Table 1. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 3)

Building Type	Zone 1	Zone 2	Zone 3
Convenience Store	1887	1699	1546
Education - Community	1972	1776	1616
Education – Primary	2394	2156	1961
Education – Secondary	2561	2306	2098
Health/Medical – Clinic	2234	2012	1830
Health/Medical – Hospital	2508	2258	2054
Lodging	2361	2126	1934
Manufacturing	1397	1258	1144
Multifamily	2324	2092	1904
Office-Low Rise	1966	1770	1610
Office-Mid Rise	2189	1971	1793
Office-High Rise	2149	1935	1760
Restaurant	1868	1681	1530
Retail - Large Department Store	1763	1587	1444
Retail - Strip Mall	1701	1531	1393
Warehouse	1872	1685	1533
Other/Miscellaneous	2123	1911	1739

Table 2. In-Service Rates (Ref. 7)

Program Delivery	ISR
Direct Install	1.0
Other, or unknown	0.56

Methodology and Assumptions

$EFLH_{Heat}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3). Values were scaled as follows: $EFLH_{MN} = EFLH_{IL} \times HDD_{55,MN} / HDD_{55,IL} \times DTD_{IL} / DTD_{MN}$, where DTD is the design temperature difference.

Table 3. Heating degree days and design temperature difference

Geography	HDD55	DTD
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MN Zone 3	5,233	84.5

Demand savings are assumed to be minimal, as it is assumed that demand savings for HVAC measures are defined as summer peak hour savings. Savings are calculated based upon a constant speed baseline operation.

References

1. Table 1, HVAC Controls, Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, 2007
2. Nicor Rider 30 Business EER Program Database, Paid Rebates with Programmable Thermostat Installation Costs, Program to Date as of January 11, 2013
3. FES scaled EFLH from those provided in the Illinois Technical Reference Manual based on Minnesota weather data. EFLH for the Illinois Technical Reference Manual were based on California DEER study prototypes modified by Illinois field data to closely match EFLH from the modeling to those calculated from field data.
4. Utilizing nominal square footage noted in DTE and CE C&I Programmable Thermostat Savings Analysis: Preliminary Findings, Navigant Energy, June 17, 2014 and assumption of 400 square feet per ton of cooling capacity results in 5 ton cooling unit. This result was then utilized to determine the nominal heating input for rooftop units in this size from the 3 largest manufacturers.
5. PA Consulting, KEMA, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, March 22, 2010. This factor implies that boilers are 30% oversized on average.
6. DTE and CE C&I Programmable Thermostat Savings Analysis: Preliminary Findings, Navigant Energy, June 17, 2014
7. "Programmable Thermostats. Report to KeySpan Energy Delivery on Energy and Cost Effectiveness," GDS Associates, Marietta, GA. 2002

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	11/12/2015

Envelope

C/I Envelope - Fast Acting Doors

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Envelope, Refrigeration
Applicable To	Commercial and Industrial Refrigeration
Actions	New Construction, Modify
Required from Customer/Contractor	Baseline doorway barrier type, length and width of doorway in feet, average number of passages per hour, average minutes per hour door is held open, annual hours of operation
Version No.	1.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 4)
Unit Participant Incremental Cost	Approximately $150/ft2 of automated door (Ref. 5)

Measure Description

High speed doors save energy by lowering infiltration by reducing the time that rooms at different air temperatures are exposed to each other. They also provide better insulation between divided spaces.

This measure characterizes the energy savings achieved by replacing open doorways, standard speed doors, or strip curtains with high speed doors through infiltration reduction. The methodology for estimating energy savings for this measure is well documented (2014 ASHRAE Refrigeration Handbook, Refrigerated-Facility Loads, Chapter 24).

Algorithms

$kWh_{SAVED} = 1/(3412 * COP) * t * (qt_B – qt_E)$

$kW_{SAVED} = CF * 1/(3412 * COP) * (qt_B – qt_E)$

Where:

3412	=	conversion factor, Btu per kWh
qt_B	=	$qt_{OPEN\ B} + qt_{CLOSED\ B}$, total sensible and latent load due to infiltration, baseline equipment (Btu/h)
qt_E	=	$qt_{OPEN\ E} + qt_{CLOSED\ E}$, total sensible and latent load due to infiltration, efficient equipment (Btu/h)
$qt_{OPEN\ B}$	=	$q * Dt_B * Df * (1 – E_{OPEN\ B})$, sensible and latent load due to infiltration when door open, baseline equipment (Btu/h)

$qt_{OPEN\ E}$	=	$q * Dt_E * Df * (1 – E_{OPEN\ E})$, sensible and latent load due to infiltration when door open, efficient equipment (Btu/h)
$qt_{CLOSED\ B}$	=	$q * (1 – Dt_B) * Df * (1 – E_{CLOSED\ B})$, sensible and latent load due to infiltration when door closed, baseline equipment (Btu/h)
$qt_{CLOSED\ E}$	=	$q * (1 – Dt_E) * Df * (1 – E_{CLOSED\ E})$, sensible and latent load due to infiltration when door closed, efficient equipment (Btu/h)
q	=	$795.6 * A * (h_I – h_R) * \rho_R * (1 – \rho_I/\rho_R)^{0.5} * (gH)^{0.5} * F_M$, sensible and latent load if unrestricted airflow between rooms (Btu/h) (Ref. 3) See Table 2 for typical loads.
A	=	doorway area (ft2), provided by customer
h_I	=	enthalpy of infiltration air (Btu/lb), see Table 1
h_R	=	enthalpy of refrigerated air (Btu/lb), see Table 1
ρ_I	=	density of infiltration air (lb/ft^3) , see Table 1
ρ_R	=	density of refrigerated air (lb/ft^3) , see Table 1
g	=	32.174, gravitational constant (ft/s^2)
H	=	doorway height in feet, provided by customer (typically 10 ft)
F_M	=	$(2 / (1 + (\rho_r/\rho_i)^{1/3}))^{1.5}$, density factor (Ref. 3)
Dt_B	=	(P * Θ_P_b + 60 x Θ_o) / 3600, decimal fraction per hour that door is open, baseline equipment (Ref. 3). If baseline equipment is open doorway or strip curtains, Dt_b = 1.
Dt_E	=	(P * Θ_P_e + 60 x Θ_o) / 3600, decimal fraction per hour that door is open, efficient equipment (Ref. 3).
P	=	average number of doorway passages per hour, provided by customer
Θ_P_b	=	door open-close time, baseline equipment (seconds). Refer to Table 3, or customer-provided.
Θ_P_e	=	door open-close time, efficient equipment (seconds). Refer to Table 3, or customer-provided.
Θ_o	=	average minutes per hour door is held open, provided by customer
60	=	conversion factor, minutes per hour
3600	=	conversion factor, seconds per hour
Df	=	Doorway flow factor, 0.8 if temperature differential > 20˚F, 1.1 if temperature differential < 20˚F (Ref. 3)
$E_{OPEN\ B}$	=	effectiveness of doorway barrier during passage, baseline equipment. See Table 3.
$E_{CLOSED\ B}$	=	effectiveness of doorway barrier when closed, baseline equipment. See Table 3.

$E_{OPEN\ E}$	=	effectiveness of doorway barrier during passage, efficient equipment. See Table 3.
$E_{CLOSED\ E}$	=	effectiveness of doorway barrier when closed, efficient equipment. See Table 3.
t	=	annual hours of operation, provided by customer.
COP	=	coefficient of performance, 1.3 for freezers, 2.5 for coolers (Ref. 2)
CF	=	peak coincident factor, assumed to be 0.9 (Ref. 6)

Examples:

Fast-acting doors are proposed for an 8ft x 10ft doorway between an unconditioned loading dock and a cooler. The existing barrier is a manual door that is held open during business hours and closed during non-business hours. On average, a forklift passes through the doorway 6 times per hour during business hours. The facility operates two-shifts per day, five days per week (4,160 hours per year). The proposed fast-acting doors will be held open 3 minutes per hour on average during business hours.

From Table 2, q = 917 * 8 * 10 = 73,360 Btu/h, Df = 1.1

Dt_B = 1 (open doorway)

Dt_E = (6 * 5 + 60 * 3)/3600 = 0.058

From Table 3, $E_{OPEN\ B} = E_{CLOSED\ B} = 0$, $E_{OPEN\ E} = 0$, $E_{CLOSED\ E} = 0.95$

$qt_{OPEN\ B}$ = 73,360 * 1 * 1.1 * (1-0) = 80,696 Btu/h

$qt_{CLOSED\ B}$ = 73,360 * (1-1) * 1.1 * (1-0) = 0 Btu/h

$qt_{TOTAL\ B}$ = 80,696 + 0 = 80,696 Btu/h

$qt_{OPEN\ E}$ = 73,360 x 0.058 x 1.1 x (1-0) = 4,707 Btu/h

$qt_{CLOSED\ E}$ = 73,360 x (1-0.058) x 1.1 x (1-0.95) = 3,799 Btu/h

$qt_{TOTAL\ E}$ = 4,707 + 3,799 = 8,507 Btu/h

COP = 2.5 (cooler)

kWh_{SAVED} = 1/(3412 * 2.5) * 4,160 * (80,696 – 8,507) = 35,206

kW_{SAVED} = 0.9 * 1/(3412 * 2.5) * (80,696 – 8,507) = 7.62

Fast-acting doors are proposed for an 8ft x 10ft doorway between a cooler and a freezer. The existing barrier is a manual door with strip curtains that is held open during business hours and closed during non-business hours. On average, a forklift passes through the doorway 6 times per hour during business hours. The facility operates two-shifts per day, five days per week (4,160 hours per year). The proposed fast-acting doors will be held open 3 minutes per hour on average during business hours.

Note that this example requires two kWh calculations: one for the load on the cooler, one for the load on the freezer. The net kWh savings are the sum of the cooler and freezer loads.

Cooler Load:

From Table 2, q = -4580 * 8 x 10 = -366,400 Btu/h, Df = 0.8

Dt_B = 1 (strip curtains)

Dt_E = (6 * 5 + 60 * 3)/3600 = 0.058

From Table 3, $E_{OPEN\ B} = E_{CLOSED\ B}$ = 0.58, $E_{OPEN\ E}$ = 0, $E_{CLOSED\ E}$ = 0.95

$qt_{OPEN\ B}$ = -366,400 * 1 * 0.8 * (1 - 0.58) = -123,110 Btu/h

$qt_{CLOSED\ B}$ = 73,360 * (1 - 1) * 0.8 * (1 - 0.58) = 0 Btu/h

$qt_{TOTAL\ B}$ = -123,110 + 0 = -123,110 Btu/h

$qt_{OPEN\ E}$ = -366,400 * 0.058 * 0.8 * (1-0) = -17,099 Btu/h

$qt_{CLOSED\ E}$ = 73,360 * (1-0.058) * 1.1 * (1-0.95) = -13,801 Btu/h

$qt_{TOTAL\ E}$ = -30,900 Btu/h

COP = 2.5 (cooler)

kWh_{SAVED} = 1/(3412 * 2.5) * 4,160 * (-123,110 – (-30,900)) = -44,970

kW_{SAVED} = 0.9 * 1/(3412 * 2.5) * (-123,110 – (-30,900)) = -9.73

Freezer Load:

$qt_{TOTAL\ B}$ = 123,110 Btu/h

$qt_{TOTAL\ E}$ = 30,900 Btu/h

COP = 1.3 (freezer)

kWh_{SAVED} = 1/(3412 * 1.3) * 4,160 * (123,110 – 30,900) = 86,481

kW_{SAVED} = 0.9 * 1/(3412 * 1.3) * (123,110 – 30,900) = 18.71

Net Savings:

kWh_{SAVED} = -44,970 + 86,481 = 41,511 kWh

kW_{SAVED} = -9.73 + 18.71 = 8.98 kW

Deemed Input Tables

Table 1. Assumed Air Conditions (Ref. 7)

Space Type	Dry bulb temp. (˚F)	Relative Humidity	Enthalpy, h (Btu/lb)	Density, ρ (lb/ft3)
Freezer	-10.0	40%	-2.21	0.0856
Cooler	35.0	40%	10.24	0.0777
Outside (ave.)	45.9	66%	15.71	0.0759

Table 2. Typical Sensible and Latent Refrigeration Loads, Unrestricted Flow; Flow Factor (Ref. 3)

Doorway location	Load per Unit Area, q/A (Btu/h)/ft^2	Flow Factor, Df
Cooler-Unconditioned Space	917	1.1
Freezer-Unconditioned Space	7132	0.8
Cooler-Freezer (cooler load)	-4580	0.8
Cooler-Freezer (freezer load)	4580	0.8

Table 3. Assumed Effectiveness and Typical Open-Close Time of Doorway Barrier Types

Doorway Barrier	Effectiveness	Open-Close Time, Θ_P (sec)	Reference
Open Doorway	0	n/a	3
Strip Curtains (existing)	0.58	n/a	1
Standard door (existing)	0.90	20	3
High speed door	0.95	5	3

Methodology and Assumptions

Conductive heat transfer through barrier devices is not included in the savings algorithms. Also, the waste heat generated by standard or fast-acting automated door motors, which is typically small compared to infiltration heat losses, is not included in the savings algorithm.

In new construction, the baseline equipment is assumed to be a standard speed door.

Per Ref. 3, the typical open-close time *Θ_P* for conventional pull-cord-operated doors ranges from 15 to 25 s per passage. The time for high-speed doors ranges from 5 to 10 s, although it can be as low as 3 s. The fact that steady-state flow becomes established 3 s after the cold-room door is opened may be used as a basis to reduce *Θ_P* for high-speed doors.

References

1. Pennsylvania Technical Reference Manual 2015, Table 3-115, p.418
2. US DOE Publication #46230-00, “Energy Savings Potential for Commercial Refrigeration Equipment", 1996, Arthur C. Little, Inc, Table 4-4 p.12, http://www.scribd.com/doc/13260953/Energy-Savings-Potential-for-Commercial-Refrigeration-Equipment
3. 2014 ASHRAE Handbook – Refrigeration, Chapter 24. Refrigerated-Facility Loads, Infiltration Air Load; Eqns. 15, 17.
4. DEER 2008; based on similar refrigeration measures, anti-sweat heaters, and case doors.
5. Approximated from Rite Hite – Industrial High Speed Door pricing.

6. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.
7. Enthalpies and densities calculated from 2013 ASHRAE Handbook – Fundamentals, Chapter 1, Eqns. 11, 28, 32; and Table 2 – Thermodynamic Properties of Moist Air at Standard Atmospheric Pressure, 14.696 psia. Outside air average temperature, relative humidity, and enthalpy was calculated from TMY3 data for Minneapolis.

Revision History

Version	Description	Author	Date
1.0	Created specification for Commercial and Industrial Fast Acting Doors	Franklin Energy Services	11/01/15
1.1	Updated algorithm, assumptions, and example calculations	Franklin Energy Services	11/28/17
1.2	Corrected equations for infiltration loads	Cadmus	11/2020

C/I Envelope - Loading Dock Door and Pit Seals

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	Envelope
Applicable To	Commercial and industrial customer facilities with loading docks
Actions	New Construction (pit seals only), Modify
Required from Customer/Contractor	Leak area of existing dock doors and pits, climate zone, temperature setpoint
Version No.	1.1
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10
Unit Participant Incremental Cost	$2,857 Dock Door Seals, $780 for Pit/Ramp Seals

Measure Description

Loading dock seals, sometimes called shelters, stop unconditioned air from leaking into a building when trucks are loading or being unloaded. Typically, there will be a four to six-inch gap between a semi and the dock door opening. Installing seals can remove this potentially large source of infiltration.

Commonly, facilities will also have a built-in pit ramp that elevates to the level of a semi-trailer floor. The pits below these ramps typically remain open, creating year-round infiltration of outside air. Ramp pit seals can be installed to fill these gaps.

Algorithms

Unit Dth Savings per Year = C_1 x Average Infiltration CFM x HDD x C_2 x t_{week} / C_3 / Eff / C_4

Where:

Average Infiltration CFM = LA x $\sqrt{(C_{stack} \times (T_{set} - T_{ave}) + C_{wind} \times (V_{wind}^2))}$

LA	=	Effective Leakage Area, measured area of openings, in²
C_{stack}	=	Stack Coefficient, 0.0225 Assuming a 1.5 story building (Ref. 1)
T_{set}	=	Temperature Setpoint, typically 68°F or 55˚F
T_{ave}	=	Average Winter Temperature, see Table 1 for average temperature for the given climate zone
C_{wind}	=	Wind Coefficient, 0.0138 Assuming a 1.5 story building average with no obstructions or local shielding (Ref. 1)
V_{wind}	=	Average Winter Wind Speed, see Table 1 for average wind speed for the given climate zone
HDD	=	Heating Degree Days, see Table 1 for heating degree-days base 65˚F or 55˚F depending on heating setpoint, for the climate zone

t_{week}	=	10 hours, per week, for dock doors;168 hours, per week, for pit rampsEff = Heating System Efficiency, 80 percent for a typical heating system
C_1	=	1.08 Btu/h/CFM/˚F
C_2	=	24 hours/day
C_3	=	168 hours/week
C_4	=	1,000,000 Btu/Dth

Example:

Door Seals: A single loading dock with leaks along the door measuring 20in² for a warehouse in Minneapolis is installing seals. The temperature setpoint is 68˚F.

Average Infiltration CFM = 20 in² x √(0.0225 x (68 °F - 36.0 °F) + 0.0138 x ((11.5 mph)²)) = 31.9 CFM

Unit Dth Savings per Year = 1.08 Btu/CFM x 31.9 CFM x 8,512 HDD x 24 hr/day x 10 hours/week / 168 hours/week / 80% Efficiency / 1,000,000 Btu/Dth = 0.52 Dth

Deemed Input Tables

Table 1. Heating Degree Days (HDD), Heating Design Temperatures and Average Wind Speed by Zone

	Zone 1	Zone 2	Zone 3
	Northern MN	Central MN	Southern MN/Twin Cities
HDD Base 65˚F (for setpoints approx. 68˚F) (Ref. 2)	9,833	8,512	7,651
HDD Base 55˚F (for setpoints approx. 55˚F) (Ref. 2)	6,956	5,888	5,233
Average heating season temperature (°F) (Ref. 3)	33.3 °F	35.5 °F	36.0 °F
Average wind speed, winter (mph) (Ref. 5)	9.4	10.3	11.6

Notes

The 2015 Minnesota Commercial Energy Code requires weather seals for cargo doors and loading dock doors to restrict infiltration when vehicles are parked in the doorway (Ref. 4).

References

1. 2013 ASHRAE Handbook - Fundamentals, Chapter 16: Ventilation and Infiltration, page 16.23-24.
2. National Climate Data Center - National Oceanic and Atmospheric Administration 1981-2010 Normals. Weather data for Duluth and International Falls was averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3.
3. Typical Meteorological Year 3 data from the National Solar Radiation Data Base http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html#M. Weather data for Duluth and International Falls was averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3. Average winter temperature equal to weighted average temperature below 65°F.

4. Minnesota Rules 1323.0402, Section C402.4.6.
5. NOAA-National Centers for Environmental Information-Comparive Climate Data, 1981-2015, Wind – Average Speed (MPH) http://www1.ncdc.noaa.gov/pub/data/ccd-data/wndspd15.dat, accessed December 4, 2017. Average wind speeds for October-April. Monthly wind speeds for Duluth and International Falls were averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3.

Revision History

Version	Description	Author	Date
1.0	Created standalone Specification Loading Dock Door and Pit Seals	Franklin Energy Services	11/12/15
1.1	Updated algorithm to use average winter temperature, updated example calculation.	Franklin Energy Services	12/4/17

Refrigeration

C/I Refrigeration – Add Doors to Open Multideck Case

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial and Industrial Refrigeration
Actions	Modify
Required from Customer/Contractor	Length of case in feet, refrigeration type (cooler or freezer), climate zone Optional inputs: Refrigerated case total load, HVAC COP (cooling), HVAC heating efficiency
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$126.53/linear ft. (Ref. 2)

Measure Description

Existing open multi-deck style cases can be retrofitted with doors. The doors are designed to fit right onto the open multi-deck style cases with minimal case modification. The measure savings are based on a per-foot-of-case enclosed.

Algorithms

Unit kWh Savings per Year = P_c x F_I x (1 – F_{CR}) / 3412 x (LF x 8760 / COP_R – HRS_C / COP_H) x LEN

Unit Peak kW Savings = (Unit kWh Savings per Year)/8760

Unit Dth Savings per Year = (P_c x F_I x (1 – F_{CR}) / Eff_{heat} / 1,000,000 x HRS_H) x LEN

Where:

LEN	=	case length in feet, provided by customer
P_C	=	Total case load in Btu/h per linear foot. If unknown see Table 1.
F_I	=	68%; Amount of case load associated with infiltration reduction (Ref. 3)
F_{CR}	=	13%; Amount of case load associated with conduction and radiation (Ref. 5)
3412	=	Conversion factor, Btu/h per kW
LF	=	Case load factor, the compressor duty cycle needed to maintain case temperatures. Refer to Table 1.

8760	=	Annual operating hours for case (Ref. 9)
COP_R	=	Coefficient of performance of refrigeration system. Refer to Table 1.
HRS_C	=	Annual cooling hours, equal to annual hours above an assumed balance point of 60˚F. Refer to Table 2.
HRS_H	=	Annual heating hours, equal to annual hours below an assumed balance point of 60˚F.
COP_H	=	Cooling coefficient of performance of HVAC system, assume 3.2 if unknown (Ref. 7)
Eff	=	Heating system efficiency, assume 80% if unknown (Ref. 7)
1,000,000	=	Conversion factor, Btu per Dth

Example:

Adding doors to a multideck cooler case that is six-feet wide, Zone 2.

Unit kWh Savings per Year = 1500 x 0.68 x (1-0.13)/3412 x (0.62 x 8760/2.5 – 2424/3.2) x 6 = 2,208

Unit Peak kW Savings = 2208/8760 = 0.252 kW

Unit Dth Savings per Year = 1500 x 0.68 x (1-0.13)/0.8/1,000,000 x 6336 x 6 = 42.2 Dth

Deemed Input Tables

Table 1. Cooler and Freezer calculation values

Multideck Case Type	P_C (Btuh/ft.)	LF (Ref. 9)	COP_R (Ref. 8)
Cooler	1500 (Ref. 8)	62%	2.5
Freezer	1850 (Ref. 4)	80%	1.3

Table 2. Annual Cooling (HRSC) and Heating (HRSH) Hours by Climate Zone with Balance Point of 60˚F (Ref. 6)

Climate Zone	HRS_C	HRS_H
Zone 1 (Northern MN)	2025	6735
Zone 2 (Central MN)	2424	6336
Zone 3 (Southern MN/Twin Cities)	2809	5951

References

1. California Energy Commission and California Public Utilities Commission. “Database for Energy Efficient Resources.” June 2, 2008. Available online: http://www.deeresources.com/.
2. Historic Focus on Energy project data, 2013. Two projects, average cost is $126.53 per foot.
3. Investigation of Energy-Efficient Supermarket Display Cases California Edison Research and Thermal Test Center. December 2004.

4. Manufacturer's specification sheet for open multideck style freezer case. Hussmann Excel F6L. December 2015.
5. Comparison of Vertical Display Cases: Energy and Productivity Impacts of Glass Doors Versus Open Vertical Display Cases. ASHRAE RP-1402. 2009.
6. Cooling degree data and heating degree data derived from Typical Meteorological Year 3 (TMY3) weather data for the following cities in Minnesota: averaged of International Falls and Duluth (Zone 1), average of Duluth and Minneapolis/St. Paul (Zone 2), and average of Minneapolis/St. Paul and Rochester (Zone 3).
7. U.S. Department of Energy Building Technology Program. Advanced Energy Retrofit Guide: Practical Ways to Improve Energy Performance, Grocery Stores. National Renewable Energy Laboratory. June 2012.
8. Arthur D. Little, Inc. Energy Savings Potential for Commercial Refrigeration Equipment – Final Report. 1996.
9. PA Consulting Group Inc. *State of Wisconsin Public Service Commission, Focus on Energy Evaluation Business Programs: Deemed Savings Manual V1.0.* Updated March 22, 2010.

Revision History

Version	Description	Author	Date
1.0	Original issue for adding doors to multideck cases	Franklin Energy Services	12/5/17

C/I Refrigeration - Anti-Sweat Heat Control

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial reach-in coolers and freezers with standard, low, or no-heat doors
Actions	Modify, New Construction
Required from Customer/Contractor	Equipment type (cooler or freezer), door type (standard/low/no heat), number of doors, temperature (high/medium/low), humidity or conductivity-based control
Version No.	1.3
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$200 (Ref. 2)

Measure Description

Glass doors on refrigerator and freezer cases can have anti-sweat or anti-condensate heaters in the frames and mullions of the case. These heaters operate continuously in order to prevent condensation/frosting on the glass and frame that occurs when the surface temperature is below the dew point of the surrounding air. Anti-sweat heater controls control the operation of these heaters so that they do not run continuously when not needed (lower dew point in the air as typically occurs in winter). Anti-sweat heaters are only required to operate at full capacity when the space humidity is 55%. This results in energy savings due to reduced operation of the heater elements.

Algorithms

Unit kWh Savings per Year = kW_base * n_door * ESF * BF * Hours

Where:

kW_base = Connected load kW for reach-in cooler or freezer door and frame with a heater. Refer to Table 1 for typical loads.

n_door = number of doors controlled by sensor, actual installed

Hours = 8,760 operating hours over the course of a year

ESF = Energy Savings Factor; represents the percentage of hours annually that the door heater is powered off due to the controls. Assumed to be 55% for humidity based controls, 70% for conductivity based control (Ref. 4)

BF = Bonus Factor; represents the increased savings due to reduction in cooling load inside the cases, and the increase in cooling load in the building space to cool the additional heat generated by the door heaters. Assumed to be 1.36 for low temp, 1.22 for

medium temp, and 1.15 for high temp application (Ref. 4)
Low Temperature: Freezers, -35F to 0F evaporator temp., frozen foods, ice cream, etc.
Medium Temperature: Coolers, 0F to 20F evaporator temp., meat, milk, dairy, etc.
High Temperature: Coolers, 20F to 45F evaporator temp., floral, produce, etc.

Example:

Install anti-sweat humidity-based heat control on 2-door low-temperature freezer with standard door.

Unit kWh Savings per Year = 0.195 * 2 * 0.55 * 1.36 * 8760 = 2557 kWh

Deemed Input Tables

Table 1. Typical Anti-Sweat Heater kW for Reach-in Case Doors

Application Type and Door Type	Heater kW	Ref. #
Freezer Door, Standard	0.195	(Ref. 3)
Freezer Door, Low-Heat	0.132	(Ref. 5)
Freezer Door, No-Heat	0.054	(Ref. 5)
Cooler Door, Low-Heat	0.092	(Ref. 3)
Cooler Door, No-Heat	0.052	(Ref. 5)

References

1. 2008 Database for Energy-Efficiency Resources (DEER), Version 2008.2.05, “Effective/Remaining Useful Life Values”, California Public Utilities Commission, December 16, 2008.
2. Efficiency Vermont Technical Reference User Manual (TRM) Measure Savings Algorithms and Cost Assumptions, February, 19, 2010, Pg. 208-210
3. Based on a range of wattages from two manufacturers and metered data
4. Efficiency Vermont Technical Reference User Manual (TRM) Measure Savings Algorithms and Cost Assumptions, February, 19, 2010
5. PSC of Wisconsin, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, p. 4-100 to 4-102.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	FES	8/20/2012
1.1	Corrected required inputs, defined temperature ranges, corrected example calculation, changed measure name, removed erroneous 0.9 factor in example calculation, removed Reference 5 referring to 0.9 factor, changed annual hours from 8760 to 8766	Joe Plummer	11/22/2013
1.2	Eliminated option to provide connected load and removed connected load from required inputs to simply the Smart Measure design, added equipment type to Required Inputs.	Joe Plummer	3/2/2014
1.3	Added low-heat and no-heat door options	FES	9/24/2016

C/I Refrigeration - Case Night Covers

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial and Industrial Refrigeration
Actions	Modify, New Construction
Required from Customer/Contractor	Equipment use, cooler temperature, length Optional inputs: Unoccupied hours/hours of night cover use
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0 (no expectation to utilize night covers during peak loads)
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 2)
Unit Participant Incremental Cost	$40.20/linear foot (Ref. 3)

Measure Description

Refrigeration thermal blinds, or night covers, are utilized to create a protective thermal barrier between ambient air and the cooled, conditioned air in open refrigerated cases. Deployed when grocery centers close, night covers insulate cold refrigeration cases while maintaining the desired displayed food temperature. Night covers are typically constructed of a flexible, woven fabric. Night covers differ from case strip curtains, because night covers can be designed with no gaps and are stowed during unoccupied store hours. The thermal barrier results in energy savings due to reduced refrigeration load from the loss of chilled air and the thermal gain from ambient air.

Algorithms

Unit kWh Savings per Year = CL * SF * Hours (Ref. 1)

Where:

CL	=	Case length, feet
SF	=	Savings factor per unit length based on a cooler case temperature in Table 1 (Ref. 1).
Hours	=	Unoccupied grocery hours over the course of a year (Default of 2190 hours assumes 6 hours per day)

Example

Adding an aluminum fabric night cover to a dairy case that is thermostatically set at 34°F (1°C). The 3-deck dairy case is eight (8) feet in length.

Unit kWh Savings per Year = 8 ft * 0.01 kW/ft * 2190 hrs = 175 kWh

Deemed Input Tables

Table 1. Savings factor for thermal night covers.

Refrigerated Case Temperature, °F (°C)	SF - Savings Factor, kW/ft
-35 to -5 °F (-37 to -21 °C)	0.03
0 to 30 °F (-17 to -1 °C)	0.02
35 to 55 °F (2 to 13 °C)	0.01

References

1. "Effects of low emissive shields on performance and power use of a refrigerated display case", Southern California Edison, 1997. http://www.econofrost.com/acrobat/sce_report_long.pdf. Accessed 08/23/16.
2. DEER Effective Useful Life (EUL) Summary Update, April 5, 2014. http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EUL-table-update_2014-02-05.xlsx. Accessed 08/23/16.
3. Workpaper PGECOREF101 Night Covers for Display Cases, Pacific Gas & Electric Company, May 29, 2009.

Revision History

Version	Description	Author	Date
1.0	Original issue for C&I Night Covers	Franklin Energy Services	07/19/16

C/I Refrigeration – Strip Curtains for Walk in Freezers and Coolers

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial and Industrial Refrigeration
Actions	New
Required from Customer/Contractor	Length of door(s) in linear feet, refrigeration type (cooler or freezer), climate zone
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	4 (Ref. 1)
Unit Participant Incremental Cost	$10.22/ sq ft of door opening (Ref. 2)

Measure Description

This measure pertains to the installation of infiltration barriers (strip curtains) on walk-in coolers or freezers. Strip curtains impede heat transfer from adjacent warm and humid spaces into walk-ins when the main door is opened, thereby reducing the refrigeration load. As a result, compressor run time and energy consumption are reduced. The most likely areas of application are grocery stores, supermarkets, restaurants, and refrigerated warehouse. Strip curtains must be at least 0.06 inches thick. Low temperature strip curtains must be used for low temperature applications.

Algorithms

Unit kWh Savings per Year = ΔkWh/SqFt * A

Unit Peak kW Savings = ΔkW/SqFt * A

Where:

ΔkWh/SqFt = Savings per square foot of door, as shown in Table 1

A = Doorway area (length * width) in square feet. If the actual doorway area in square feet is unknown, use the square footage value for the facility type and cooler type in Table 1. The default doorway area values assume that walk-in unit doors are 7 feet tall.

Example:

A grocery store adds a new strip curtain on a walk-in cooler that does not currently have one installed. The door width of the walk-in cooler is 4 feet and the height is 7 feet. The square footage of this doorway is 28 square feet.

Unit kWh Savings per Year = 37 kWh/SqFt x 28 SqFt = 1,036 kWh

Unit Peak kW Savings = 0.0042 kW/SqFt x 28 SqFt = 0.1176 kW

Deemed Input Tables

Table 1. Equivalent Full Load Hours of heating per zone in Minnesota by building type (Ref. 3)

Facility Type	Pre Existing Curtain Condition	Energy Savings (kWh/SqFt)	Demand Reduction (kW/SqFt)	Default Doorway Area (square feet)
Supermarket - Cooler	Existing curtain	37	0.0042	35
	No curtain	108	0.0123	
	Unknown	108	0.0123	
Supermarket - Freezer	Existing curtain	119	0.0136	35
	No curtain	349	0.0398	
	Unknown	349	0.0398	
Convenience Store - Cooler	Existing curtain	5	0.0006	21
	No curtain	20	0.0023	
	Unknown	11	0.0013	
Convenience Store - Freezer	Existing curtain	8	0.0009	21
	No curtain	27	0.0031	
	Unknown	17	0.0020	
Restaurant - Cooler	Existing curtain	8	0.0009	21
	No curtain	30	0.0034	
	Unknown	18	0.0020	
Restaurant - Freezer	Existing curtain	34	0.0039	21
	No curtain	119	0.0136	
	Unknown	81	0.0092	
Refrigerated Warehouse	Existing curtain	254	0.0290	80
	No curtain	729	0.0832	
	Unknown	287	0.0327	

Notes

This algorithm and savings values are currently used by the Wisconsin,[5] Arkansas,[6] and Illinois[7] TRMs, adapted from the 2016 Pennsylvania TRM,[4] and its earlier versions. Details on its derivation can be found in the Pennsylvania and Arkansas TRMs.

References

1. California Energy Commission and California Public Utilities Commission. "Database for Energy Efficient Resources." EUL Table. 2014. http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EUL-table-update_2014-02-05.xlsx
2. 2008 Database for Energy-Efficiency Resources (DEER). Revised DEER Measure Cost Summary, revised 6/2/2008. http://www.deeresources.com/files/deer0911planning/downloads/DEER2008_Costs_ValuesAndDocumentation_080530Rev1.zip

3. Default Energy Savings and Demand Reductions for Strip Curtains in Pennsylvania Public Utility Commission TRM, chapter 3.5.9 Strip Curtains for Walk-in Freezers and Coolers. The source algorithm from which the savings per square foot values are determined is based the ASHRAE handbook (*American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). 2010. ASHRAE Handbook, Refrigeration: 13.4, 13.6*).
4. Assumed Doorway area for four different facility types including supermarket, convenience store, restaurant and refrigerated warehouse. Pennsylvania Public Utility Commission 2016 TRM, chapter 3.5.9 Strip Curtains for Walk-in Freezers and Coolers. http://www.puc.pa.gov/pcdocs/1370278.docx
5. Cadmus. *Wisconsin Focus on Energy 2020 Technical Reference Manual*. Page 820. https://focusonenergy.com/sites/default/files/Focus_on_Energy_2020_TRM.pdf
6. Arkansas Public Service Commission. *Arkansas Technical Reference Manual*, Version 7.0. August 31, 2017. Page 443. http://www.apscservices.info/EEInfo/TRMv7.0.pdf
7. Illinois Stakeholder Advisory Group. *State of Illinois Energy Efficiency Technical Reference Manual, Version 6.0, Volume 3: Residential Measures*. October 17th, 2019. Page 541. https://ilsag.s3.amazonaws.com/IL-TRM_Effective_0-10-120_v8.0_Vol_2_C_and_I_10-17-19_Final.pdf

Revision History

Version	Description	Author	Date
01	Initial Submittal	Cadmus	9/2020

C/I Refrigeration - ECM Compressor/Condenser Fan Motors

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial and Industrial Refrigeration
Actions	Replace on Fail, Replace Working, New Construction, Modify
Required from Customer/Contractor	Type of motor that was replaced (shaded pole or permanent split capacitor) and size of the motor installed
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$80 (Ref. 2)

Measure Description

This measure includes replacing an existing shaded pole and permanent split capacitor motors with higher efficiency electronically commutated motors (ECM) in a commercial refrigeration system compressor or condensing unit.

Algorithms

Unit kWh Savings per Year = Motor_HP x LF x Conversion_Factor x (1/Baseline_Motor_Eff – 1/Proposed_Motor_Eff) x Hrs x Duty_Cycle

Unit Peak kW Savings = Motor_HP x LF x Conversion_Factor x (1/Baseline_Motor_Eff – 1/Proposed_Motor_Eff) x CF

Where:

Motor_HP = horsepower of the motor per Table 1

LF = load factor for the motor. Assumed to be 0.9 (Ref. 3)

Baseline_Motor_Eff = baseline motor efficiency per Table 2

Proposed_Motor_Eff = 76.35% (Ref. 4)

Hrs = hours per year = 8,760

Duty_Cycle = percent of time the compressor or condensing unit is actually running = 85% for freezers and 55% for coolers (Ref. 5)

CF = coincidence factor = 0.90 (Ref. 6)

Conversion_Factor = 0.746 kW per horsepower

Example:

Replacement of a 1/15 hp shaded pole condensing unit fan motor for a freezer application with an ECM motor.

Motor_HP = 0.0667

Baseline_Motor_Eff = 24.40%

Unit kWh Savings per Year = 0.0667 hp x 0.9 x 0.746 watts per hp x (1/24.40% - 1/76.35%) x 8,760 x 0.85
= 930 kWh Saved

Unit Peak kW Savings = 0.0667 hp x 0.9 x 0.746 kW per hp x (1/24.40% - 1/76.35%) x 0.90 = 0.112 kW

Deemed Input Tables

Table 1. Typical Motor Horsepower (Ref. 4)

Motor Size (Fraction)	Motor Size (Decimal)
1/20 hp	0.050
1/15 hp	0.067
1/10 hp	0.100
1/6 hp	0.167
1/3 hp	0.333
If unknown, use average of sizes above	0.143

Table 2. Baseline Motor Efficiency (Ref. 4)

Motor Type	Motor Efficiency (%)
Shaded Pole Motor	24.40%
Permanent Split Capacitor Motor (baseline for New Cons.)	53.29%
If motor type is unknown	38.85%

Methodology and Assumptions

Assumes that power output of the baseline and proposed motors are the same.

For new construction projects, the baseline motor efficiency should be the permanent split capacitor motor efficiency.

Notes

This measure does not cover the use of ECM fan motors in walk-in or reach-in cooler or freezer evaporators; refer to separate measure for ECM fan motors for those applications.

References

1. State of Wisconsin Public Service Commission of Wisconsin: Focus on Energy Evaluation, Business Programs: Measure Life Study. PA Consulting Group. October 28, 2009.
2. Public Service Commission of Wisconsin, Wisconsin Focus on Energy Technical Reference Manual, October 22, 2015, pages 435-436 and 686.
3. PSC of Wisconsin, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, p. 4-103 to 4-106.
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5. Arthur D. Little Inc. Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, Section 8.2. Final Report to the Alliance for Responsible Atmospheric Policy. March 21, 2002.
6. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/26/16

C/I Refrigeration - Demand Defrost Controls

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial and Industrial Refrigeration
Actions	Replace Working, Replace on Fail, Modify
Required from Customer/Contractor	Wattage of defrost controlled
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$619 per controller (Ref. 2, Ref. 3, see Notes)

Measure Description

Evaporator coils in walk-in freezers will accumulate ice if not intermittently defrosted. This defrosting occurs by introducing heat to the coils, which does not allow for proper heat exchange. Demand defrost controls incorporate sensors and software that statistically model the defrost cycle and only initiate defrost cycles when deemed necessary by the sensors. This measure includes replacement of an existing walk-in freezer system without electronic Demand Defrost Controls which defrosts on a timed cycle, assumed to be a 20-minute cycle occurring every 4 hours. The efficient condition of this measure is a walk-in freezer system that triggers the defrost cycle only when the software, triggered by the array of sensors, determines that defrosting must occur.

Algorithms

Unit kWh Savings per Year = $kW_{DEFROST}$ x HOU_{BASE} x SF x (1 + 1 / COP)

Unit Peak kW Savings = (Unit kWh Savings per Year) / 8,760

Where:

$kW_{DEFROST}$	=	Wattage of electric defrost; provided by customer/contractor
HOU_{BASE}	=	Yearly hours defrost occurs without defrost controls, 548 (see Notes)
SF	=	Savings Factor, 47% (see Notes)
COP	=	Coefficient of Performance, 1.3 (Ref. 4)
8,760	=	Hours of freezer use per year

Example 1:

Retrofit an existing, standard walk-in freezer with Demand Defrost Control Sensors and Software using 1,500 W of electric defrost.

Unit kWh Savings per Year = 1.5 * 548 * 47% * [1 + 3.412 / (12 * 1.3)] = 471 kWh

Unit Peak kW Savings = 471 / 8,760 = 0.054 kW

Methodology and Assumptions

Baseline Hours of Use reflect the standard defrost cycle of 4 cycles per day, each cycle taking 20 minutes.

Notes

This measure applies to high efficiency small walk-ins, not reach-ins.

The incremental cost is the difference between the cost for timer controls ($146, Ref. 2) and demand defrost controls ($765, Ref. 4). $765 - $146 = $619.

Estimates of baseline defrost hours and percent reduction in hours vary by source.

Baseline run hours

- An Oak Ridge National Laboratory paper (Ref. 5) states “Defrosts are typically scheduled to occur every six or eight hours, with a duration of 20 to 30 minutes.” This indicates HOU ranging from 365 to 730 hours a year, or **548 hours** on average.
- The Wisconsin TRM (Ref. 6) uses the Oak Ridge National Laboratory reference and assumes every six hours for 20 minutes, producing **487 hours** a year.
- A Minnesota CARD study (Ref. 7) examined two installations of KE2 brand controllers for 7 to 14 days before and after installation. The study observed the equivalent of 973 hours a year of baseline defrost in a cafeteria and 681 hours a year in a convenience store, or **827 hours** on average. The study states “Typically the defrost heaters on walk-in freezers run on a timer that turns on the heaters for 15

minutes 3 times per day," which would project to **274 hours** a year. The study also showcases a KE2 fact sheet reading "The defrost coil is controlled by a time-clock, typically set to run for 30 minutes four times a day," which is **730 hours** a year.

Savings factor

- A National Renewable Energy Laboratory paper (Ref. 8) states "In one field study, a manufacturer of these controls found that smart defrost controls reduced the number of defrost cycles by **30%** (Criscione 2006)" although their 2006 reference, titled "New Energy Saving Opportunity For Walk-In Freezers" from E Source Tech News in November 2006, is not available.
- The Massachusetts TRM (Ref. 9) deems **35%**, citing "Supported by 3rd party evaluation: Independent Testing was performed by Intertek Testing Service on a Walk-in Freezer that was retrofitted with Smart Electric Defrost capability"
- The Minnesota CARD study (Ref. 7) observed equivalent reduced hours of 164 hours a year in the cafeteria, an 83% reduction, and 209 hours in the convenience store, a 69% reduction, or a **76%** average reduction for the two sites.

Taking the bolded HOU values above as independent sources and averaging them, an HOU value of 573 hours is deemed. Taking the bolded SF values above as as independent sources and averaging them, a SF value of 47% is deemed.

References

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5. Fricke, Brian A., and Sharma, Vishal. Oak Ridge National Laboratory. "Demand Defrost Strategies in Supermarket Refrigeration Systems." October 2011. https://info.ornl.gov/sites/publications/files/pub31296.pdf
6. Cadmus. *Wisconsin Focus on Energy Technical Reference Manual*. 2021. Page 954. https://focusonenergy.com/sites/default/files/inline-files/Focus%20on%20Energy%202021%20TRM.pdf

7. Michaels Energy. *Cost-effective Recommissioning of Restaurants*. October 2015. Page 93, Appendix A, Appendix N. https://www.cards.commerce.state.mn.us/CARDS/security/search.do?method=showPoup&documentId=%7B44ECFDC5-283A-455F-A4E1-6122450D6E43%7D&documentTitle=384566&documentType=6
8. National Renewable Energy Laboratory. *Advanced Energy Retrofit Guide—Grocery Stores.* Appendix F.2.9: Detailed Retrofit Measure Description. Page 168. June 2013. https://www.osti.gov/biblio/1045045
9. Mass Save. *Massachusetts Technical Reference Manual*. May 2020. Page 649. https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/12190505

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Cadmus	9/2021

C/I Refrigeration – ENERGY STAR Ice Machines

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Refrigeration
Applicable To	Commercial air-cooled ice making head (IMH), remote condensing unit (RCU) and self-contained unit (SCU) batch and continuous-type ice making machines
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Equipment type (ICH, RCU, SCU), Harvest Type (Batch, Continuous) Ice Daily Harvest Rate (H)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 2)
Unit Participant Incremental Cost	$200 (Ref. 3)

Measure Description

Commercial ice machines are used in restaurants, hospitals, hotels, schools, offices and grocery stores. ENERGY STAR rates air-cooled ice machines. ENERGY STAR ice machines are designed with higher efficiency compressors and use less water than standard ice machines.

Algorithms

Unit kWh Savings per Year = DC x H/C x Days x (kWh_base – kWh_proposed) (Ref. 1)

Unit Peak kW Savings = CF x (Unit kWh Savings per Year)/(Days x 24) (Ref. 1)

Where:

kWh_base = baseline unit daily consumption per 100 lbs. of ice produced

kWh_proposed = proposed unit daily consumption per 100 lbs. of ice produced

DC = Duty cycle. Assumed to be 57%(Ref. 4)

H = Average ice machine harvest rate, lbs. of ice/day

C = Conversion factor, from lbs. of ice/day to 100 lbs. of ice/day

Days = Annual days of operation, 365

CF = Deemed coincidence factor, equal to 0.937 Ref. 1)

Example:

Install ENERGY STAR Ice Making Head with a batch harvest rate of 1,219 lbs. of ice/day

Unit kWh Savings per Year = 0.57 x 1,219/100 x 365 x ((6.89 - 0.0011 x 1,219) – (37.72x1219^(-0.298)) = 2,562 kWh

Unit Peak kW Savings = 0.937 x 2,562/(365x24) = 0.274 kW

Deemed Input Tables

Table 1. Air-Cooled Batch-Type Ice Makers (Ref. 5 and Ref. 6).

Ice Machine Type H = rated ice harvest rate (lbs per 24 hours)	kWh_base (kWh/100 lbs ice)	kWh_proposed (kWh/100 lbs ice)
Ice Making Head (300 ≤ H < 850)	7.05 – 0.0025 x H	37.72 x $H^{-0.298}$
Ice Making Head (1,500 ≤ H < 1,600)	4.61	37.72 x $H^{-0.298}$
Remote Condensing Unit, without remote compressor (400 ≤ H < 988)	7.97 – 0.00342 x H	22.95 x $H^{-0.258}$ + 1.00
Remote Condensing Unit, without remote compressor (988 ≤ H < 1,600)	4.59	
Remote Condensing Unit, without remote compressor (1,600 ≤ H < 4,000)	4.59	-0.00011 x H + 4.60
Remote Condensing Unit, with remote compressor (200 < H < 930)	7.97 – 0.00342 x H	22.95 x $H^{-0.258}$ + 1.00
Remote Condensing Unit, with remote compressor (1,600 ≤ H < 4,000)	4.79	-0.00011 x H + 4.60

Table 2. Air-Cooled Continuous-Type Ice Makers (Ref. 5 and Ref.6).

Ice Machine Type H = rated ice harvest rate (lbs per 24 hours)	kWh_base (kWh/100 lbs ice)	kWh_proposed (kWh/100 lbs ice)
Ice Making Head (H < 310)	9.19 – 0.00629 x H	9.18 x $H^{-0.057}$
Ice Making Head (310 ≤ H < 820)	8.23 – 0.0032 x H	
Remote Condensing Unit, without remote compressor (400 < H < 800)	9.7 - 0.0058 x H	6.00 x $H^{-0.162}$ + 3.50
Remote Condensing Unit, with remote compressor (400 ≤ H < 800)	9.9 – 0.0058 x H	6.00 x $H^{-0.162}$ + 3.50
Remote Condensing Unit, without remote compressor (800 ≤ H < 4,000)	5.26	
Self Contained Unit (700 ≤ H < 4,000)	5.1	59.45 x $H^{-0.349}$ + 0.08

Methodology and Assumptions

In Tables 1 and 2, base kWh represents federal standard maximum energy consumption for units manufactured on or after January 28, 2018 per Ref. 5. Proposed kWh represents maximum energy consumption for ENERGY STAR-labeled units per Automatic Commercial Ice Makers specification, Version 2.0. H = rated ice harvest rate in pounds per 24 hours.

Ice machine types where the ENERGY STAR maximum energy consumption exceeds the federal standard maximum energy consumption are not included in this measure.

References

1. The State of Illinois, Illinois Statewide Technical Reference Manual for Energy Efficiency DEER 2014, Version 5.0, page 59.
2. DEER 2014, http://www.deeresources.com/files/DEER2013codeUpdate/download/DEER2014-EUL-table-update_2014-02-05.xlsx, Accessed 8/8/17.
3. San Diego Gas & Electric, Work Paper WPSDGENRCC0004, Revision 2, pages i-ii.
4. Fisher-Nickel Inc., Ice Machine Field Study: Energy and Water Saving with Ice Machine Upgrade and Load Shifting, https://fishnick.com/publications/fieldstudies/Ice_Machine_Upgrade_Load_Shifting_Field_Study.pdf, Accessed 8/8/17.
5. US Department of Energy, EERE-2010-BT-STD-0037-0137, https://www.regulations.gov/document?D=EERE-2010-BT-STD-0037-0137, Accessed 8/8/17.
6. US Environmental Protection Agency, ENERGY STAR® Program Requirements for Automatic commercial ice makers, https://www.energystar.gov/sites/default/files/specs//private/ENERGY_STAR_ACIM_V_2_Specification.pdf, Accessed 8/8/17.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	12/5/17

C/I Refrigeration - ENERGY STAR Refrigerator and Freezer

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Vertical closed and horizontal closed commercial refrigerators with transparent or solid doors and self-contained condensing units
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Actual installed frozen compartment volume in cubic feet, solid or glass door, refrigerator or freezer
Version No.	3.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	See Table 1

Measure Description

This measure relates to the installation of a new reach-in commercial refrigerator or freezer meeting ENERGY STAR efficiency standards. In order for this characterization to apply, the efficient equipment is assumed to be a new vertical glass door refrigerator or freezer or vertical chest freezer meeting the minimum ENERGY STAR efficiency level standards.

Algorithms

Unit kWh Savings per Year = (kWh_base - kWh_EE) x 365

Unit Peak kW Savings = kWh Savings/8760

Where:

kWh_base	=	baseline maximum daily energy consumption in kWh, calculated using actual chilled or frozen compartment volume (V) of the efficient unit as shown in Table 2
kWh_EE	=	efficient maximum daily energy consumption in kWh, calculated using actual chilled or frozen compartment volume (V) of the efficient unit as shown in the Table 3
V	=	the chilled or frozen compartment volume (ft.^{3}) (as defined in the Association of Home Appliance Manufacturers Standard HRF1–1979), actual installed
8,760	=	operating hours over the course of a year
365	=	days per year

Example

Install an ENERGY STAR vertical glass door refrigerator with a volume of 15 ft3 (see Notes).

Unit kWh Savings per Year = ((0.1 x 15+0.86) – (0.066 x 15 + 0.31)) x 365 = 387kWh

Unit Peak kW Savings = 387 / 8760 x 0.9 = 0.040 kW

Deemed Input Tables

Table 1. Incremental capital costs for commercial ENERGY STAR refrigerators (Ref. 2)

	Refrigerator	Freezer
Vertical Closed		
Solid Door(s)		
All volumes	$86	$113
Transparent Door(s)		
All volumes	TBD*	TBD*
Horizontal Closed		
Solid Door(s)		
All volumes	TBD*	$30
Transparent Door(s)		
All volumes	$84	TBD*

*TBD means there were no product options meeting the ENERGY STAR 4.0 standard in the Technical Support Document (Ref. 2)

Table 2. Baseline maximum daily energy consumption in kWh (Ref. 3)

Product Volume (in cubic feet)	Refrigerator	Freezer
Vertical Closed		
Solid Door(s)		
All volumes	0.05V + 1.36	0.22V + 1.38
Transparent Door(s)		
All volumes	0.1V + 0.86	0.29V + 2.95
Horizontal Closed		
Solid Door(s)		
All volumes	0.05V + 0.91	0.06V + 1.12
Transparent Door(s)		
All volumes	0.06V + 0.37	0.08V + 1.23

Table 3. ENERGY STAR maximum daily energy consumption in kWh (Ref.4) Product Volume (in cubic feet)

	Refrigerator	Freezer
Vertical Closed		
Solid Door(s)		
0 < V < 15	0.022V + 0.97	0.21V + 0.9
15 ≤ V < 30	0.066V + 0.31	0.12V + 2.248
30 ≤ V < 50	0.04V + 1.09	0.285V - 2.703
V ≥ 50	0.024V + 1.89	0.142V + 4.445
Transparent Door(s)		
0 < V < 15	0.095V + 0.445	0.232V + 2.36
15 ≤ V < 30	0.05V + 1.12	
30 ≤ V < 50	0.076V + 0.34	
V ≥ 50	0.105V - 1.111	
Horizontal Closed		
Solid or Transparent		
All volumes	0.05V + 0.28	0.057V + 0.55

Notes

ENERGY STAR Program Requirements for Commercial Refrigerators and Freezers, Version 4.0, was finalized on September 20, 2016 and will take effect on March 27, 2017 (Ref. 4). Table 1 should be revised as more products are produced that meet the new ENERGY STAR standard.

References

1. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, Inc. June 2007. http://www.ctsavesenergy.org/files/Measure%20Life%20Report%202007.pdf.
2. Derived from Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Refrigeration Equipment. US DOE, February 2014. Tables 8.2.4 and 8.2.5. Determined incremental costs from mapping maximum daily energy consumption per ENERGY STAR 4.0 and Federal minimum standards to Efficiency Levels (EL) in Table 8.2.5.
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Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/20/2012
2.0	Corrected example, changed 365 days/yr. to 365.25, changed 8760 h/yr. to 8,766, changed name	Joe Plummer	2/11/2013
2.1	Corrected example	Joe Plummer	5/8/2014
2.2	Updated to new standard	Franklin Energy Services	12/18/2014
2.3	Changed example description	Joe Plummer	1/5/2015
3.0	Updated federal standards, added notes section with comment about ENERGY STAR versions, updated references and example	Franklin Energy Services	12/2/2016

C/I Refrigeration - Evaporator Fan Motor Retrofit

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial and Industrial Refrigeration
Actions	Motors > 1 hp or > 460 volts, or in walk-ins manufactured before 1/1/2009: Replace Working, Replace on Fail, Modify Motors < 1 hp and < 460 volts in walk-ins manufactured on or after 1/1/2009: Replace Working
Required from Customer/Contractor	Equipment type (refrig or freezer, reach-in or walk-in), motor category (1-14W, 16-23W, 1/20 HP, 1/15 HP, 1/10 HP) Optional inputs: wattages of existing and new evaporator fan motors
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$100 (Ref. 1)

Measure Description

This measure includes replacement of an existing, working standard-efficiency shaded-pole evaporator fan motor in refrigerated/freezer display cases or walk-in coolers with a high efficiency electronically commutated motor (ECM).

Note that Federal code requires that motors less than 1 horsepower and less than 460 volts in walk-in coolers manufactured on or after January 1, 2009 shall use ECM or 3-phase evaporator fan motors (Ref. 7). For such scenarios, this measure shall be replace working only.

Algorithms

Unit kWh Savings per Year = (W_base - W_EE)/1000 * LF * DC_evap * (1 + 1/(DG * COP)) * 8760

Unit Peak kW Savings = (W_base - W_EE)/1000 * LF * DC_evap * (1 + 1/(DG * COP)) * CF

Where:

W_base = Input wattage of existing/baseline evaporator fan motor. See Table 1 for reach-ins and Table 2 for walk-ins.

W_EE = Input wattage of new energy efficient evaporator fan motor. See Table 1 for reach-ins and Table 2 for walk-ins.

LF = Load Factor of evaporator fan motor. Assumed to be 0.9 (Ref. 2)

DC_evap = Duty cycle of evaporator fan motor for refrigerator/freezer. DC_evap = 100% for refrigerator, DC_evap = 94.4% for freezer (Ref. 2)

DG	=	Degradation factor of compressor COP. Assumed to be 0.98 (Ref. 5)
COP	=	Coefficient of performance of compressor in the refrigerator/freezer. COP = 2.5 for refrigerator, COP = 1.3 for freezer (Ref. 1, 2)
8760	=	Operating hours over the course of a year
CF	=	Coincidence factor = 0.9 (Ref. 4)

Example 1:

Replace working 19.5 Watt SP evaporator fan motor with ECM fan motor for a reach-in cooler

Unit kWh Savings per Year = (93 - 30)/1000 * 0.9 * 1 * (1 + 1/(0.98 * 2.5)) * 8760 = 700.0

Example 2:

Retrofit 1/15 HP ECM fan motor in walk-in freezer. The existing motor type is unknown.

Unit kWh Savings per Year = (193.9 - 65.1)/1000 * 0.9 * 0.944 * (1 + 1/(0.98 * 1.3)) * 8760 = 1712.2

Deemed Input Tables

Table 1. Reach-in Display Case Evaporator Fan Motor Wattages (Ref. 3, 7)

Motor Category	% of All Units[1]	Motor Output Watts	SP Eff	SP Input Watts	PSC Eff	PSC Input Watts	SP/PSC Wtd Avg Base Watts	ECM Eff	ECM Input Watts
1-14 watts (9 watt as industry average)	91%	9	18%	50	41%	22	43	66%	14
16-23 watts (19.5 watt as industry average)	3%	19.5	21%	93	41%	48	82	66%	30
1/20 HP (~37 watts)	6%	37	26%	142	41%	90	129	66%	56

Table 2. Walk-in Cooler and Freezer Evaporator Fan Motor Wattages (Ref. 6, 7)

Motor Type	Input Watts, Full Speed
1/20 hp Shaded pole	152.8
1/15 hp Shaded pole	203.8
1/10 hp Shaded Pole	305.7
1/20 hp PSC	70.0
1/15 hp PSC	93.3
1/10 hp PSC	140.0
1/20 hp ECM	48.9
1/15 hp ECM	65.1
1/10 hp ECM	97.7
1/20 hp Weighted Average of SP/PSC	145.3
1/15 hp Weighted Average of SP/PSC	193.9
1/10 hp Weighted Average of SP/PSC	290.8

Table 3. Split between shaded pole and permanent split capacitor motors for walk-in and reach-in units (Ref. 6)

Unit Type	SP %	PSC %
Walk In	91%	9%
Reach In	75%	25%

References

5. US DOE Publication #46230-00, "Energy Savings Potential for Commercial Refrigeration Equipment", 1996, Arthur C. Little, Inc http://www.scribd.com/doc/13260953/Energy-Savings-Potential-for-Commercial-Refrigeration-Equipment
6. PSC of Wisconsin, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, p. 4-103 to 4-106.
7. Regional Technical Forum (RTF) as part of the Northwest Power & Conservation Council, Deemed Measures List. Grocery Display Case ECM, FY2010, V2. Accessed from RTF website: http://www.nwcouncil.org/rtf/measures/Default.asp on July 30, 2010
8. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.
9. Regional Technical Forum. Evaporator Fan Controls and Evaporator Fan Uniform Energy Savings Measures Calculations. 2010. Available online: http://rtf.nwcouncil.org/meetings/2010/09/leds%20open%20display%20cases%20and%20ecmotor%20evap%20fan%20controllers_rev.ppt
10. Walk-in motor split is based on a random sampling of Focus on Energy projects from 2012 through August 2016; reach-in motor split is estimated based on Franklin Energy program experience.
11. Motor input watts are calculated from data in Table 5-3. 2009 of: US DOE Publication ID 6180. "Energy Savings Potential and Research & Development Opportunities for Commercial Refrigeration." Navigant Consulting, Inc. Available online: http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_refrig_report_10-09.pdf
12. Code of Federal Regulations. Title 10, Chapter II, Subchapter D, part 431.306. https://www.ecfr.gov/cgi-bin/text-idx?SID=06bb5275babde5c3b0d48497ae00764f&mc=true&node=pt10.3.431&rgn=div5#se10.3.431_1306

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/20/2012
1.1	Minor revisions, changed name, corrected required inputs, removed qty from algorithms, changed hours from 8760 to 8766 to be consistent with other measures, removed New Construction and Replace on Fail from action types since as of 2009 federal standard requires ECM motors for evaporator fan motors < 1 HP and < 460V, changed measure description, replaced "cooler" with "refrigerator", removed reference 5 (applied to new construction)	Joe Plummer	2/8/2013
1.2	Corrected Required Inputs	Joe Plummer	3/29/2014
1.3	Added weighted-average watts for baseline motors, added Table 2 for walk-in coolers and freezers, added example	Franklin Energy Services	9/6/16
2.0	Clarified that many motor types are required to be ECM	Cadmus	10/2020

C/I Refrigeration - Evaporator Fan Speed Controls

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial and Industrial Refrigeration; Single Phase Permanent Split Capacitor (PSC), Shaded Pole (SP), or Electronically Commutated (EC) Evaporator Fan Motors in Walk-in Coolers and Freezers
Actions	New Construction, Modify
Required from Customer/Contractor	Where controls were installed (cooler or freezer), number of motors controlled by each controller, type of motor used in the evaporator (shaded pole, permanent split capacitor, or ECM), and size of the motor
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	16 (Ref. 1)
Unit Participant Incremental Cost	$161.74 per motor controlled (Ref. 2)

Measure Description

This measure adds controls to vary the speed of evaporator fan motors in walk-in coolers and freezers. The evaporator fans are used to both provide cooling when the compressor is running and to provide air circulation when the compressor is off. The controls provide a lower fan speed during periods when the compressor is off.

Algorithms

Unit kWh Savings per Year = N_motors x (Watts_Full_Speed x (1-Percent_Low_Speed) + Watts_Low_Speed x Percent_Low_Speed) / Conversion_Factor x (1 + 1/(DG x COP)) x (Hrs x (1 – Percent_Defrost))

Unit Peak kW Savings = N_motors x (Watts_Full_Speed x (1-Percent_Low_Speed) + Watts_Low_Speed x Percent_Low_Speed) / Conversion_Factor x (1 + 1/(DG x COP)) x CF

Where:

N_motors = number of motors controlled

Watts_Full_Speed = wattage of fan motor at full speed, selected from Table 1 or use 138.7 watts if fan motor type and hp are unknown

Watts_Low_Speed = wattage of fan motor at low speed setting, selected from Table 1 or use 10.4 watts if fan motor type and hp are unknown

Percent_Low_Speed = percent of time the fan runs at the low speed setting = 32% for freezers and 42% for coolers (Ref. 3)

DG = Degradation factor of compressor COP. Assumed to be 0.98 (Ref. 3)

COP = Coefficient of Performance, = 2.5 for coolers, 1. 3 for freezers. (Ref. 4, Ref. 5)

Hrs = hours per year = 8,760

Percent_Defrost = percent of hours the fan is off for defrost cycle = 0% for coolers and 4% for freezers (Ref. 3)

CF = coincidence factor = 0.90 (Ref. 6)

Conversion_Factor = 1,000 watts per kW

Example:

Add evaporator fan controls to an evaporator with one 1/10 hp PSC fan motor for a walk-in freezer.

Watts_Full_Speed = 140.0

Watts_Low_Speed = 10.5

Percent_Low_Speed = 32%

COP = 1.3

Percent_Defrost = 4%

Unit kWh Savings per Year = (140.0 watts x (1-32%) + 10.5 watts x 32%) / 1,000 watts per kW x (1 + 1/(0.98 x 1.3)) x (8,760 x (1 – 4%)) = 1,480 kWh

Unit Peak kW Savings = (140.0 watts x (1-32%) + 10.5 watts x 32%) / 1,000 watts per kW x (1 + 1/(0.98 x 1.3)) x 0.90 = 0.158 kW

Deemed Input Tables

Table 1. Typical Evaporator Fan Motor Watts

Motor Type	Input Watts, Full Speed (Ref. 7)	Input Watts, Low Speed (Ref. 3)
1/20 hp Shaded pole	152.8	11.5
1/15 hp Shaded pole	203.8	15.3
1/10 hp Shaded Pole	305.7	22.9
1/20 hp PSC	70.0	5.2
1/15 hp PSC	93.3	7.0
1/10 hp PSC	140.0	10.5
1/20 hp ECM	48.9	3.7
1/15 hp ECM	65.1	4.9
1/10 hp ECM	97.7	7.3
1/20 hp Type Unknown	90.6	6.8

Motor Type	Input Watts, Full Speed (Ref. 7)	Input Watts, Low Speed (Ref. 3)
1/15 hp Type Unknown	120.7	9.1
1/10 hp Type Unknown	181.1	13.6
If neither motor type or size is known, use average of the 3 "Type Unknown" wattages:	130.8	9.8

Methodology and Assumptions

Assumes that in both the baseline and proposed cases the evaporator fan motor is off during the defrost cycle for freezer applications. Evaporator must use single phase shaded pole, permanent split capacitor, or ECM motors. Larger systems with three phase and/or induction motors are excluded from this measure.

Input watts at low speed are based on adjusting full speed input watts using fan law, using reported typical RPM from (Ref. 3), which is 1550 RPM for full speed and 550 RPM for low speed. A fan law exponent of 2.5 was used to be conservative.

Notes

This measure only covers evaporator fan controls for walk-in coolers and freezers. It does not cover reach-in coolers and freezers.

References

1. California Energy Commission and California Public Utilities Commission. Database for Efficient Resources (DEER) 2008, Effective/Remaining Useful Life Values. Available online: http://www.deeresources.com/files/deer2008exante/downloads/EUL_Summary_10-1-08.xls
2. California Energy Commission and California Public Utilities Commission. Database for Efficient Resources (DEER) 2008, Measure Cost Summary.
3. Regional Technical Forum. Evaporator Fan Controls and Evaporator Fan Uniform Energy Savings Measures Calculations. 2010. Available online: *http://rtf.nwcouncil.org/meetings/2010/09/leds%20open%20display%20cases%20and%20ecmotor%20evap%20fan%20controllers_rev.ppt*
4. US DOE Publication #46230-00, "Energy Savings Potential for Commercial Refrigeration Equipment", 1996, Arthur C. Little, Inc. Available Online: http://www.scribd.com/doc/13260953/Energy-Savings-Potential-for-Commercial-Refrigeration-Equipment
5. PSC of Wisconsin, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, p. 4-103 to 4-106.

6. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.
7. Motor input watts are calculated from data in Table 5-3. 2009 of: US DOE Publication ID 6180. "Energy Savings Potential and Research & Development Opportunities for Commercial Refrigeration." Navigant Consulting, Inc. Available online: http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_refrig_report_10-09.pdf

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/26/16

C/I Refrigeration - Loading Dock Pit Seals

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Envelope
Applicable To	Cold storage facilities
Actions	Modify, New Construction
Required from Customer/Contractor	Climate zone
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10
Unit Participant Incremental Cost	$780 for Pit/Ramp Seals (Ref. 7)

Measure Description

Many loading dock pits include a leveler ramp that has an area underneath that is exposed to the outside, and gaps that allow infiltration of outside air, causing sensible and latent heat loads that must be removed by the refrigeration system in a cold storage facility. This measure characterizes the savings from installing pit seals and/or thermal blankets to reduce these heat gains.

Algorithms

Unit kWh Savings per Year = $(\Delta Q_{infil,ave} + \Delta Q_{cond,ave}) / 3412 / COP \times Hours$

Unit Peak kW Savings = $(\Delta Q_{infil,max} + \Delta Q_{cond,max}) / 3412 / COP$

Where:

$\Delta Q_{infil,ave}$ = $4.5 \times CFM_{infil.ave} \times (h_{OA,ave} - h_0)$, average reduction in heat loss due to infiltration in Btu/hr

$\Delta Q_{cond,ave}$ = $F_1 \times A_{ramp} \times (T_{OA,ave} - T_O) \times (1/R_1 - 1/R_2)$, average reduction in heat loss due to conduction in Btu/hr

$\Delta Q_{infil,max}$ = $4.5 \times CFM_{infil.max} \times (h_{OA,max} - h_0)$, maximum reduction in heat loss due to infiltration in Btu/hr

$\Delta Q_{cond,max}$ = $F_1 \times A_{ramp} \times (T_{OA,,max} - T_O) \times (1/R_1 - 1/R_2)$, maximum reduction in heat loss due to conduction in Btu/hr

3412 = conversion factor, Btu per kWh

COP = typical coefficient of performance for refrigeration system, 2.5 for coolers (Ref. 4)

Hours = 8760, average hours per year

$CFM_{infil,ave}$ = $F_2 \times LA \times \sqrt{(C_{stack} \times (T_{OA,ave} - T_0) + C_{wind} \times V_{wind,ave}^2)}$, average outside air infiltration rate in cubic feet per minute. (Ref. 1)

$CFM_{infil,max}$	=	F_2 x LA x √(C_{stack} x ($T_{OA,max}$ - T_0) + C_{wind} x $V_{wind,max}^2$), maximum outside air infiltration rate in cubic feet per minute. (Ref. 1)
LA	=	Effective Leakage Area in square inches. If unknown, assume 16.8 in^2 (assumes a 0.05-inch gap around perimeter of 84" x 78" ramp) (Ref. 6).
C_{stack}	=	Stack Coefficient, 0.0225 Assuming a 1.5 story building (Ref. 1)
T_O	=	Indoor Temperature Setpoint. If unknown, assume 35˚F.
$T_{OA,ave}$	=	Average Outside Air Temperature, see Table 1
C_{wind}	=	Wind Coefficient, 0.0138 Assuming a 1.5 story building average with no obstructions or local shielding (Ref. 1)
$V_{wind,Ave}$	=	Average Wind Speed, see Table 1
$h_{OA,ave}$	=	Average Outside Air Enthalpy, see Table 1
h_o	=	Indoor enthalpy in Btu/lb. If unknown assume 10.24 Btu/lb. (Ref. 5)
A_{ramp}	=	Area of leveler ramp in square feet. Assume 45.5 ft^2 if unknown (84" x 78").
R_1	=	1.36, R-value of uninsulated ramp, approximately equal to R-value of air films (R-0.68) above and below ramp
R_2	=	R_{ins} + 1.36, R-value of insulated ramp, approximately equal to R-value of insulating material plus air films.
R_{ins}	=	R-value of ramp insulation. Assume R-1 if unknown.
F_1	=	0.75, adjustment factor accounting for possibility of positive pressure within the building, which will reduce the rate of heat transfer due to conduction (Ref. 6).
F_2	=	0.75, adjustment factor accounting for orientation of the dock door relative to the direction of prevailing winds (Ref. 6).

Example:

A refrigerated warehouse in Minneapolis installs a pit seal and an R-2 ramp leveler blanket. The indoor temperature setpoint is 35°F.

Energy savings calculation:

$CFM_{infil,ave}$ = 0.75 x 16.8 x √(0.0225 x (44.8 - 35) + 0.0138 x 11.5^2) = 18.0 CFM

$\Delta Q_{infil,ave}$ =4.5 x 18.0 x (17.0 – 10.24) = 547.6 Btu/h

$\Delta Q_{cond,ave}$ =0.75 x 45.5 x (44.8 – 35) x (1/1.36 – 1/3.36) = 146.4 Btu/h

Unit kWh Savings per Year = (547.6 + 146.4)/3412/2.5 x 8,760 = 713.2 kWh

Peak demand savings calculation:

$CFM_{infil,max}$ = 0.75 x 16.8 x √(0.0225 x (94.4 - 35) + 0.0138 x 40.4²) = 61.5 CFM

$\Delta Q_{infil,max}$ =4.5 x 61.5 x (49.5 – 10.24) =10,873.6 Btu/h

$\Delta Q_{cond,max}$ =0.75 x 45.5 x (94.4 – 35) x (1/1.36 – 1/3.36) = 887.2 Btu/h

Unit Peak kW Savings = 0.9 x (10,873.6 + 887.2)/3412/2.5 = 1.38 kW

Deemed Input Tables

Table 1. Outside air conditions (Ref. 2 and Ref. 3)

Climate Zone	$h_{OA,ave}$ Btu/lb.	$h_{OA,max}$ Btu/lb.	$T_{OA,ave}$ °F	$T_{OA,max}$ °F	$V_{wind,ave}$ miles/hr.	$V_{wind,max}$ miles/hr.
Zone 1 (Northern MN)	14.6	45.3	38.6	90.4	9.5	33.5
Zone 2 (Central MN)	16.0	46.8	42.6	92.8	10.4	37.5
Zone 3 (Southern MN/Twin Cities)	17.0	49.5	44.8	94.4	11.5	40.4

References

1. 2013 ASHRAE Handbook - Fundamentals, Chapter 16: Ventilation and Infiltration, page 16.23-24. Infiltration rate formula includes a 0.75 factor to account for wind orientation relative to dock door (engineering judgement).
2. National Climate Data Center - National Oceanic and Atmospheric Administration 1981-2010 Normals. Weather data for Duluth and International Falls was averaged for Zone 1, Duluth and Minneapolis for Zone 2, and Minneapolis and Rochester for Zone 3.
3. 2013 ASHRAE Handbook - Fundamentals, Climate Design Information Appendix Table, Minnesota Heating DB 99.6%.
4. US DOE Publication #46230-00, "Energy Savings Potential for Commercial Refrigeration Equipment", 1996, Arthur C. Little, Inc.
5. Assumes 40% relative humidity at 35˚F dry bulb.
6. *Energy Efficiency Evaluation: Warehouse Dock Leveler Improvements.* Prepared for Minnesota Department of Commerce by Franklin Energy, April 2011.
7. "Deemed savings estimate – Dock Pit-Door systems-v2.xls". Prepared for Minnesota Department of Commerce by Franklin Energy, April 2011.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	9/14/17

C/I Refrigeration - Low-Heat and No-Heat Doors

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Commercial and Industrial Refrigeration
Actions	New Construction, Modify
Required from Customer/Contractor	Where doors were installed (cooler or freezer), number of doors installed, type of door installed (low heat or no heat), temperature range (low, medium, or high)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	See Table 1

Measure Description

This measure replaces standard refrigerated case doors which incorporate electric resistance heaters in the door to prevent condensation from forming on the glass and frost from forming on the door frames with more efficient doors that have a smaller electric resistance heater (low heat) or no heater at all (no heat). Low heat and no heat doors are more efficient due to having three panes of glass, a low conductivity filler gas (such as argon), and/or a low-E coating on the glass.

Algorithms

Unit kWh Savings per Year = (kW_base – kW_new) x n_door x BF x Hrs

Unit Peak kW Savings = (kW_base – kW_new) x n_door x BF x CF

Where:

kW_base = connected load kW for baseline reach-in cooler or freezer door and frame with a heater per Table 2

kW_new = connected load kW for new reach-in cooler or freezer door and frame with a either a low wattage heater or no heater per Table 2

n_door = number of doors replaced

BF = Bonus Factor; represents the increased savings due to reduction in cooling load inside the cases, and the decrease in cooling load in the building space to cool the additional heat generated by the door heaters. Assumed to be 1.36 for low temp (roughly -10 to +10°F), 1.22 for medium temp (roughly 30-45°F), and 1.15 for high temp (> 50°F) application (Ref. 2)

Hrs = operating hours over the course of a year = 8,760

CF = coincidence factor = 0.90 (Ref. 3)

Example:

Retrofit a 4-door freezer from standard doors to no-heat doors.

kW_base = 0.195

kW_new = 0.054

n_door = 4

BF = 1.36 for freezers

Unit kWh Savings per Year = (0.195 – 0.054) x 4 doors x 1.36 x 8,760 = 6,724 kWh

Unit Peak kW Savings = (0.195 – 0.054) x 4 doors x 1.36 x 0.90 = 0.690 kW

Deemed Input Tables

Table 1. Incremental Cost for Low-Heat and No-Heat Doors (Ref. 4)

Application Type and Door Type	Incremental Cost per Door
Freezer Door, Low-Heat	$145.00
Freezer Door, No-Heat	$290.00
Cooler Door, No-Heat	$72.50

Table 2. Typical Anti-Sweat Heater kW for Reach-in Case Doors

Application Type and Door Type	Heater kW	Ref. #
Freezer Door, Standard	0.195	(Ref. 5)
Freezer Door, Low-Heat	0.132	(Ref. 6)
Freezer Door, No-Heat	0.054	(Ref. 6)
Cooler Door, Low-Heat	0.092	(Ref. 5)
Cooler Door, No-Heat	0.052	(Ref. 6)

Methodology and Assumptions

This measure assumes that the doors being retrofitted / upgraded have anti-sweat heaters without controls.

Cooler doors are only available in low- and no-heat options, as the smaller temperature difference across the glass results in less condensation forming. Low-heat is therefore considered the standard option for cooler doors.

Heater kW in Table 2 accounts for the door heater wattage and mullion heater wattage. No-heat doors will still have a heater in the mullion, which may be a smaller or larger wattage depending on the

manufacturer. The mullion heater wattage is why the no-heat doors don't show 0 kW for the heater kW in Table 2.

Notes

Uses methodology from anti-sweat heater controls measure in MN TRM V2.0, but adapted to have a base kW and new door kW. It is also similar to methodology used in 2015 Efficiency Vermont TRM for zero-energy doors and frames.

For cooler doors, there are only two efficiency levels available: low-heat (which is the baseline) and no-heat.

References

1. California Energy Commission and California Public Utilities Commission. Database for Efficient Resources (DEER) 2008, Effective/Remaining Useful Life Values. Available online: http://www.deeresources.com/files/deer2008exante/downloads/EUL_Summary_10-1-08.xls
2. Efficiency Vermont Technical Reference User Manual (TRM) Measure Savings Algorithms and Cost Assumptions, February, 19, 2010
3. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.
4. Public Service Commission of Wisconsin, Wisconsin Focus on Energy Technical Reference Manual, October 22, 2015, page 682.
5. Standard door kW based on a range of wattages from two manufacturers and metered data
6. PSC of Wisconsin, Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, p. 4-100 to 4-102.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/26/16

C/I Refrigeration - Floating Head Pressure Controls

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Refrigeration
Applicable To	Refrigeration systems without floating head pressure controls
Actions	Modify, New Construction
Required from Customer/Contractor	Equipment type (refrigerator or freezer), Condenser type (condensing unit or remote condenser), project location (county)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	See Table 1

Measure Description

Reducing the compressor discharge pressure reduces the pressure ratio across the compressor and improves the operating efficiency. Many systems have controls that maintain a minimum condensing pressure to ensure proper operation of all components. By letting the condensing pressure drop down at lower ambient temperatures with head pressure controls, energy savings can be achieved. The typical design target for refrigeration systems for head pressure is the equivalent of approximately 95°F saturated condensing temperature.

Algorithms

$kWh_{SAVED} = HP_{COMPRESSOR} \times (kWh / HP)$

Where:

$HP_{COMPRESSOR}$ = Actual rated horsepower of compressor

kWh / HP = Annual savings per horsepower per Table 2

Example:

A customer in climate zone 1 installed floating head pressure controls on a freezer with a five horsepower compressor and a remote condenser.

$kWh_{SAVED} = 5 \times 852 = 4{,}260$ kWh

Deemed Input Tables

Table 3. Incremental Cost by Equipment Type (Ref. 2, Ref. 3, See Assumptions)

Equipment Type	Incremental Cost ($/HP)
Refrigerator (Condensing)	$451
Refrigerator (Remote)	$239
Freezer (Condensing)	$343
Freezer (Remote)	$182

Table 4. Annual Savings (kWh/HP) by Location and Equipment Type (Ref. 2, Ref. 4, Ref. 5, See Assumptions)

Equipment Type	Zone 1 (Northern MN)	Zone 2 (Central MN)	Zone 3 (Southern MN/Twin Cities)
Refrigerator (Condensing)	887	829	736
Refrigerator (Remote)	617	577	511
Freezer (Condensing)	1,057	988	876
Freezer (Remote)	852	797	707
Unknown (Condensing)	942	880	780
Unknown (Remote)	692	647	574

Methodology and Assumptions

Incremental costs from RTF (Ref. 2) include adjustable pressure control (flood back) valve, bypass valve, filter drier, and balance port valves. Values adjusted to 2018 dollars using US inflation calculator (Ref. 3).

Billings, MT was chosen as the closest representation of a MN climate that was modeled by RTF (Ref. 2). The RTF algorithm uses eQUEST models to derive savings for several northwest cities. Billings, MT savings were adapted to the state of MN by using TMY3 data (Ref. 4) to interpolate savings as a function of temperature and applying this to MN temperature bins.

Separate savings and interpolations were used for medium and low temp, unitary and remote units. Each interpolation produced a linear fit based on two points from which slope and intercept was calculated. The first point assumes zero savings at 75°F. The second point is based on the average temperature below 75°F and the average annual savings modeled by RTF. This savings per temp interpolation is applied across temperature bins for each of the three MN TRM climate zones.

Savings for the unknown equipment type are a weighted average of refrigerators and freezers where the weights were determined using the ASHRAE Refrigeration Handbook (Ref. 5).

References

1. PA Consulting Group Inc. "State of Wisconsin Public Service Commission of Wisconsin Focus on Energy Evaluation Business Programs: Measure Life Study. Final Report." August 25, 2009. https://focusonenergy.com/sites/default/files/bpmeasurelifestudyfinal_evaluationreport.pdf
2. Regional Technical Forum. "Commercial: Grocery - Floating Head Pressure Controls for Single Compressor Systems." UES Measure Workbook 1.6. Floating Head Pressure Controls for Single Compressor Systems measures. December 5, 2016. https://rtf.nwcouncil.org/measure/floating-head-pressure-controls-single-compressor-systems
3. US Inflation Calculator. https://www.usinflationcalculator.com/
4. National Solar Radiation Data Base TMY3 weather files. https://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html
5. 2010 ASHRAE Refrigeration Handbook, page 15.1 "Medium- and low-temperature display refrigerator line-ups account for roughly 68% and 32%, respectively, of a typical supermarket's total display refrigerators."

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Cadmus	10/2018

Hot Water

Commercial Hot Water - Faucet Aerator with Electric Water Heater

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	DHW
Applicable To	Commercial facilities with electric water heaters.
Actions	Replace Working
Required from Customer/Contractor	Confirmation of electric water heater, project location (county), number of people, number of faucets, bath or kitchen faucets
Version No.	5.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$6.70 (Ref. 5)

Measure Description

This measure includes replacing an existing faucet aerator with low-flow aerator.

Algorithms

Unit kWh Savings per Year = $[(GPM_{BASE} \times TF_{BASE} - GPM_{LOW} \times TF_{LOW}) \times FLU \times (People / Faucets) \times Days \times DF \times Density \times C_P \times (T_{OUT} - T_{IN}) / (ReEff \times 3{,}412)$

Unit Peak kW Savings = Unit kWh Savings per Year x CF / Hours

Where:

GPM_{BASE}	=	Actual or 2.2 gallons per minute (Ref. 4)
TF_{BASE}	=	Throttling factor for base use = 0.83 (Ref. 9)
GPM_{LOW}	=	Actual
TF_{LOW}	=	Throttling factor for installed use = 0.95 (Ref. 9)
FLU	=	Fixture length of use = 3 min/person/day (Ref. 8)
People	=	Number of people in facility = Actual or, If unknown, assume 10 people.
Faucets	=	Number of faucets in facility = Actual or, If unknown, assume 3 faucets. (Ref. 7)
Days	=	Days of operation per Table 3 (Ref. 6)
DF	=	Drain factor per Table 2 (See Assumptions). Drain factor accounts for the fact that a portion of faucet use is dictated by volume, not time (generally filling vessels, as opposed to washing items).

Density	=	8.34 lb / gal
C_P	=	1.0 Btu / (lb x °F)
T_{OUT}	=	Temperature of faucet usage per Table 2 (Ref. 10)
T_{IN}	=	Average groundwater temperature per Table 1 (Ref. 3)
ReEff	=	Recovery Efficiency = 98% (electric water heater) (Ref. 2)
3,412	=	Conversion from Btu to kWh
CF	=	Coincidence factor per Table 2 (Ref. 11)
Hours	=	Hours of use per year = (People x FLU / Faucets) x Days / 60

Example:

Direct installation of a 1.5 GPM faucet aerator in a location with electric water heat. The type of business, zone, number of people, number of faucets, and flow rate of existing aerator is unknown.

Unit kWh Savings per Year = (2.2 x 0.83 – 1.5 x 0.95) x 3 x 10 / 3 x 304.4 x 0.95 x 8.34 x 1 x (90 – 49) / (0.98 x 3,412) = 119 kWh

Hours = (10 x 3 / 3) x 304.4 / 60 = 50.7 hours

Unit Peak kW Savings = 119 x 0.0023 / 50.7 = 0.005 kW

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 3)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Faucet Drain Factor (See Assumptions), T_{OUT} (Ref. 10), and Coincidence Factor (Ref. 11)

Application	DF	T_{OUT}	CF
Kitchen	90%	93°F	0.0033
Bath	100%	86°F	0.0012
If application is unknown	95%	90°F	0.0023

Table 3. Deemed Annual Hot Water Use by Building Type (Ref. 6)

Building Type	Days Per Year
Small Office	250
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Retail	365
Grocery	365
Warehouse	250
Elementary School	200
Jr. High/High School/College	200
Health	365
Motel	365
Hotel	365
Other Commercial	250
If building type is unknown	304.4

Methodology and Assumptions

The IL TRM (Ref. 2) assumes drain factors of 75% for kitchen and 90% for bathroom aerators. These are agreed-upon values based on engineering judgement as determined by the Illinois Stakeholder Advisory Group. However, while these seem appropriate for residential settings, here commercial sites are deemed to have 90% kitchen and 100% bathroom drain factors.

References

1. 2008 Database for Energy-Efficient Resources, EUL/RUL (Effective/Remaining Useful Life) Values. http://www.deeresources.com/deer2008exante/downloads/DEER%200607%20Measure%20Update%20Report.pdf. Accessed on 7/31/12.
2. Illinois Stakeholder Advisory Group. State of Illinois Energy Efficiency Technical Reference Manual, Version 6.0, Volume 2: Residential Measures. February 8th, 2017. Page 90. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_2_C_and_I_020817_Final.pdf
3. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* https://www.energy.gov/eere/buildings/building-america-analysis-spreadsheets
4. Title 10, Code of Federal Regulations, Part 430 – Energy Conservation Program for Consumer Products, Subpart C – Energy and Water Conservation Standards and Their Effective Dates. https://www.ecfr.gov/cgi-bin/text-idx?SID=45151ba12ebfbba8afbf95d31bcd2ace&mc=true&node=pt10.3.430&rgn=div5#sp10.3.430.c

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7. Assumes one kitchen faucet and two restroom faucets. Franklin Energy Services.
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Revision History

Version	Description	Author	Date
1.0	Created standalone spec from ResidentialElectricDHW_v03.2	Joe Plummer	
2.0	Revised formatting and algorithms	Franklin Energy Services	7/27/2012
2.1	Update the measure life and measure cost	Franklin Energy Services	7/27/2012
3.0	Update the algorithm to IL TRM	Franklin Energy Services	8/27/2012
3.1	Update the Peak kW algorithm	Franklin Energy Services	8/28/2012
3.2	Changed Action from Direct Install to Replace Working, changed from 8760 to 8766 hours per year to be consistent with other measures, minor edits	Joe Plummer	3/13/2013
3.3	Changed “electric or gas water heater” to “confirmation of gas water heater” in Required Inputs	Joe Plummer	11/25/2013
4.0	Changed “L” from 9.85 minutes to 3 minutes to more accurately reflect commercial faucet usage patterns	Franklin Energy Services	1/6/2016
5.0	Updated algorithm for kWh and kW savings, splitting out savings for kitchen and bathroom aerators, and using actual installed GPM and drain and throttling factors	Cadmus	10/2018

Commercial Hot Water - Faucet Aerator with Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	DHW
Applicable To	Commercial facilities with gas water heaters.
Actions	Replace Working
Required from Customer/Contractor	Confirmation of gas water heater, project location (county), number of people, number of faucets, bath or kitchen faucets
Version No.	5.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$6.70 (Ref. 5)

Measure Description

This measure includes replacing an existing faucet aerator with low-flow aerator.

Algorithms

Unit Dth Savings per Year = $[(GPM_{BASE} \times TF_{BASE} - GPM_{LOW} \times TF_{LOW}) \times FLU \times (People / Faucets) \times Days \times DF \times Density \times C_P \times (T_{OUT} - T_{IN}) / (ReEff \times 1{,}000{,}000)$

Where:

GPM_{BASE}	=	Actual or 2.2 gallons per minute (Ref. 4)
TF_{BASE}	=	Throttling factor for base use = 0.83 (Ref. 9)
GPM_{LOW}	=	Actual
TF_{LOW}	=	Throttling factor for installed use = 0.95 (Ref. 9)
FLU	=	Fixture length of use = 3 min/person/day (Ref. 8)
People	=	Number of people in facility = Actual or, If unknown, assume 10 people.
Faucets	=	Number of faucets in facility = Actual or, If unknown, assume 3 faucets. (Ref. 7)
Days	=	Days of operation per Table 3 (Ref. 6)
DF	=	Drain factor per Table 2 (See Assumptions). Drain factor accounts for the fact that a portion of faucet use is dictated by volume, not time (generally filling vessels, as opposed to washing items).
Density	=	8.34 lb / gal
C_P	=	1.0 Btu / (lb x °F)
T_{OUT}	=	Temperature of faucet usage per Table 2 (Ref. 10)
T_{IN}	=	Average groundwater temperature per Table 1 (Ref. 3)

ReEff	=	Recovery Efficiency = 67% (gas water heater) (Ref. 2)
1,000,000	=	Conversion from Btu to kWh

Example:

Direct installation of a 1.5 GPM faucet aerator in a location with gas water heat. The type of business, zone, number of people, number of faucets, and flow rate of existing aerator is unknown.

Unit Dth Savings per Year = (2.2 x 0.83 – 1.5 x 0.95) x 3 x 10 / 3 x 304.4 x 0.95 x 8.34 x 1 x (90 – 49) / (0.67 x 1,000,000) = 0.59 Dth

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 3)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Faucet Drain Factor (See Assumptions) and T_{OUT} (Ref. 10)

Application	DF	T_{OUT}
Kitchen	90%	93°F
Bath	100%	86°F
If application is unknown	95%	90°F

Table 3. Deemed Annual Hot Water Use by Building Type (Ref. 6)

Building Type	Days Per Year
Small Office	250
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Retail	365
Grocery	365
Warehouse	250
Elementary School	200
Jr. High/High School/College	200
Health	365
Motel	365
Hotel	365
Other Commercial	250
If building type is unknown	304.4

Methodology and Assumptions

The IL TRM (Ref. 2) assumes drain factors of 75% for kitchen and 90% for bathroom aerators. These are agreed-upon values based on engineering judgement as determined by the Illinois Stakeholder Advisory Group. However, while these seem appropriate for residential settings, here commercial sites are deemed to have 90% kitchen and 100% bathroom drain factors.

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6. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
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5.0	Updated algorithm for Dth savings, splitting out savings for kitchen and bathroom aerators, and using actual installed GPM and drain and throttling factors	Cadmus	10/2018

Commercial Hot Water - Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Water Heating
Applicable To	Storage or instantaneous gas water heaters installed in commercial applications
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Water heater type (gas storage or gas instantaneous), input Btu/h, uniform energy factor (UEF) or thermal efficiency (TE), UEF usage bin (High or Medium) if applicable, tank size in gallons, building type, square footage, project location (county)
Version No.	8.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	See Table 5
Unit Participant Incremental Cost	See Table 6

Measure Description

This measure includes replacement of failed or working gas water heaters in existing commercial facilities with high efficiency gas units, as well as installation of high efficiency gas water heaters in new commercial facilities. Includes installation of high efficiency instantaneous gas water heaters.

Algorithms

Residential and residential-duty commercial water heaters (≤ 75,000 Btu/h, see Notes):

Unit Dth Savings per Year = $Energy_{HEATWATER}$ x $(1/UEF_{MIN} – 1/UEF) / CF$

Non-residential storage water heaters (> 75,000 Btu/h, see Notes):

Unit Dth Savings per Year = $Energy_{HEATWATER}$ x $(1/TE_{MIN} – 1/TE) / CF + (SL_{BASE} – SL) \times 8{,}760 / CF$

Non-residential gas tankless water heaters (> 200,000 Btu/h, see Notes):

Unit Dth Savings per Year = $Energy_{HEATWATER}$ x $(1/TE_{MIN} – 1/TE) / CF + (SL_{BASE} / TE_{MIN}) \times 8{,}760 / CF$

Where:

$Energy_{HEATWATER}$ = SpecificHeat × Density × (Gallons /1,000 SF / Day) × Area / 1,000 × Days/Yr × $(T_{SET} - T_{cold})$

SpecificHeat = 1.0 btu / (lb·°F)

Density = 8.34 lbs / gal

Gallons/1,000 SF / Day = See Table 2; gallons per 1,000 ft^2/day based on building type.

Days = See Table 2; days per year of operation

T_{SET}	=	130˚F (Ref. 9)
T_{COLD}	=	See Table 1; average groundwater temperature
UEF_{MIN}	=	See Table 3; uniform energy factor of standard minimum efficiency consumer or residential-duty commercial water heater
TE_{MIN}	=	See Table 4; thermal efficiency of standard minimum efficiency commercial water heater
UEF	=	Uniform Energy Factor (UEF) of new consumer or residential-duty commercial water heater
TE	=	Thermal efficiency of new commercial water heater
CF	=	1,000,000 Btu⁄Dth
SL_{BASE}	=	Standby loss of baseline unit = (input Btu/h) / 800 + 100 x (tank size in gallons)^0.5
SL	=	Nameplate standby loss of new water in Btu/h Use actual if possible, otherwise use SL = 6.35 x (Tank Volume) + 413 for gas storage, or SL = 6.47 x (Tank Volume) + 430 for gas instantaneous (see Notes)

Area = Minimum of:

- Floor area served by the water heater in ft^2, provided by customer/contractor
- Tank Size / (Min Storage Capacity per 1,000 sq. ft., see Table 2) x 1000, the maximum floor area that could be served by the water heater in ft^2 based on tank size (not applicable for instantaneous units)
- (Input Mbh) / (Min Heating Capacity per 1,000 sq. ft., see Table 2) x 1000, the maximum floor area that could be served by the water heater in ft^2 based on heating capacity

Example:

A 3,000 ft^2 sit-down restaurant in Zone 2 installed a new 100-gallon, 200,000 Btu/h gas storage water heater with TE of 94%.

Max area based on tank size = 100 / 36.0 × 1,000 = 2,778 ft^2

Max area based on heating capacity = (200,000 ⁄ 1,000) / 31.9 × 1,000=6,270 ft^2

Area = minimum (3000, 2778, 6270) = 2,778 ft^2

$Energy_{HEATWATER}$ = 1 (Btu/lb·°F) × 8.34 (lbs/gal) × 816.0 (gal/1,000ft^2) × 2,778 (ft^2) / 1,000 (ft^2) × 365 (Days / Yr) × (130°F – 49.1°F) = 558,251,421 Btu⁄yr

TE_{MIN} = 80%

SL_{BASE} = 200,000 (Btu/h) / 800 + 100 x (100 gallons)^0.5 = 1,250 Btu/h

SL = 6.3526 (Btu/h/gal) x (100 gal) + 413.12 (Btu/h) = 1,048 Btu/h

Unit Dth Savings per Year = 558,251,421 x (1/0.80 – 1/0.94) / 1,000,000 + (1,250 – 1,048) x 8,760 / 1,000,000 = 103.93 + 0.84 = 105.70

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 1)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Deemed Annual Hot Water Use by Building Type, Minimum Storage Capacity and Heating Capacity (Ref. 2)

Building Type	Days Per Year	Annual Hot Water Load (Gal per 1,000 sq. ft. Per Day)	Minimum Storage Capacity (Gal per 1,000 sq. ft.)	Minimum Heating Capacity (kBtu/hr. per 1,000 sq. ft.)
Small Office	250	2.3	0.7	0.6
Large Office	250	2.3	0.7	0.6
Fast Food Restaurant	365	549.2	38.9	34.4
Sit-Down Restaurant	365	816.0	36.0	31.9
Retail	365	2.0	0.6	0.6
Grocery	365	2.2	0.7	0.6
Warehouse	250	1.0	0.3	0.3
Elementary School	200	5.7	4.6	4.0
Jr. High/High School/College	200	17.1	7.6	6.7
Health	365	342.0	21.4	27.8
Motel	365	100.0	23.9	21.1
Hotel	365	30.8	8.8	7.8
Other Commercial	250	0.7	0.2	0.2

Table 3. Minimum Uniform Energy Factor (UEF) for Residential Water Heaters (Ref. 3)

Product Class	Rated Storage Volume and Input Rating	Draw Pattern	Uniform Energy Factor
Gas-fired Storage Water Heater	≥ 20 gallons and ≤ 55 gallons	Medium	0.6483 – (0.0017 × gal)
		High	0.6920 – (0.0013 × gal)
	> 55 gallons and ≤ 100 gallons	Medium	0.7897 – (0.0004 × gal)
		High	0.8072 – (0.0003 × gal)
Gas-fired Instantaneous Water Heater	< 2 gallons and > 50,000 Btu/h	Medium	0.81
		High	0.81

Table 4. Minimum Thermal Efficiency (TE) for Commercial Water Heaters (Ref. 4)

Product Class	Minimum Thermal Efficiency
Gas-fired Storage Water Heaters	80%
Gas-fired Instantaneous Water Heaters	80%

Table 5. Equipment Lifetime by Type (Ref. 4)

Equipment Type	Lifetime (years)
Gas Storage Water Heaters	11
Gas Instantaneous Water Heaters	20

Table 6. Incremental Cost by Type (Ref. 6 and Ref. 7)

Equipment Type	Input Btu/h	Incremental Cost
Gas Storage Water Heaters	≤75,000 Btu/h	$577.00
	>75,000 Btu/h	$1,350.00
Gas Instantaneous Water Heaters	>50,000 Btu/h and <200,000 Btu/h	$1,096.60
	≥ 200,000 Btu/h	$1,800.00

Notes

In its July 2014 Final Rule (Ref. 11), the US Department of Energy (DOE) amended its test procedure for residential water heaters and certain commercial water heaters to establish a uniform efficiency descriptor. This rule also established a new equipment class of commercial waters termed "residential-duty commercial water heaters" that are required to be tested using the procedure for the uniform efficiency descriptor.

The July 2014 Final Rule also propogated the following criteria for defining non-residential water heaters, which are not subject to the uniform efficiency test procedures:

- Non-residential Gas-fired Storage: rated input > 105 kBtu/h, rated storage volume > 120 gallons
- Non-residential Gas-fired Instantaneous: rated input > 200 kBtu/h, rated storage volume > 2 gallons

Residential-duty Gas Commercial Water Heaters were defined as not meeting the above criteria, and not designed to provide outlet hot water at temperatures greater than 180 ˚F. This class of water heaters is subject to the 2014 amended test procedures.

ENERGY STAR definitions include the following criteria:

- Residential Gas-fired Storage: hot water temperature < 180˚F, rated input ≤ 75 kBtu/h and rated storage volume ≥ 20 gallons and < 100 gallons (Ref. 10)
- Residential Gas-fired Instantaneous: initiate heating upon sensing water flow, hot water temperature < 180˚F, ≥ 4 (kBtu/h)/gal, rated input > 50 kBtu/h and < 200 kBtu/h (Ref. 10)

- Commercial Gas-fired Storage: rated input > 75 kBtu/h (Ref. 12)
- Commercial Gas-fired Storage: rated input ≥ 4 (kBtu/h)/gal (Ref. 12)

Table 7. ENERGY STAR Residential Gas Water Heater Standards, Version 3.2 (Ref. 10)

Criteria		ENERGY STAR Requirements
Gas Storage Water Heaters	≤75,000 Btu/h and ≤ 55 gallons	Medium Draw Pattern UEF ≥ 0.64
		High Draw Pattern UEF ≥ 0.68
	≤75,000 Btu/h and >55 gallons	Medium Draw Pattern UEF ≥ 0.78
		High Draw Pattern UEF ≥ 0.80
Gas Instantaneous Water Heaters		UEF ≥ 0.87

Table 8. ENERGY STAR Commercial Gas Water Heater Standards (Ref. 12)

Criteria	Type	ENERGY STAR Requirements
Thermal Efficiency (TE)	Storage (> 75,000 Btu/h); Instantaneous (> 200,000 Btu/h)	TE ≥ 0.94
Maximum Standby Loss (Btu/h)	Storage (> 75,000 Btu/h)	≤ 0.84 * [(Input Btu/h / 800) + 110(tank volume in gallons)^0.5]
	Instantaneous (> 200,000 Btu/h)	N/A

The curve fitting equations for ENERGY STAR qualified gas water heaters is based on data from the ENERGY STAR Certified Products List (Ref. 13). Data from 405 gas storage and 94 gas instaneous models is used. The fit is poor, but SL is often difficult to obtain so the approximation is made here.

Notes

In its July 2014 Final Rule (Ref. 11), the US Department of Energy (DOE) amended its test procedure for residential water heaters and certain commercial water heaters to establish a uniform efficiency descriptor. This rule also established a new equipment class of commercial waters termed “residential-duty commercial water heaters” that are required to be tested using the procedure for the uniform efficiency descriptor.

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ENERGY STAR definitions include the following criteria:

- Residential Gas-fired Storage: hot water temperature < 180˚F, rated input ≤ 75 kBtu/h and rated storage volume ≥ 20 gallons and < 100 gallons (Ref. 10)
- Residential Gas-fired Instantaneous: initiate heating upon sensing water flow, hot water temperature < 180˚F, ≥ 4 (kBtu/h)/gal, rated input > 50 kBtu/h and < 200 kBtu/h (Ref. 10)
- Commercial Gas-fired Storage: rated input > 75 kBtu/h (Ref. 12)
- Commercial Gas-fired Storage: rated input ≥ 4 (kBtu/h)/gal (Ref. 12)

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	Instantaneous (> 200,000 Btu/h)	N/A

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1. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules.* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
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Revision History

Version	Description	Author	Date
7.0	Corrected instantaneous water heater efficiency requirement	Franklin Energy Services	11/11/15
7.1	Updated EF efficiency value to UEF value for residential-sized water heaters. Updated incremental costs for gas storage water heaters ≤ 75,000 Btu/h and instantaneous water heaters >50,000 Btu/h and <200,000 Btu/h	Franklin Energy Services	9/28/17
8.0	Updated to account for standby losses, changed example, updated T_{OUT}	Cadmus	10/2018

Commercial Hot Water - Heat Pump Water Heater

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Water Heating
Applicable To	Small commercial customers with residential-sized water heaters
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Tank size in gallons, new water heater uniform energy factor (UEF), UEF Usage Bin (High, Medium, or Low), building type, project location (county), input power in kW, and space heat fuel source
Version No.	1.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	10 (Ref. 3)
Unit Participant Incremental Cost	$784 (Ref. 3)

Measure Description

This measure includes replacement of failed or working storage-type electric resistance water heaters (≤ 120 gallons) in commercial facilities with more efficient storage-type heat pump water heaters.

Algorithms

Unit kWh Savings per Year = $Energy_{HeatWater} \times (1/UEF_{min} - 1/UEF) \times ESAF / CF_1$

Unit Peak kW Savings = (Unit kWh Savings per Year) / 8760 / ESAF

Unit Dth Savings per Year = (Unit kWh Savings per Year) / ESAF × CF_2 × GIF

Where:

$Energy_{HeatWater}$ = SpecificHeat × Density × Gallons/1,000 SF / Day × Area/1,000 × Days / Yr × (T_{set} - T_{cold})

SpecificHeat = 1.0 btu / lb ·°F

Density = 8.34 lbs / gal

Gallons / 1,000 SF / Day = See Table 2; gallons per 1,000 ft^2/day based on building type.

Days = See Table 2; days per year of operation

T_{set} = 140˚F (Ref. 7)

T_{cold} = See Table 1; average groundwater temperature

UEF_{min} = See Table 3; base water heater efficiency based on tank size

UEF = Uniform Energy Factor (UEF) of new water heater

ESAF = 0.50 if electric space heat,1.0 if gas space heat; electric savings adjustment factor. (Ref. 8)

GIF	=	-0.65 if gas space heat,0 if electric space heat; Gas Impact Factor. (Ref. 11)
CF_1	=	3,412 Btu⁄kWh
CF_2	=	0.003412 Dth⁄kWh

Area Minimum of:

- Floor area served by the water heater in ft^2, provided by customer/contractor
- Tank Size / (Min Storage Capacity per 1,000 sq. ft., see Table 2) x 1000, the maximum floor area that could be served by the water heater in ft^2 based on tank size (not applicable for instantaneous units)
- (Input kW x 3.412) / (Min Heating Capacity per 1,000 sq. ft., see Table 2) x 1000, the maximum floor area that could be served by the water heater in ft^2 based on heating capacity

Example:

A 10,000 ft^2 small office in Zone 2 installed a new 50-gallon, heat pump medium draw water heater with an UEF of 2.56 and input power of 3.5 kW. Space heat is electric.

The area used to calculate savings is the minimum of:

- 10,000 ft^2
- 50/2.3 x 1000 = 21,739 ft^2
- 3.5x3.412/0.6 x 1000 = 19,903 ft^2

EFmin = 0.9307 – (0.0002 x 50) = 0.9207

EnergyHeatWater = 1 x 8.34 x 2.3 x 10,000/1,000 x 250 x (140 – 49.1) = 4,359,110 Btu/yr

Unit kWh Savings per Year = 4,359,110 x (1/0.9207 – 1/2.56) x 0.5 / 3412 = 444 kWh

Unit Peak kW Savings = 444 / 8760 / 0.5 = 0.10 kW

Unit Dth Savings per Year = 444 / 0.5 x 0.003412 x 0 = 0 Dth

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 1)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Deemed Annual Hot Water Use by Building Type (Ref. 2)

Building Type	Days Per Year	Gal per 1,000 sq. ft. per Day	Minimum Heating Capacity (kBtu/hr. per 1,000 sq. ft.)
Small Office	250	2.3	0.6
Large Office	250	2.3	0.6
Fast Food Restaurant	365	549.2	34.4
Sit-Down Restaurant	365	816.0	31.9
Retail	365	2.0	0.6
Grocery	365	2.2	0.6
Warehouse	250	1.0	0.3
Elementary School	200	5.7	4.0
Jr. High/High School/College	200	17.1	6.7
Health	365	342.0	27.8
Motel	365	100.0	21.1
Hotel	365	30.8	7.8
Other Commercial	250	0.7	0.2

Table 3. Baseline efficiency based federal minimum efficiency standards (UEF), effective for products manufactured (Ref. 4)

Product Class	Rated Storage Volume	Draw Patten	Uniform Energy Factor
Electric Storage Water Heaters	≥ 20 gallons and ≤ 55 gallons	Very Small	0.8808 – (0.0008 × Gal)
		Low	0.9254 – (0.0003 × Gal)
		Medium	0.9307 – (0.0002 × Gal)
		High	0.9349 – (0.0001 × Gal)
	> 55 gallons and ≤ 100 gallons	Very Small	1.9236 – (0.0011 × Gal)
		Low	2.0440 – (0.0011 × Gal)
		Medium	2.1171 – (0.0011 × Gal)
		High	2.2418 – (0.0011 × Gal)

Methodology and Assumptions

Assumes water heaters are installed in conditioned space.

Notes

Table 4. ENERGY STAR Equipment Standards, effective 4/16/2015 (Ref. 12)

Type of Equipment	Energy Factor
Electric Storage Water Heaters, ≤ 55 gallons	UEF ≥ 2.00
Electric Storage Water Heaters, > 55 gallons	UEF ≥ 2.16

References

1. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules. http://energy.gov/eere/buildings/building-america-analysis-spreadsheets Accessed 12/19/2014.
2. US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.
3. 2008 Database for Energy-Efficiency Resources (DEER), Version 2008.2.05, "Effective/Remaining Useful Life Values", California Public Utilities Commission, December 16, 2008.
4. §430.32 Energy and water conservation standards and their compliance dates. https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8.
5. NOTICE OF PROPOSED RULEMAKING TECHNICAL SUPPORT DOCUMENT ENERGY CONSERVATION PROGRAM FOR CONSUMER PRODUCTS: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters. Chapter 8. US Department of Energy. November 23, 2009.
6. Interpolated values from Table 38, Ohio Technical Reference Manual. October 15, 2009. Page 52.
7. U.S. Census Bureau, Selected Housing Characteristics 2010 American Community Survey 1-Year Estimates) for the state of MN. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_10_1YR_DP04&prodType=table.
8. This factor accounts for the water heater location (assumes all are located in conditioned space) and that no electric savings will occur in the heating season (50 percent of the year) if the space heat is electric. 0.5 = 1 - (100% x 50%).
9. 2011 Residential Building Stock Assessment: Single-Family Characteristics and Energy Use. Page 83. http://neea.org/docs/reports/residential-building-stock-assessment-single-family-characteristics-and-energy-use.pdf.
10. Heating system usage assumed to be 24 hours x 182.5 days/year = 4,380. Based on MN TRM v2.0 Electronic Ignition Hearth measure.

11. This factor accounts for the increase in gas usage that results from the water heater being located in conditioned space. 1.3 = 6.6/5.0*50%, where 6.6 kWh represents the increase in daily space heating usage and 5.0 kWh represents the daily DHW usage and 50 percent accounts for the heating season being approximately half of the year. From The Impact of Heat Pump Water Heaters on Whole-House Energy Consumption, Canadian Mortgage and Housing Corporation.
12. ENERGY STAR Water Heater Product Criteria. https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria.

Revision History

Version	Description	Author	Date
1.0	Created standalone measure	Franklin Energy Services	11/10/15
1.1	Removed Table 4, added ENERGY STAR criteria	Franklin Energy Services	9/27/16
1.2	Updated EF efficiency value to UEF value	Franklin Energy Services	12/5/17

Commercial Hot Water - Pre-Rinse Sprayers with Electric Water Heater

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	DHW
Applicable To	Commercial facilities with kitchens: restaurants, large office buildings, etc., with gas water heaters
Actions	Replace Working
Required from Customer/Contractor	Confirmation of electric water heater, building type, project location (county)
Version No.	3.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 1)
Unit Participant Incremental Cost	Actual cost should be used; if unknown use $92.90 (Ref. 3)

Measure Description

This measure includes retrofit of working standard pre-rinse sprayers with low-flow pre-rinse sprayers in commercial kitchen applications.

Algorithms

Unit kWh Savings per Year = C_P x Density x (T_{OUT} – T_{IN}) x (GPM_{BASE} x $Hours_{BASE}$ – GPM_{EFF} x $Hours_{EFF}$) / (Eff x 3,412)

Unit Peak kW Savings = (Unit kWh Savings per Year) / 8,760 hours

Where:

C_P	=	1.0 Btu / (lb x °F); specific heat of water
Density	=	8.34 lbs / gal
GPM_{BASE}	=	2.23 gal/min (Ref. 1)
GPM_{EFF}	=	Actual or 1.12 gal/min (Ref.1)
$Hours_{BASE}$	=	0.44 hr/day (Ref. 1)
$Hours_{EFF}$	=	0.60 hr/day (Ref. 1)
Days	=	See Table 2
T_{OUT}	=	110 °F; spray water temperature (Ref. 7)
T_{IN}	=	Average groundwater temperature per Table 1 (Ref. 2)
Eff	=	0.97; electric water heater efficiency (Ref. 3)
3,412	=	Conversion from Btu to kWh

Example:

A direct install crew has installed a low-flow pre-rinse spray valve (rated flow unknown) in a local sit-down restaurant kitchen. The existing water heater is electric and the location is unknown.

WaterSaved = (2.23 gal/min x 0.44 hr/day - 1.12 gal/min x 0.60 hr/day) x 60 min/day x 365 day/yr = 6,776 gal/yr

EPG = (1 Btu/lb°F) x (8.34 lbs/gal) x (110°F - 49.0°F) = 508.7 Btu/gal

Unit kWh Savings per Year = 508.7 Btu/gal x 6,776 gal/yr / 0.97 / (3,412 Btu/kWh) = 1,020 kWh/yr

Unit Peak kW Savings = 1,020 kWh / 8,760 hours = 0.116 kW

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 2)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Deemed Days of Hot Water Use by Building Type (Ref. 5)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250
Senior Living	365

Methodology and Assumptions

The following building types were considered not to apply to this measure: Small Office, Retail, Warehouse and Motel.

Notes

The federal maximum flow standard for pre-rinse spray valves manufactured on or after January 1, 2006 is 1.6 GPM (Ref. 4). Pre-rinse spray valves manufactured on or after January 28, 2019 shall have a flow rate that does not exceed the following:

Table 3. Pre-rinse Spray Valve Flow Rate by Product Class (Ref. 4)

Effective January 28, 2019

Product Class (Spray Force in Ounce-Force, ozf)	Flow Rate (Gallons Per Minute, gpm)
Product Class 1 (≤5.0 ozf)	1.00
Product Class 2 (>5.0 ozf and ≤8.0 ozf)	1.20
Product Class 3 (>8.0 ozf)	1.28

Federal agencies are required to purchase US EPA WaterSense-labeled products where applicable. Version 1 of the WaterSense Specification for Commercial Pre-Rinse Spray Valves went into effect in September 2013 and requires a maximum flow rate value equal to 1.28 GPM or less (Ref. 6, 8).

References

1. SBW Consulting. *Impact and Process Evaluation Final Report for California Urban Water Conservation Council 2004-5 Pre-Rinse Spray Valve Installation Program (Phase 2).* February 21, 2007. http://infohouse.p2ric.org/ref/50/49026.pdf
2. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
3. Illinois Stakeholder Advisory Group. *Illinoise Statewide Technical Reference Manual for Energy Efficiency, Version 6.0, Volume 2.* Page 60. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_2_C_and_I_020817_Final.pdf
4. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment, Subpart O - Commercial Prerinse Spray Valves. January 1, 2010. https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=314b19ef2b3eab0c89f644fe6f841fe2&mc=true&n=pt10.3.431&r=PART&ty=HTML#sp10.3.431.o
5. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
6. Purchasing Water-Efficient Faucets, Pre-Rinse Spray Valves, Showerheads, Toilets, and Urinals. http://www.energy.gov/eere/femp/purchasing-water-efficient-faucets-pre-rinse-spray-valves-showerheads-toilets-and-urinals. Accessed 09/24/16.
7. 110°F is an average of surveyed results in *Pre-Rinse Spray Valves Field Study Report*, EPA WaterSense. March 31, 2011. http://www3.epa.gov/watersense/docs/final_epa_prsv_study_report_033111v2_508.pdf.
8. WaterSense® Specification for Commercial Pre-Rinse Spray Valves, Version 1.0, September 19, 2013. https://www3.epa.gov/watersense/docs/prsv-finalspec-091913-final-508.pdf. Accessed 09/24/16.

Revision History

Version	Description	Author	Date
3.0	Added Senior Living building type and unknown location to Table 1. The average hot water temperature has been increased from 105˚F to 110˚F based on the results of a 2011 EPA study.	Franklin Energy Services	12/1/2015
3.1	Added 2019 federal standard to Notes, updated purchasing requirements for federal agencies.	Franklin Energy Services	8/22/2016
3.2	Algorithm reworked, permitting actual installed flowrate	Cadmus	10/2018

Commercial Hot Water - Pre-Rinse Sprayers with Gas Water Heater

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	DHW
Applicable To	Commercial facilities with kitchens: restaurants, large office buildings, etc., with gas water heaters
Actions	Replace Working
Required from Customer/Contractor	Confirmation of gas water heater, building type, project location (county)
Version No.	3.2
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	5 (Ref. 1)
Unit Participant Incremental Cost	Actual cost should be used; if unknown use $92.90 (Ref. 3)

Measure Description

This measure includes retrofit of working standard pre-rinse sprayers with low-flow, 1.6 gpm pre-rinse sprayers in commercial kitchen applications.

Algorithms

Unit Dth Savings per Year = C_P x Density x (T_{OUT} – T_{IN}) x (GPM_{BASE} x $Hours_{BASE}$ – GPM_{EFF} x $Hours_{EFF}$) / (Eff x 1,000,000)

Where:

C_P	=	1.0 Btu / (lb x °F); specific heat of water
Density	=	8.34 lbs / gal
GPM_{BASE}	=	2.23 gal/min (Ref. 1)
GPM_{EFF}	=	Actual or 1.12 gal/min (Ref.1)
$Hours_{BASE}$	=	0.44 hr/day (Ref. 1)
$Hours_{EFF}$	=	0.60 hr/day (Ref. 1)
Days	=	See Table 2
T_{OUT}	=	110 °F; spray water temperature (Ref. 7)
T_{IN}	=	Average groundwater temperature per Table 1 (Ref. 2)
Eff	=	0.80; gas water heater efficiency (Ref. 3)
1,000,000	=	Conversion from Btu to Dth

Example:

A direct install crew has installed a low-flow pre-rinse spray valve (rated flow unknown) in a local sit-down restaurant kitchen. The existing water heater is gas and the location is unknown.

WaterSaved = (2.23 gal/min x 0.44 hr/day – 1.12 gal/min x 0.60 hr/day) x 60 min/day x 365 day/yr = 6,776 gal/yr

EPG = (1 Btu/lb°F) x (8.34 lbs/gal) x (110°F – 49.0°F) = 508.7 Btu/gal

Unit Dth Savings per Year = 508.7 Btu/gal x 6,776 gal/yr / 0.80 / (1,000,000 Btu/Dth) = 4.3 Dth/yr

Deemed Input Tables

Table 1. Average groundwater temperatures (Ref. 2)

Location	Temperature (°F)
Zone 1 (Northern MN)	46.5
Zone 2 (Central MN)	49.1
Zone 3 (Twin Cities/Southern MN)	51.3
If location is unknown	49.0

Table 2. Deemed Days of Hot Water Use by Building Type (Ref. 5)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250
Senior Living	365

Methodology and Assumptions

The following building types were considered not to apply to this measure: Small Office, Retail, Warehouse and Motel.

Notes

The federal maximum flow standard for pre-rinse spray valves manufactured on or after January 1, 2006 is 1.6 GPM (Ref. 4). Pre-rinse spray valves manufactured on or after January 28, 2019 shall have a flow rate that does not exceed the following:

Table 3. Pre-rinse Spray Valve Flow Rate by Product Class (Ref. 4)

Effective January 28, 2019

Product Class (Spray Force in Ounce-Force, ozf)	Flow Rate (Gallons Per Minute, gpm)
Product Class 1 (≤5.0 ozf)	1.00
Product Class 2 (>5.0 ozf and ≤8.0 ozf)	1.20
Product Class 3 (>8.0 ozf)	1.28

Federal agencies are required to purchase US EPA WaterSense-labeled products where applicable. Version 1 of the WaterSense Specification for Commercial Pre-Rinse Spray Valves went into effect in September 2013 and requires a maximum flow rate value equal to 1.28 GPM or less (Ref. 6, 8).

References

1. SBW Consulting. *Impact and Process Evaluation Final Report for California Urban Water Conservation Council 2004-5 Pre-Rinse Spray Valve Installation Program (Phase 2).* February 21, 2007. http://infohouse.p2ric.org/ref/50/49026.pdf
2. US DOE Building America Program. Building America Analysis Spreadsheet, *Standard Benchmark DHW Schedules* http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html
3. Illinois Stakeholder Advisory Group. *Illinoise Statewide Technical Reference Manual for Energy Efficiency, Version 6.0, Volume 2.* Page 60. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_2_C_and_I_020817_Final.pdf
4. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment, Subpart O - Commercial Prerinse Spray Valves. January 1, 2010. https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=314b19ef2b3eab0c89f644fe6f841fe2&mc=true&n=pt10.3.431&r=PART&ty=HTML#sp10.3.431.o
5. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
6. Purchasing Water-Efficient Faucets, Pre-Rinse Spray Valves, Showerheads, Toilets, and Urinals. http://www.energy.gov/eere/femp/purchasing-water-efficient-faucets-pre-rinse-spray-valves-showerheads-toilets-and-urinals. Accessed 09/24/16.
7. 110°F is an average of surveyed results in *Pre-Rinse Spray Valves Field Study Report*, EPA WaterSense. March 31, 2011. http://www3.epa.gov/watersense/docs/final_epa_prsv_study_report_033111v2_508.pdf.
8. WaterSense® Specification for Commercial Pre-Rinse Spray Valves, Version 1.0, September 19, 2013. https://www3.epa.gov/watersense/docs/prsv-finalspec-091913-final-508.pdf. Accessed 09/24/16.

Revision History

Version	Description	Author	Date
3.0	Added Senior Living building type and unknown location to Table 1. The average hot water temperature has been increased from 105˚F to 110˚F based on the results of a 2011 EPA study.	Franklin Energy Services	12/1/2015
3.1	Added 2019 federal standard to Notes, updated purchasing requirements for federal agencies.	Franklin Energy Services	8/22/2016
3.2	Algorithm reworked, permitting actual installed flowrate	Cadmus	10/2018

Compressed Air

Industrial Compressed Air - Compressed Air Leak Detection

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Industrial Process
Applicable To	Industrial customers who have medium-to-large compressed air systems used in their manufacturing plant
Actions	Operation and Maintenance
Required from Customer/Contractor	Number of leaks repaired, leak size (CFM), air compressor type, air compressor control strategy, and annual operating hours of compressor. The customer must also maintain a 2 or 3-tag leak detection, repair, and monitoring system to receive incentives. Incentives can only be paid after the detected leaks have been repaired, and tested to ensure the repairs were actually performed.
Version No.	1.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	1 year (Ref. 1)
Unit Participant Incremental Cost	$8 per horsepower (Ref. 2)

Measure Description

This measure shows the energy savings potential associated with reducing compressed air losses through ultrasonic leak detection, and the repair of compressed air leaks. Compressed air leaks can be responsible for as much as 20-30 percent of the total air compressor output in a facility. This measure is applicable for compressed air systems in manufacturing environments where they are used for blow off, pneumatic tools, and manufacturing processes of many varieties.

Algorithms

Unit kWh Savings per Year = N_leaks x CFM_leaks x C_aircomp x t x Control_factor

Unit Peak kW Savings = (unit kWh Savings per Year x CF)/t

Where:

N_leaks = Number of leaks repaired

CFM_leaks = CFM loss per leak (review Table 1)

C_aircomp = See Table 2. If unknown compressor type, use 0.19 kW/CFM (Ref. 3)

Control_factor = See Table 3. If unknown control type, use 0.3 %kW/%load (Ref. 4)

t	=	Hours of operation per year for an average manufacturing plant 6240 (Ref. 5)
CF	=	Coincidence Factor (0.845) (Ref. 6)

Example:

An ultrasonic leak detection service is performed at the facility, and identifies 10 small leaks, of 1/64th inch diameter. Assumptions:

- Facility operates at 100 PSIG
- Facility operates three shifts (6240 hours per year)
- Single-acting Reciprocating Air Compressor
- Inlet Valve Modulated Compressor Controls

Using the cfm value from Table 1 for a very small leak

Unit KWh Savings per Year = 10 x 0.41 x .23 x 6,240 x .31 = 1,824 kWh/year

Unit Peak KW Savings per Year = (1,824 x 0.845)/6,240 = 0.247 KW

Deemed Input Tables

Table 1. CFM per Leak Size for Compressed Air Leaks (Ref. 7)

Pressure (psig)	Orifice Diameter (inches)					
	1/64	1/32	1/16	1/8	1/4	3/8
70	0.3	1.2	4.8	19.2	76.7	173
80	0.33	1.3	5.4	21.4	85.7	193
90	0.37	1.5	5.9	23.8	94.8	213
100	0.41	1.6	6.5	26	104	234
125	0.49	2	7.9	31.6	126	284

Table 2. kW/CFM Efficiencies for Several Compressor Types (Ref. 3)

Type	Efficiency
Single-acting Reciprocating Air Compressor	0.23 kW/CFM
Double-acting Reciprocating Air Compressor	0.155 kW/CFM
Lubricant-injected Rotary Screw Compressor	0.185 kW/CFM
Lubricant-free Rotary Screw Compressor	0.2 kW/CFM
Centrifugal Compressor	0.18 kW/CFM
AVERAGE:	**0.19 kW/CFM**

*Data from Compressed Air Challenge "Fundamentals of Compressed Air Systems" Pgs. 28-32

Table 3. Efficiency Factors per control type for air compressors (Ref. 4)

Control Type	Percent kW/Percent load
Inlet Valve Modulated	0.31
Variable Displacement	0.69
Variable Speed Drive	0.85

*Data extrapolated from Compressed Air Challenge "Fundamentals of Compressed Air Systems" Pg. 90-91

Methodology and Assumptions

Assumptions were made based on average data for several different types of air compressors from Fundamentals of Compressed Air. Averages were assumed for compressor type to make calculations simpler.

Notes

Savings are based on a load-unload control style compressor. Load-unload style compressors will have much less savings than their VSD or Variable Displacement counterparts. There are limited studies available on the market saturation of VSD air compressors, and therefore estimates based on the load-unload model are more conservative, and more likely.

References

1. One year measure life is based on typical recommendation of annual leak survey.
2. Engineering estimate: estimated from previous project cost data review and engineering judgment.
3. Compressed Air Challenge "Fundamentals of Compressed Air Systems" Pgs. 28-32.
4. Compressed Air Challenge "Fundamentals of Compressed Air Systems" Pgs. 90-91.
5. This is based on 3 shifts per day, 5 days per week. This figure is supported by a survey of previous compressed air projects within Michigan and Ohio energy efficiency programs.
6. KEMA, New Jersey's Clean Energy Program Energy Impact Evaluation and Protocol Review, July 10, 2009.
7. "Energy Tips: Minimize Compressed Air Leaks" http://www.energystar.gov/ia/business/industry/compressed_air3.pdf.

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	11/12/2015

Industrial Compressed Air - Cycling Air Dryers

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Process
Applicable To	Compressed air systems. Existing air dryers must run exclusively in non-cycling mode and cannot be equipped with a feature allowing operation in a cycling mode.
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Capacity of cycling dryer (CFM), Annual Operating Hours
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$11 per CFM (Ref. 2)

Measure Description

This measure includes replacing existing standard non-cycling refrigerated air dryers with new cycling air dryers. Cycling compressed air dryers are able to better match air drying with demand. Due to a significant degree of variability in types of compressed air dryers, the savings algorithms reflect average savings from switching from non-cycling to cycling implementations.

Algorithms

Unit kWh Savings per Year = (ΔkW/CFM) * CFM_Capacity * hours

Unit Peak kW Savings = CF * (ΔkW/CFM) * CFM_Capacity

Where:

CF = 0.865; electrical peak coincidence factor (Ref. 6)

ΔkW/CFM = kW_base * (EC_{nc}-$EC_{cycling}$) = 0.00238 kW/CFM; demand savings per CFM of dryer capacity

kW_base = 0.007 kW/CFM (Ref. 3); typical power draw of a fully loaded non-cycling air dryer.

EC_{nc} = 95% (Ref. 4); average % kW for non-cycling dryer

EC_c = 61% (Ref. 4); average % kW for cycling dryer

Hours = Annual operating hours, provided by customer/contractor or use 6,240 hours per year if unknown (Ref. 5).

CFM_capacity = Capacity of cycling dryer in cubic feet per minute (CFM), provided by customer/contractor.

Example:

Replacement of a non-cycling air dryer with a capacity of 300 CFM with a cycling air dryer with a capacity of 300 CFM. In this case customer does not specifically provide operating hours.

Unit kWh Savings per Year = 0.00238 * 300 * 6240 = 4,455

Unit Peak kW Savings = 0.865 * 0.00238 * 300 = 0.618

Methodology and Assumptions

The calculation in this TRM reflects average savings moving from a non-cycling dryer to a cycling dryer. If more accuracy is required, a custom calculation should be used.

References

1. *Measure Life Study* prepared for the Massachusetts Joint Utilities. Energy and Resource Solutions, 2005. http://rtf.nwcouncil.org/subcommittees/nonreslighting/Measure%20Life%20Study_MA%20Joint%20Utilities_2005_ERS-1.pdf, accessed 9/25/16.
2. Analysis of material cost between cycling and non-cycling dryers according to prices from Grainger (September 2016). Cost provided is the average incremental cost when comparing non-cycling dryers and cycling dryers of the same CFM capacity.
3. Based on a survey of available CAGI data sheets on non-cycling units from Gardner Denver, Hankison, Ingersoll Rand, Sullair and Zeks.
4. 95% and 61% represent the average percent power at 50% capacity for a non-cycling and cycling dryer, respectively. These figures were determined by all available CAGI data for refrigerated dryers manufactured by Atlas Copco, Gardner Denver, Hankison, Ingersoll Rand, Sullair and Zeks.
5. Annual operating hours assume 3 shifts per day, 5 days per week. This figure is supported by a survey of previous compressed air projects within Michigan and Ohio energy efficiency programs.
6. New Jersey's Clean Energy Program Energy Impact Evaluation and Protocol Review. KEMA, July 2009. Page 3-73. http://www.njcleanenergy.com/files/file/Library/SmartStart%20Protocol%20Review%20-%20Final%20July%2010%202009.pdf, accessed 9/25/16.

Revision History

Version	Description	Author	Date
1.0	New workpaper	Franklin Energy Services	9/25/2016

Industrial Compressed Air - Engineered Nozzles

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Industrial Process
Applicable To	Primarily manufacturing facilities with compressed air systems
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	Operating pressure at nozzle inlet; nozzle diameter; compressed air system pressurized hours per year
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$77 (Ref. 2)

Measure Description

This measure includes replacement of standard air nozzles with engineered nozzles, also referred to as Venturi or air amplification nozzles. Engineered nozzles use compressed air to entrain and amplify atmospheric air into a stream, thus increasing pressure while reducing compressed air use by up to 70%. The velocity of the resulting air stream is lower than an open jet, but the mass flow of the air is increased, thus increasing the cooling and drying effect. Engineered nozzles have the added benefits of noise reduction and improved safety in systems with pressures greater than 30 psig.

Algorithms

Unit kWh Savings per Year = (kW_base – kW_EE) * %USE * Hours

Unit Peak kW Savings = (kW_base – kW_EE) * CF

Where:

kW_base	=	SCFM_base * (ΔkW/CFM); standard nozzle demand (kW)
kW_EE	=	SCFM_EE * (ΔkW/CFM); engineered nozzle demand (kW)
SCFM_base	=	rated flow of standard air nozzle at operating pressure. If unknown, estimate from SCFM_base=C_flow * 14.5 * (14.7 + P) * Dia^2 (Ref. 3)
SCFM_EE	=	rated flow of engineered air nozzle at operating pressure. If unknown, estimate from SCFM_EE=SCFM_base * %ΔSCFM
C_flow	=	0.79 (Ref. 3); coefficient of flow
P	=	gauge pressure at orifice or nozzle. 80 psig is a reasonable estimate if unknown (Ref. 4)
Dia	=	diameter of orifice or nozzle in inches.
%ΔSCFM	=	percent reduction in air loss per nozzle, estimated at 50% (Ref. 4).

ΔkW/CFM	=	system power reduction per air demand (kW per CFM). If unknown, assume 0.20 kW/SCFM (Ref. 7).
Hours	=	provided by customer/contractor; compressed air system pressurized hours per year. If unknown, assume 6240 (Ref. 8).
%USE	=	5%; percent of the compressor total operating hours that the nozzle is in use. (Ref. 5)
CF	=	0.865 (Ref. 6); peak electrical coincidence factor

Example:

A plant that produces plastic packaging has installed an engineered nozzle to replace an existing ¼" diameter nozzle on an injection molding machine. The packaging plant operates on a two-shift schedule, at 3,952 hours annually. The operating pressure and air compressor/control type are unknown.

SCFM_base = 0.79 * 14.5 * (14.7 + 80) * 0.25^2 = 67.80 CFM

SCFM_EE = 67.80 * 0.5 = 33.90 CFM

kW_base = 67.80 * 0.20 = 13.56 kW

kW_EE = 33.90 * 0.20 = 6.78 kW

Unit kWh Savings per Year = (13.56 - 6.78) * 0.05 * 3952 = 1,440 kWh

Unit Peak kW Savings = (13.56 – 6.78) * 0.865 = 5.86 kW

Table 1. Calculated Annual Energy Savings by Nozzle Diameter

Nozzle Diameter	kWh Savings per Year	Peak kW Savings
1/8"	397	0.055
3/16"	892	0.124
1/4"	1587	0.220
5/16"	2479	0.344
3/8"	3570	0.495
7/16"	4859	0.674
1/2"	6346	0.880

Assumptions: 6,240 hours/yr, 80 psig, %ΔSCFM = 50%, Screw Compressor/Load-Unload Control or Variable Displacement.

Methodology and Assumptions

Compressor is assumed to be between 40% and 100% capacity before and after changes to system demand.

Notes

Savings are sensitive to inlet pressure. It is best to obtain inlet pressure from customer, although estimates using 80 psig are reasonable if unknown.

References

1. *Business Programs: Measure Life Study.* PA Consulting Group, 2009. Prepared for the State of Wisconsin Public Service Commission.
2. Average of incremental measure costs, Illinois Technical Reference Manual, v5.0, February 2016. Costs are from EXAIR's website, accessed March 20, 2014.
3. Adapted from Air Flow Through Orifices; Air Compressor Works, Inc. CFM = 14.5 x P x D^2, where P is in absolute pressure. Because gauge pressure is provided for this measure, a factor of 14.7 psi (1 atm.) must be added to ensure absolute pressure. http://www.aircompressorworks.com/airflowthroughorifices.html. Accessed 08/24/16.
4. Illinois Technical Reference Manual, v5.0, February 2016. Conservative estimate based on average values provided by the Compressed Air Challenge Handbook.
5. Ohio Technical Reference Manual, August 2010. Assumes 50% handheld air guns and 50% stationary air nozzles. Manual air guns tend to be used less than stationary air nozzles, and a conservative estimate of 1 second of blow-off per minute of compressor run time is assumed. Stationary air nozzles are commonly more wasteful as they are often mounted on machine tools and can be manually operated resulting in the possibility of a long term open blow situation. An assumption of 5 seconds of blow-off per minute of compressor run time is used.
6. New Jersey's Clean Energy Program Energy Impact Evaluation and Protocol Review. KEMA, July 2009. Page 3-73.
7. The default value of 20 kW/100 cfm is from a market survey of 5 yr old model air compressor systems manufactured by Kaeser, Sullair, and Ingersoll Rand and is typical of older systems found in the field.

Revision History

Version	Description	Author	Date
1.0	Measure created	Franklin Energy Services	12/5/16

Industrial Compressed Air - Low Pressure Drop Filters

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Process
Applicable To	Compressed air systems ≥ 50 HP. Low pressure drop filter must have an initial pressure drop of 1 psid or less, and must replace a standard coalescing filter.
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Compressor nominal HP, nominal inlet flow of filter in SCFM. If SCFM is rated for both upstream and downstream of dryer are given, use the lower upstream value. Optional: Motor efficiency, compressed air system annual operating hours, pressure drop reduction in psi.
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 years (Replace on Fail, New Construction) or 3 years (Replace Working) (Ref. 1)
Unit Participant Incremental Cost	$1,740 + $2 per SCFM (Ref. 2)

Measure Description

This measure includes replacing standard coalescing filters with low pressure drop filters (aka Mist Eliminators). Oil filters will have pressure drops associated with their presence in a compressed air system, and generally low pressure filters will reduce the average required pressure by 5 psi. Lowering the pressure requirements of the system enable the compressor pressure setpoint to be lowered, reducing the energy input required by the system.

Algorithms

Unit kWh Savings per Year = C * HP/Eff * LF * Hours * Δpsid * SF/100

Unit Peak kW Savings = (Unit kWh Savings per Year) / Hours * CF

Where:

C	=	0.746 kW/HP; conversion factor from HP to kW.
HP	=	compressor nominal horsepower
Eff	=	provided by customer/contractor; compressor motor efficiency. If unknown, assume 90% (Ref. 3).
LF	=	75% (Ref. 4); typical compressor load factor
Hours	=	provided by customer/contractor; annual operating hours. If unknown, use 6240 hours (Ref. 5)

SF	=	0.5; Savings Factor (for every 2 psi reduced, annual consumption is reduced by 1%) (Ref. 6)
Δpsid	=	Provided by customer/contractor; initial pressure drop reduction from switching from standard coalescing to mist eliminator filter. If unknown, assume 5 psig (Ref. 7).
CF	=	0.865 (Ref. 8); peak electrical coincidence factor.

Example:

A manufacturer installs a 435 SCFM mist eliminator filter to replace a working standard coalescing filter on a 100 HP compressed air system.

Unit kWh Savings per Year = 0.746 * 100 / 0.90 * 0.75 * 6240 * 5 * 0.5/100 = 9,698 kWh

Unit Peak kW Savings = 9,698/6240 * 0.865 = 1.3 kW

Methodology and Assumptions

The kWh savings algorithm reflects average savings based on typical load factors for compressed air systems and pressure drop reductions, and uses a standard savings per unit of pressure reduction (1% reduction in compressor drive energy versus 2 psi in pressure drop reduction).

References

1. Massachusetts Technical Reference Manual, 2013-2015 Program Years – Plan Version, October 2012. Page 266. Based on typical replacement schedules for low pressure filters (NSTAR staff estimates).
2. Estimated by regressing cost vs. rated SCFM over a range of products manufactured by Pneumatech, Aircel, Deltech, and Donaldson.
3. Franklin Energy Services default value for compressor motor efficiency.
4. Twelve custom compressed air projects (within MI and OH programs) were surveyed, where older, traditional controlled air compressors were replaced with similar-sized VSD air compressors. On average, these compressors were loaded to 47% (approx. 50%) of their full-load CFM. For load-unload control as typically found on older systems, this translates to approximately 75% of full-load kW.
5. Annual operating hours assume 3 shifts per day, 5 days per week. This figure is supported by a survey of previous compressed air projects within Michigan and Ohio energy efficiency programs.
6. *Improving Compressed Air System Performance: A Sourcebook for Industry.* US Department of Energy, November 2003.

7. Conservative estimate based on a review of datasheets from AirTak, Van Air, ZEKS, Motivair, Aircel and Deltech.
8. New Jersey's Clean Energy Program Energy Impact Evaluation and Protocol Review. KEMA, July 2009. Page 3-73.

Revision History

Version	Description	Author	Date
1.0	New workpaper	Franklin Energy Services	9/6/2016

Industrial Compressed Air - No Loss Drains

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Industrial Process
Applicable To	Industrial and commercial customers
Actions	Replace Working, Replace on Fail
Required from Customer/Contractor	CAGI Data Sheet for Air Compressor, Annual Hours of Operation
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	13 (Ref. 5)
Unit Participant Incremental Cost	$450/drain (Ref. 4)

Measure Description

This measure includes replacement of a failed or working open tube, timed, or manual condensate drain in a compressed air system with a qualified electronic, pneumatic, or hybrid "no loss drain" that is designed to automatically adjust with system demand and completely eliminate condensate with zero compressed air loss.

Algorithms

Unit kWh Savings per Year = kW_100_CFM*Hours*Drain_CFM/100

Unit Peak kW Savings = kW_100_CFM*Drain_CFM*CF/100

Where:

kW_100_CFM = Compressor efficiency, kW/100 CFM as listed on Compressed Air and Gas Institute (CAGI) datasheet. 20 kW/100 CFM is default value

Hours = Annual hours of operation. 3,528 hr default value. (reference 2)

Drain_CFM = Average CFM of existing drain, 3 CFM (reference 3)

CF = Coincidence Factor = 0.80

Example:

Install a no loss drain on a 40hp compressed air system, with a CAGI efficiency of 16 kW/100CFM and running 2,000 hr/yr

Unit kWh Savings per Year = 16 x 3 x 2000 / 10 = 960

Unit kW Savings per Year = 16 x 3 x 0.8 / 100 = 0.39

Notes

The default value of 20 kW/100 cfm is from a market survey of 5 yr old model air compressor systems. Kaeser, Sullair, Ingersoll Rand

The average drain loss (cfm) assumes a timed drain system operating approximately 5% of the time. Average size is 1/4" orifice.

Focus on Energy (WI) and New York Standard Approach uses a CF = 0.80.

Consider updating default hours in future update.

References

1. US Department of Energy. Improving Compressed Air System Performance - A Sourcebook for Industry. November 2003.
2. US Department of Energy. United States Electric Motor Systems Market Opportunities Assessment. Appendix B. Dec 2002.
3. Orr, Ross. The Importance of Condensate Drains on Air System Efficiency. airbestpractices.com. May 2012.
4. Pliske, Jim. Compressed Air System Survey and Consultation. Brabazon Engineered Systems & Technology. Sept 2010.
5. Measure Life Study. Energy & Resource Solutions. Prepared for the Massachusetts Joint Utilities; Table 1-1. 2005.

Revision History

Version	Description	Author	Date
1.0	Original issue	Franklin Energy Services	8/28/2012
1.1	Added Replace on Fail to Action Types, changed measure name, added note to consider updating default hours in future update	Joe Plummer	9/12/2013

Industrial Compressed Air – Pressure/Flow Controller

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Industrial Process
Applicable To	Compressed air systems
Actions	Modify, New Construction
Required from Customer/Contractor	Compressor nominal HP Optional: Motor efficiency, compressed air system annual operating hours, pressure drop reduction in psi.
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 years (Ref. 1)
Unit Participant Incremental Cost	$27.15 per hp (Ref. 2)

Measure Description

This measure includes the installation of a pressure/flow controller on the downstream side of an air storage receiver in a compressed air system, allows the creation of a pressure differential entering and leaving the vessel. This pressure differential creates stored energy in the form of "squished air," which can be used to supply the peak air demand in situations where the event is short in duration, instead of having to use more compressor horsepower to feed this peak demand. Benefits include:

- Shaving kW of peak demand, especially with multiple-compressor configurations.
- Saving kWh by allowing compressor to run at most efficient loads, and turning itself off in low/no demand periods
- Saving kWh by reducing plant air pressure to minimum allowable. This leads to reduced loads on the electric motors and greater efficiency of the system. Rule of Thumb: for every 2-psi reduced in the system, 1 percent of energy is saved.
- Maintaining a reduced, constant pressure in the plant also means less wasted air due to leakage, and less volume required by the compressor.
- Constant pressure to process ensures quality control of the process. Machines can produce differences in the product quality when pressure is allowed to fluctuate.

Algorithms

Unit kWh Savings per Year = C x HP/Eff x LF x Hours x Δpsid x SF/100

Unit Peak kW Savings = (Unit kWh Savings per Year) / Hours x CF

Where:

C	=	0.746 kW/HP; conversion factor from HP to kW
HP	=	compressor nominal horsepower
Eff	=	provided by customer/contractor; compressor motor efficiency. If unknown, assume 90% (Ref. 3)
LF	=	75% (Ref. 4); typical compressor load factor
Hours	=	provided by customer/contractor; annual operating hours. If unknown, use 6,240 hours (Ref. 5)
SF	=	0.5; Savings Factor (for every 2-psi reduced, annual consumption is reduced by 1%) (Ref. 6)
Δpsid	=	Provided by customer/contractor; initial pressure reduction from installing pressure/flow controller. If unknown, assume 5 psig (Ref. 7)
CF	=	0.865 (Ref. 8); peak electrical coincidence factor

Example:

A manufacturer installs a pressure/flow controller on a 100 HP compressed air system.

Unit kWh Savings per Year = 0.746 x 100 / 0.90 x 0.75 x 6,240 x 5 x 0.5/100 = 9,698 kWh

Unit Peak kW Savings = 9,698/6,240 x 0.865 = 1.3 kW

Methodology and Assumptions

The kWh savings algorithm reflects average savings based on typical load factors for compressed air systems and pressure drop reductions, and uses a standard savings per unit of pressure reduction (1 percent reduction in compressor drive energy versus 2-psi in pressure drop reduction).

References

1. Wisconsin Focus on Energy Technical Reference Manual. 2017 version. Page 37. Based on estimate from product representative.
2. Wisconsin Focus on Energy Technical Reference Manual. 2017 version. Page 37. Based on the average cost of 71 past projects since 2012.
3. Franklin Energy Services default value for compressor motor efficiency.
4. Twelve custom compressed air projects (within MI and OH programs) were surveyed, where older, traditional controlled air compressors were replaced with similar-sized VSD air compressors. On average, these compressors were loaded to 47 percent (approx. 50 percent) of their full-load CFM. For load-unload control as typically found on older systems, this translates to approximately 75 percent of full-load kW.
5. Annual operating hours assume three shifts per day, five days per week. This figure is supported by a survey of previous compressed air projects within Michigan and Ohio energy efficiency programs.

6. Improving Compressed Air System Performance: A Sourcebook for Industry. US Department of Energy, November 2003.
7. Michigan Energy Measures Database. 2017 version.
8. New Jersey's Clean Energy Program Energy Impact Evaluation and Protocol Review. KEMA, July 2009. Page 3-73.

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	8/30/2017

Industrial Compressed Air – Storage Tank

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Industrial Process
Applicable To	Compressed air systems with load/unload control
Actions	Modify, New Construction
Required from Customer/Contractor	Compressor nominal HP, existing storage volume (gal/cfm), proposed storage volume (gal/cfm). Optional: Motor efficiency, compressed air system annual operating hours.
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 years (Ref. 1)
Unit Participant Incremental Cost	$36 per hp (Ref. 2)

Measure Description

This measure includes the installation of an extra storage tank for compressed air system. Storage tanks provide extra capacity for a compressed air system. The energy savings associated with this measure is obtained by preventing the compressor from reacting to every demand event. For example, a load/no-load compressor without adequate storage tends to short-cycle which causes system inefficiency. Also, for compressors with other types of controls, having a storage tank in the system prevents the compressor from potentially ramping up to meet a very short demand event. Having a receiver tank in an air system also has the benefits of preventing oil from being deposited downstream if there is an issue.

Algorithms

Unit kWh Savings per Year = C x HP/Eff x Hours x (PPD_x - PPD_p)

Unit Peak kW Savings = (Unit kWh Savings per Year) / Hours x CF

Where:

C	=	0.746 kW/HP; conversion factor from HP to kW.
HP	=	compressor nominal horsepower
Eff	=	provided by customer/contractor; compressor motor efficiency. If unknown, assume 90% (Ref. 3).
Hours	=	provided by customer/contractor; annual operating hours. If unknown, use 6,240 hours (Ref. 4)
PPD_x	=	percent power draw of the system with existing storage volume (Table 1)

PPD_p = percent power draw of the system with added storage (Table 1)

CF = 0.865 (Ref. 5); peak electrical coincidence factor.

Deemed Input Tables

Table 1. Percent Power Draw by storage volume for load/unload-controlled compressors (Ref. 6)

	1 gal/cfm	3 gal/cfm	5 gal/cfm	10 gal/cfm
50% load factor	87%	76%	71%	67%

Example:

A manufacturer increases the storage volume from 3gal/cfm to 5gal/cfm on a 100 HP compressed air system.

Unit kWh Savings per Year = 0.746 x 100 / 0.90 x 6,240 x (76%-71%) = 25,861 kWh

Unit Peak kW Savings = 25,861/6,240 x 0.865 = 3.58kW

Methodology and Assumptions

The kWh savings algorithm reflects average savings based on typical load factors for load/unload controlled compressed air systems. The savings from the other control types was assumed to be similar with that of load/unload.

References

1. Michigan Energy Measures Database, 2017 version, reduced from 25 to 20 years in accordance with maximum lifetimes in Minnesota Conservation Improvement Program.
2. Michigan Energy Measures Database. 2017 version. Based on survey of compressor vendors, the cost of air tank is about $4 per gallon; therefore, 2 gal/cfm x 4.5cfm/hp x $4/gal=$36/hp.
3. Franklin Energy Services default value for compressor motor efficiency.
4. Annual operating hours assume three shifts per day, five days per week. This is supported by a survey of previous compressed air projects within Michigan and Ohio energy efficiency programs.
5. New Jersey's Clean Energy Program Energy Impact Evaluation and Protocol Review. KEMA, July 2009. Page 3-73.
6. The percent power draw is based on an average load factor of 50% for load/unload controlled air compressor. Plant Services "Special Report on Compressed Air System Efficiency." http://www.hollandindustrial.com/wp-content/uploads/sites/197/2015/12/compressed-air-ebook.pdf, accessed August 25, 2017.

Revision History

Version	Description	Author	Date
1.0	New workpaper	Franklin Energy Services	8/25/17

Industrial Compressed Air - Variable Speed Drive Air Compressors < 50hp

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Industrial Process
Applicable To	Industrial and commercial customers
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	CAGI Data sheet (new), CAGI Data sheet (existing) or nameplate data Optional: Annual facility hours where compressed air is required
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$428/hp (Replace Working) or $100/hp (Replace on Fail or New Construction)

Measure Description

This measure includes replacement of an inlet modulated, variable displacement, or load/no load controlled air compressor units < 50hp with variable speed drive (VSD) controlled units. Base load units do not qualify

Algorithms

Unit kWh Savings per Year = hp * SF * C * Hours

Unit Peak kW Savings = hp * SF * C * CF

Where:

hp	=	nominal horsepower of VSD air compressor motor
SF	=	Savings Factor: reference Table 1
Hours	=	annual facility hours where compressed air is required, default 4024 (reference 2)
C	=	conversion constant = 0.746 kW/hp
CF	=	coincidence factor, Default = 0.95

Example:

Replace an a inlet modulated 25hp air compressor with a 25 hp VSD air compressor

Unit kWh Savings per Year = 25 * 18% * 0.746 * 4024 = 13,509 kWh

Unit kW Savings per Year = 25 * 18% * 0.746 * 0.95 = 3.2 kW

Deemed Input Tables

Table 1. Savings factor for VSD replacing existing control strategy (reference 3)

	Existing Control		
	Inlet Modulating	Load/No Load	Variable Displacement
% Savings Factor	18%	15%	6%

Notes

$428/hp from surveyed cost from MI and Ohio implemented projects. Full install cost for "replace working"

$100/hp is the incremental cost for replace upon fail or new construction

Focus on Energy (WI) and New York Standard Approach uses a CF = 0.80. The Illinois TRM lists CF = 0.95 and Vectren lists it at 1.0.

Savings factor assumes 75% loaded and the savings factor was interpolated from the part load curves of reference 3 (pages 43-45)

References

1. Measure Life Study. Energy & Resource Solutions. Prepared for the Massachusetts Joint Utilities; Table 1-1. 2005.
2. US Department of Energy. United States Electric Motor Systems Market Opportunities Assessment. Appendix B. Dec 2002.
3. US Department of Energy. Improving Compressed Air System Performance - A Sourcebook for Industry. Pages 43-45. November 2003.

Revision History

Version	Description	Author	Date
1.0	Original issue	Franklin Energy Services	8/28/2012
1.1	Specified that hp corresponds to VSD compressor, added optional input for facility hours, minor fixes	Joe Plummer	3/4/2013

Food Service

Commercial Food Service - Electric Oven and Range

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type, heating only or heating and cooling, and new equipment type
Version No.	4.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 4)
Unit Participant Incremental Cost	See Table 1

Measure Description

This measure includes replacement of failed or working electric ovens and ranges with new high efficiency ovens and ranges. May also include new construction if facility does not have gas service.

Algorithms

Unit kWh Savings per Year = (kW_Base - kW_EE) x Hrs x Rapid_Cook_Factor x HVAC_cooling_kWhsavings_factor

Unit Peak kW Savings = (kW_Base - kW_EE) x CF x Rapid_Cook_Factor x HVAC_cooling_kWsavings_factor

Where:

kW_EE = Deemed wattage (kW per unit) for high-efficiency cooking equipment meeting minimum efficiency standards

kW_Base = Deemed corresponding wattage (kW per unit) of baseline cooking technology calculated as kW_EE*New_Tech_Eff÷Base_Tech_Eff from Table 1 below

Rapid_Cook_Factor = Deemed increased savings resulting from increased throughput or reduced cooking times associated with advanced cooking technology

Hrs = Deemed annual operating hours by building type per Table 3

HVAC_cooling_kWhsavings_factor = Deemed cooling system energy savings factor resulting from efficient cooking per Table 2

CF = Deemed coincident demand factor based on cooking establishment type per Table 3.

HVAC_cooling_kWsavings_factor = Deemed cooling system demand savings factor resulting from efficient cooking per Table 2 below

Example:

A high school cafeteria installed a new high efficiency flashbake oven.

Unit kWh Savings per Year = (1.24 kW - 0.91 kW) x 2,282 hrs x 1.67 x 1.03 = 1,295 kWh

Unit Peak kW Savings = (1.24 kW - 0.91 kW) x 39% x 1.67 x 1.04 = 0.224 kW

Deemed Input Tables

Table 1. Pre- and Post-retrofit Equipment Parameters (Ref. 3, 5, 6)

Baseline Equipment	Efficient Equipment	kW_Base	kW_EE	Baseline Product Efficiency	Efficient Product Efficiency	Rapid Cook Factor	Incremental Cost (Ref. 5)
Full-size Range w/Std. Oven	Efficient Range w/Convection Oven	11.10	8.14	55.0%	75.0%	1.25	$3,000
Standard Oven	Flashbake Oven	1.24	0.91	55.0%	75.0%	1.67	$3,600
Standard Oven	Convection / Microwave Oven	1.28	0.80	50.0%	80.0%	1.25	$2,200
Standard Range	Induction Cooktop	5.10	4.14	65.0%	80.0%	1.00	$2,800

Table 2. HVAC Interactive Factors (Ref. 1)

HVAC system	HVAC Cooling kWh Savings Factor	HVAC cooling kW Savings Factor
Heating only	1.00	1.00
Heating and cooling	1.03	1.04

Table 3. Deemed Coincident Peak Demand Factors and Annual Operating Hours by Building Type (Ref. 2)

Building Type	CF	Hrs
Fast Food Limited Menu	32%	1,604
Fast Food Expanded Menu	41%	1,822
Pizza	46%	2,851
Full Service Limited Menu	51%	2,049
Full Service Expanded Menu	36%	1,731
Cafeteria	39%	2,282

Notes

The following technologies have been removed from Table 1 because they now have their own measure: *Fryer, Griddle, Convection Oven and Steamer*

References

1. HVAC Interactive Factors developed based on the HVAC Interaction Factor extracted from the Arkansas Food Service Deemed Savings table
2. Hours, CF taken from Project on Restaurant Energy Performance-End-Use Monitoring and Analysis, Appendixes I and II, Claar, et. al., May 1985
3. Food Service Technology Assessment Report, Fisher-Nickel, kW_EE is productivity enhancement adjusted
4. Measure life for similar food service equipment, 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
5. Incremental costs adopted from utility assumptions based on reasonable comparison against information in reference 3, above, and manufacturer Web sites
6. MN Utility Product Technical Assumption sheets provided for 2008 MN Deemed Savings project

Revision History

Version	Description	Author	Date
2.0	Original from Nexant with extraneous tabs hidden	Nexant	
3.0	Added some clarifying notes	Joe Plummer	
3.1	Modified Hrs description to reflect that operating hours will be deemed	Joe Plummer	3/21/2012
3.2	Removed food warmers because baseline and efficient product efficiencies were identical. Original Nexant specs also did not show any savings	Joe Plummer	3/26/2012
4.0	Removed measures per note above and reformatted	Franklin Energy Services	8/29/2012
4.1	Changed measure name, changed description	Joe Plummer	2/8/2013
4.2	Hours of use changed to 365.25	Franklin Energy Services	1/13/2016

Commercial Food Service - ENERGY STAR Dishwasher

Measure Detail	Measure Value
Target Market Segments	Commercial, Restaurants, Schools
Target End Uses	Other
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Dishwasher type (see Table 2), building water heater fuel, booster water heater fuel
Version No.	1.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	See Table 4
Unit Participant Incremental Cost	See Table 3

Measure Description

This measure involves the installation of an ENERGY STAR commercial dishwasher.

Algorithms

Unit kWh Savings per Year = kWh_dhw + kWh_boost + kWh_idle

Unit Peak kW Savings = Unit kWh Savings per Year / t_annual

Unit Dth Savings per Year = therms_dhw + therms_boost

Where:

kWh_dhw = (Cp * ρH2O * ΔT_dhw / η_electric / C1) * (RPD * (GPR_base - GPR_ee) * Days) if electric water heater, otherwise 0.

kWh_boost = (Cp * ρH2O * ΔT_boost / η_electric / C1) * (RPD * (GPR_base - GPR_ee) * Days) if electric booster heater, otherwise 0.

kW_idle = (kW_idle_base - kW_idle_ee) * (t_annual - (Days * RPD * t_rack / C2)

therms_dhw = (Cp * ρH2O * ΔT_dhw / η_gas / C1) * (RPD * (GPR_base - GPR_ee) * Days) if gas water heater, otherwise 0.

therms_boost = (Cp * ρH2O * ΔT_boost / η_gas / C1) * (RPD * (GPR_base - GPR_ee) * Days) if gas booster heater, otherwise 0.

Cp = 1 Btu/lb-°F. Specific heat of water.

ρ = 8.34 lb/gallon. Density of water.

ΔT_dhw = 70°F. Inlet water temperature rise for building water heater. (Ref. 1).

ΔT_boost = 40°F. Inlet water temperature rise for booster heater. (Ref. 1).

η_gas = 80%. Gas water heater efficiency. (Ref. 1).

η_electric = 98%. Electric water heater efficiency. (Ref. 1).

RPD = Racks per day. See Tables 1 and 2.

t_rack = Typical wash time per rack. See Tables 1 and 2.

GPR_base = Gallons per rack of baseline dishwasher. See Table 1.

GPR_ee = Gallons per rack of ENERGY STAR dishwasher. See Table 2.

kW_idle_base = Idle power draw of baseline dishwasher. See Table 1.

kW_idle_ee = Idle power draw of ENERGY STAR dishwasher. See Table 2.

Days = 360 days/year. Annual days of operation. (Ref. 2).

t_annual = 6,480 hours. Annual hours of dishwasher operation. (Ref. 1).

C1_electric = 3,413 Btu/kWh. Btu to kWh conversion factor.

C1_gas = 100,000 Btu/therm. Btu to therm conversion factor.

C2 = 60 minutes/hour. Minutes per hour conversion factor.

Example:

A customer installed a new high-temp ENERGY STAR single tank door style dishwasher. The hot water is provided by an electric water heater and electric booster.

kWh_dhw = (1 Btu/lb-°F * 8.34 lb/gal * 70°F / 98% / 3,413 Btu/kWh) * (280 racks/day * (1.29 gal/rack - 0.89 gal/rack) * 360 day/yr) = 7,038 kWh

kWh_boost = (1 Btu/lb-°F * 8.34 lb/gal * 40°F / 98% / 3,413 Btu/kWh) * (280 racks/day * (1.29 gal/rack - 0.89 gal/rack) * 360 day/yr) = 4,021 kWh

kWh_idle = (0.87 kW - 0.70 kW) * (6,480 hrs - (360 day/yr * 280 rack/day * 1.0 min/rack / 60 min/hr)) = 816 kWh

Unit kWh Savings per Year = 7,038 kWh + 4,021 kWh + 816 kWh = 11,875 kWh

Unit Peak kW Savings = 11,875 kWh / 6,480 hrs * 1.0 = 1.83 kW

Deemed Input Tables

Table 1. Conventional Dishwasher Characteristics (Ref. 1)

Dishwasher Type	Racks per Day (RPD)	Time per Rack (t_rack) (minutes)	Gallons per Rack (GPR)	Idle Power (kW_Idle)
Low Temperature				
Under Counter	75	2.0	1.73	0.50
Stationary Single Tank Door	280	1.5	2.10	0.60
Single Tank Conveyor	400	0.3	1.31	1.60
Multi Tank Conveyor	600	0.3	1.04	2.00
High Temperature				
Under Counter	75	2.0	1.09	0.76
Stationary Single Tank Door	280	1.0	1.29	0.87
Single Tank Conveyor	400	0.3	0.87	1.93
Multi Tank Conveyor	600	0.2	0.97	2.59
Pot, Pan, and Utensil	280	3.0	0.70	1.20

Table 2. ENERGY STAR Dishwasher Characteristics (Ref. 1)

Dishwasher Type	Racks per Day (RPD)	Time per Rack (t_rack) (minutes)	Gallons per Rack (GPR)	Idle Power (kW_Idle)
Low Temperature				
Under Counter	75	2.0	1.19	0.50
Stationary Single Tank Door	280	1.5	1.18	0.60
Single Tank Conveyor	400	0.3	0.79	1.50
Multi Tank Conveyor	600	0.3	0.54	2.00
High Temperature				
Under Counter	75	2.0	0.86	0.50
Stationary Single Tank Door	280	1.0	0.89	0.70
Single Tank Conveyor	400	0.3	0.70	1.50
Multi Tank Conveyor	600	0.2	0.54	2.25
Pot, Pan, and Utensil	280	3.0	0.58	1.20

Table 3. Incremental Costs (Ref. 1)

Dishwasher Type	Incremental Cost
Low Temperature	
Under Counter	$50
Door Type	$0
Single Tank Conveyor	$0
Multi Tank Conveyor	$970

Dishwasher Type	Incremental Cost
High Temperature	
Under Counter	$120
Door Type	$770
Single Tank Conveyor	$2,050
Multi Tank Conveyor	$970
Pot, Pan, and Utensil	$1,710

Table 4. Equipment Lifetime (Ref. 1)

Dishwasher Type	Lifetime (Years)
Under Counter	10
Door Type	15
Single Tank Conveyor	20
Multi Tank Conveyor	20
Pot, Pan, and Utensil	10

Table 5. ENERGY STAR Criteria (Ref. 3)

ENERGY STAR Efficiency Requirements for Commercial Dishwashers				
Machine Type	High Temp Efficiency Requirements		Low Temp Efficiency Requirements	
	Idle Energy Rate*	Water Consumption**	Idle Energy Rate*	Water Consumption
Under Counter	≤ 0.50 kW	≤ 0.86 GPR	≤ 0.50 kW	≤ 1.19 GPR
Stationary Single Tank Door	≤ 0.70 kW	≤ 0.89 GPR	≤ 0.60 kW	≤ 1.18 GPR
Pot, Pan, and Utensil	≤ 1.20 kW	≤ 0.58 GPSF	≤ 1.00 kW	≤ 0.58 GPSF
Single Tank Conveyor	≤ 1.50 kW	≤ 0.70 GPR	≤ 1.50 kW	≤ 0.79 GPR
Multiple Tank Conveyor	≤ 2.25 kW	≤ 0.54 GPR	≤ 2.00 kW	≤ 0.54 GPR
Single Tank Flight Type	Reported	GPH ≤ 2.975x + 55.00	Reported	GPH ≤ 2.975x + 55.00
Multiple Tank Flight Type	Reported	GPH ≤ 4.96x + 17.00	Reported	GPH ≤ 4.96x + 17.00

*Idle results should be measured with the door closed and represent the total idle energy consumed by the machine including all tank heater(s) and controls. Booster heater (internal or external) energy consumption should not be part of this measurement unless it cannot be separately monitored per the ENERGY STAR Test Method.

**GPR = gallons per rack; GPSF = gallons per square foot of rack; GPH = gallons per hour; x = maximum conveyor speed (feet/min as verified through NSF 3 certification) x conveyor belt width (feet).

Table 6. Calculated Savings Values (Ref. 1)

Dishwasher System Description	Annual Savings		
	kW	kWh	Therms
High Temp Unit with Electric Booster Heater, Electric Water Heater			
Under Counter	0.49	3,154	-
Stationary Single Tank Door	1.83	11,875	-
Single Tank Conveyor	1.42	9,191	-
Multi Tank Conveyor	4.23	27,434	-
Pot, Pan, and Utensil	0.51	3,318	-
High Temp Unit with Electric Booster Heater, Gas Water Heater			
Under Counter	0.32	2,070	45
Stationary Single Tank Door	0.75	4,837	294
Single Tank Conveyor	0.76	4,918	179
Multi Tank Conveyor	1.73	11,222	678
Pot, Pan, and Utensil	0.19	1,206	88
High Temp Unit with Gas Booster Heater, Gas Water Heater			
Under Counter	0.22	1,451	71
Stationary Single Tank Door	0.13	816	462
Single Tank Conveyor	0.38	2,477	281
Multi Tank Conveyor	0.30	1,958	1,065
Pot, Pan, and Utensil	-	-	139
Low Temp Unit, Electric Water Heater			
Under Counter	0.39	2,545	-
Stationary Single Tank Door	2.50	16,186	-
Single Tank Conveyor	2.11	13,646	-
Multi Tank Conveyor	2.91	18,851	-
Low Temp Unit, Gas Water Heater			
Under Counter	-	-	106
Stationary Single Tank Door	-	-	677
Single Tank Conveyor	0.09	576	546
Multi Tank Conveyor	-	-	788

Notes

A high temp machine is defined as a machine that applies hot water to the surfaces of dishes to achieve sanitization. A low temp machine is defined as a machine that applies a chemical sanitizing solution to the surfaces of dishes to achieve sanitization. (Ref. 4)

References

1. Commercial Kitchen Equipment Savings Calculator, ENERGY STAR. http://www.energystar.gov/buildings/sites/default/uploads/files/commercial_kitchen_equipment_calculator.xlsx, accessed 08/19/16.
2. Focus on Energy Evaluation, Business Programs: Deemed Savings Manual V1.0, PA Consulting Group Inc., March 22, 2010. Page 4-69. https://focusonenergy.com/sites/default/files/bpdeemedsavingsmanuav10_evaluationreport.pdf
3. Energy Efficiency Requirements for Commercial Dishwashers. https://www.energystar.gov/products/commercial_food_service_equipment/commercial_dishwashers/key_product_criteria, accessed 08/19/16.
4. ENERGY STAR Program Requirements for Commercial Dishwashers: Partner Commitments. https://www.energystar.gov/ia/partners/product_specs/program_reqs/Commercial_Dishwasher_Program_Requirements.pdf, Page 2, accessed 09/15/16.

Revision History

Version	Description	Author	Date
1.0	New Measure	Franklin Energy Services	7/15/2015
1.1	Updated savings example	Franklin Energy Services	7/20/2015
1.2	Updated standards to include “Pot, Pan, and Utensil” measure. Updated references, annual hours of operation, savings values and example.	Franklin Energy Services	8/19/2016

Commercial Food Service - ENERGY STAR Electric Combination Oven

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type
Version No.	2.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 4)
Unit Participant Incremental Cost	$3,824 (Ref. 2)

Measure Description

This measure includes the replacement of an electric combination oven with an ENERGY STAR electric combination oven, or installation of an ENERGY STAR combination oven in new construction.

ENERGY STAR combination ovens incorporate timesaving features via sophisticated control packages.

Algorithms

Unit kWh Savings per Year = (Eday_base - Eday_EE) x Days

Unit Peak kW Savings = Unit kWh Savings per Year / (OpHrs x Days) x CF

Where:

Eday_base (kWh/day) = LBFood x Efood / Eff_base + IdleRate_base x [OpHrs - LBFood / PC_base - T_pre / 60] + E_pre_base

Eday_EE (kWh/day) = LBFood x Efood / Eff_EE + IdleRate_EE x [OpHrs - LBFood / PC_EE - T_pre / 60] + E_pre_EE

LBFood = 200 lbs/day; Pounds of food cooked per day (Ref. 2)

Efood = 0.0732 kWh/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 44%; Heavy load cooking energy efficiency (Ref. 4)

Eff_EE = 65.5% (Ref. 6)

IdleRate_base = 7.5 kW; Idle Energy Rate (Ref. 2)

IdleRate_EE= 2.4 kW; (Ref. 7)

OpHrs = 8 hrs/day; Daily operating hours (Ref. 5)

PC_base = 80 lbs/hr; Production Capacity (Ref. 2)

PC_EE = 100 lbs/hr (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = 3.00 kWh; Preheat energy (Ref. 2)

E_pre_EE = 1.50 kWh (Ref. 2)

Days = See Table 1

CF = 0.9 (Ref. 2)

Example

A cafeteria in a large office building installed a new ENERGY STAR electric combination oven.

Eday_base (kWh/day) = (200 lbs/day) x (0. 0732 kWh/lb) / (44%) + [7.5 kW x (8 hrs/day - (200 lbs/day / 80 lbs/hr) - (15 min / 60 min/hr))] + 3.00 kWh/day = 75.6 kWh/day

Eday_prop (kWh/day) = (200 lbs/day) x (0. 0732 kWh/lb) / (65.5%) + [2.4 kW x (8 hrs/day - (200 lbs/day / 100 lbs/hr) - (15 min / 60 min/hr))] + 1.50 kWh/day = 37.7 kWh/day

Unit kWh Savings per Year = (75.6 kWh/day - 43.2 kWh/day) x 250 days/yr = 9,475 kWh

Unit Peak kW Savings = 9,475 kWh / (8 hr/day x 250 days/yr) x 0.9 = 4.264 kW

Deemed Input Tables

Table 1. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Methodology and Assumptions

Table 2. ENERGY STAR Electric Combination Oven Criteria (Ref. 6,7)

Operation	Idle Rate, kW	Cooking-Energy Efficiency, %
Steam Mode	≤ 0.133P+0.6400	≥ 55
Convection Mode	≤ 0.080P+0.4989	≥ 76
Average (assuming 6-pan unit)	2.4	65.5

Notes

There is no code requirement for this technology.

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. Commercial Combination Ovens, Food Service Equipment Workpaper PGECOFST100 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. 2008 Database for Energy-Efficient Resources Version 2008.2.05 December 16, 2008; www.deeresources.com / DEER 2005 / DEER 2005 Version Reports and Notifications/ DEER 2005 Version 2.01 Enhancements and Notifications
5. Technology Assessment: Ovens, Food Service Technology Center, 2002. Page 7-23. http://www.fishnick.com/equipment/techassessment/7_ovens.pdf
6. Average of steam and convection cooking efficiencies listed in ENERGY STAR Commercial Ovens Key Product Criteria, Version 2.1. http://www.energystar.gov/index.cfm?c=ovens.pr_crit_comm_ovens. Accessed 7/9/14.
7. Sum of steam and convection oven idle rates (summed because they can be used simultaneously), assuming 6-pans to be conservative, rounded to nearest tenth. Ref. 6.

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/27/2012
2.0	Updated to include ENERGY STAR version 2.1 specification	Franklin Energy Services	7/31/2014
2.1	Updated description to include new construction, changed 365 to 365.25 for consistency with other measures, put Table 2 in Methodology & Assumptions section	Joe Plummer	7/31/2014

Commercial Food Service - ENERGY STAR Electric Convection Oven

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$1,682 (Ref. 2)

Measure Description

This measure includes installation of high efficiency ENERGY STAR electric convection ovens instead of standard efficiency units. Energy efficient commercial electric ovens reduce energy consumption primarily through sophisticated control packages.

Algorithms

Unit kWh Savings per Year = (Eday_base - Eday_EE) x Days

Unit Peak kW Savings = Unit kWh Savings per Year / (OpHrs x Days) x CF

Where:

Eday_base (kWh/day) = LBFood x Efood / Eff_base + IdleRate_base x [OpHrs - LBFood / PC_base - T_pre / 60] + E_pre_base

Eday_EE (kWh/day) = LBFood x Efood / Eff_EE + IdleRate_EE x [OpHrs - LBFood / PC_EE - T_pre / 60] + E_pre_EE

LBFood = 100 lbs/day; Pounds of food cooked per day (Ref. 2)

Efood = 0.0732 kWh/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 65%; Heavy load cooking energy efficiency (Ref. 2)

Eff_EE = 71% (Ref. 4)

IdleRate_base = 2.00 kW; Idle Energy Rate (Ref. 2)

IdleRate_EE= 1.6 kW; (Ref. 4)

OpHrs = 8 hrs/day; Daily operating hours (Ref. 5)

PC_base = 70 lbs/hr; Production Capacity (Ref. 2)

PC_EE = 80 lbs/hr (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = 1.50 kWh; Preheat energy (Ref. 2)

E_pre_EE = 1.00 kWh (Ref. 2)

Days = See Table 1

CF = 0.9 (Ref. 6)

Example:

A fast food restaurant installed a new ENERGY STAR Electric Convection Oven

Eday_base (kWh/day) = (100 lbs/day) x (0. 0732 kWh/lb) / (65%) + [2.00 kW x (8 hrs/day - (100 lbs/day / 70 lbs/hr) - (15 min / 60 min/hr))] + 1.50 kWh/day = 25.4 kWh/day

Eday_prop (kWh/day) = (100 lbs/day) x (0. 0732 kWh/lb) / (71%) + [1.60 kW x (8 hrs/day - (100 lbs/day / 80 lbs/hr) - (15 min / 60 min/hr))] + 1.00 kWh/day = 21.7 kWh/day

Unit kWh Savings per Year = (25.4 kWh/day - 21.7 kWh/day) x 365 days/yr = 1,351 kWh

Unit Peak kW Savings = 1,349 kWh / (8 hr/day x 365 days/yr) x 0.9 = 0.416 kW

Deemed Input Tables

Table 1. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Notes

There is no code requirement for this technology.

ENERGY STAR requires that Full Size Electric Ovens have a cooking energy efficiency ≥ 71% and an idle energy rate ≤ 1.6 kW (Ref. 4)

ENERGY STAR requires that Half Size Electric Ovens have a cooking energy efficiency ≥ 71% and an idle energy rate ≤ 1.0 kW (Ref. 4)

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. Commercial Convection Ovens, Food Service Equipment Workpaper PGEOFST101 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. Commercial Ovens Key Product Criteria, http://www.energystar.gov/index.cfm?c=ovens.pr_crit_comm_ovens. Accessed 11/11/2015.
5. Technology Assessment: Ovens, Food Service Technology Center, 2002. Page 7-22. http://www.fishnick.com/equipment/techassessment/7_ovens.pdf
6. 2004-05 Database for Energy Efficiency Resources (DEER) Update Study Final Report, pp. 3-15 to 3-18. http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/14/2012
1.1	Renamed measure	Joe Plummer	2/8/2013
1.2	Corrected preheat energy labels	Joe Plummer	10/29/13
2.0	Updated ENERGY STAR requirements	Franklin Energy Services	11/11/2015
2.1	Hours of use changed to 365.25	Franklin Energy Services	1/13/2016

Commercial Food Service - ENERGY STAR Electric Fryer

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type, fryer type (Standard or Large Vat)
Version No.	1.4
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$2,126 for Large Vat Fryers (Ref. 6), $1,344 for Standard Fryers (Ref. 2)

Measure Description

This measure includes installation of high efficiency Standard and Large Vat ENERGY STAR electric fryers instead of standard efficiency units. Energy efficient commercial electric fryers reduce energy consumption primarily through the application of advanced controls and insulation.

Algorithms

Unit kWh Savings per Year = (Eday_base - Eday_ee) x Days

Unit Peak kW Savings = Unit kWh Savings per Year / (OpHrs x Days) x CF

Where:

Eday_base (kWh/day) = LBFood x Efood / Eff_base + IdleRate_base x (OpHrs - LBFood / PC_base - T_pre / 60) + E_pre_base

Eday_ee (kWh/day) = LBFood x Efood / Eff_ee + IdleRate_ee x (OpHrs - LBFood / PC_ee - T_pre / 60) + E_pre_ee

LBFood = 150 lbs/day; Pounds of food cooked per day (Ref. 2)

Efood = 0.167 kWh/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 75% for Large Vat Fryers (Ref. 6), 75% for Standard Fryers (Ref. 2); Heavy load cooking efficiency for standard efficiency equipment

Eff_ee = 80% for Large Vat Fryers, 83% for Standard Fryers (Ref. 4); Heavy load cooking efficiency for ENERGY STAR equipment

IdleRate_base =1.35 kW for Large Vat Fryers (Ref. 6), 1.05 kW for Standard Fryers (Ref. 2); Idle Energy Rate for standard efficiency equipment

IdleRate_ee= 1.1 kW for Large Vat Fryers, 0.8 kW for Standard Fryers (Ref. 4); Idle Energy Rate for ENERGY STAR equipment

OpHrs	=	12 hrs/day for Large Vat Fryers (Ref. 6), 16 hrs/day for Standard Fryers (Ref. 2); Daily operating hours
PC_base	=	100 lbs/hr for Large Vat Fryers (Ref. 6), 65 lbs/hr for Standard Fryers (Ref. 2); Production capacity for standard efficiency equipment
PC_ee	=	110 lbs/hr for Large Vat Fryers (Ref. 6), 70 lbs/hr for Standard Fryers (Ref. 2); Production capacity for ENERGY STAR equipment (Ref. 2)
T_pre	=	15 min/day; Preheat Time (Ref. 2, 6)
E_pre_base	=	2.5 kWh/day for Large Vat Fryers (Ref. 6), 2.3 kWh/day for Standard Fryers (Ref. 2); Preheat energy for standard efficiency equipment
E_pre_ee	=	2.1 kWh/day for Large Vat Fryers (Ref. 6), 1.7 kWh/day for Standard Fryers (Ref. 2); Preheat energy for ENERGY STAR equipment
Days	=	See Table 1; Annual operating days
CF	=	0.9 (Ref. 5); Electrical peak coincidence factor

Example:

A fast food restaurant installed a new Standard-sized ENERGY STAR Electric Fryer:

Eday_base (kWh/day) = (150 lbs/day) x (0.167 kWh/lb) / (75%) + [1.05 kW x (16 hr/day - (150 lbs/day / 65 lb/hr) - (15 min / 60 min/hr))] + 2.3 kWh/day = 49.8 kWh/day

Eday_ee (kWh/day) = (150 lbs/day) x (0.167 kWh/lb) / (83%) + [0.8 kW x (16 hr/day - (150 lbs/day / 70 lb/hr) - (15 min / 60 min/hr))] + 1.7 kWh/day = 42.8 kWh/day

Unit kWh Savings per Year = (49.8 kWh/day - 42.8 kWh/day) x 365 days/yr = 2,574 kWh

Unit Peak kW Savings = 2,574kWh / (16 hr/day x 365 days/yr) x 0.9 = 0.396 kW

Deemed Input Tables

Table 1. Operating Days per Year by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Notes

There is no code requirement for this technology.

ENERGY STAR defines a Standard Fryer as a fryer with a vat that measures ≥ 12 inches and < 18 inches wide, and a shortening capacity ≥ 25 pounds and ≤ 65 pounds (Ref. 4).

ENERGY STAR defines a Large Vat Fryer as a fryer with a vat that measures ≥ 18 inches and ≤ 24 inches wide, and a shortening capacity > 50 pounds (Ref. 4).

ENERGY STAR requires Standard Open Deep-Fat Electric Fryers have a heavy-load cooking efficiency ≥ 83% and an idle energy rate ≤ 800 Watts (Ref. 4).

ENERGY STAR requires Large Vat Open Deep-Fat Electric Fryers have a heavy-load cooking efficiency ≥ 80% and an idle energy rate ≤ 1,100 Watts (Ref. 4).

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. *Commercial Fryer,* Food Service Equipment Workpaper PGEOFST102 R1, PG&E. June 1, 2009.
3. Data from Table 1 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. *ENERGY STAR Program Requirements: Product Specification for Commercial Fryers: Eligibility Criteria, Version 3.0,* https://www.energystar.gov/sites/default/files/Commercial%20Fryers%20Program%20Requirements.pdf, accessed August, 19, 2016.
5. 2004-05 Database for Energy Efficiency Resources (DEER) Update Study Final Report, pp. 3-15 to 3-18. http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf
6. *Commercial Large Vat Fryer,* Food Service Equipment Workpaper PGECOFST114 R1, PG&E. June 1, 2009.

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/24/2012
1.1	Changed measure name	Joe Plummer	2/8/2013
1.2	Corrected preheat energy labels	Joe Plummer	10/30/13
1.3	Hours of use changed to 365.25	Franklin Energy Services	1/13/2016
1.4	Updated to new ES Standard in algorithms and notes, added Large Vat fryers, updated example	Franklin Energy Services	8/19/2016

Commercial Food Service - ENERGY STAR Electric Griddle

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type
Version No.	1.2
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$2,162 (Ref. 2)

Measure Description

This measure includes installation of high efficiency ENERGY STAR electric griddles instead of standard efficiency units. Energy efficient commercial electric griddles reduce energy consumption primarily through application of advanced controls and improved temperature uniformity.

Algorithms

Unit kWh Savings per Year = (Eday_base - Eday_EE) x Days

Unit Peak kW Savings = Unit kWh Savings per Year / (OpHrs x Days) x CF

Where:

Eday_base (kWh/day) = LBFood x Efood / Eff_base + IdleRate_base x [OpHrs - LBFood / PC_base - T_pre / 60] + E_pre_base

Eday_EE (kWh/day) = LBFood x Efood / Eff_EE + IdleRate_EE x [OpHrs - LBFood / PC_EE - T_pre / 60] + E_pre_EE

LBFood = 100 lbs/day; Pounds of food cooked per day (Ref. 2)

Efood = 0.139 kWh/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 65%; Heavy load cooking energy efficiency (Ref. 2)

Eff_EE = 70% (Ref. 2)

IdleRate_base =2.50 kW; Idle Energy Rate (Ref. 2)

IdleRate_EE= 2.13 kW (Ref. 4); Assumes a 3' x 2' griddle size and a Tier 1 idle rate

OpHrs = 12 hrs/day; Daily operating hours (Ref. 5)

PC_base = 35 lbs/hr; Production Capacity (Ref. 2)

PC_EE = 40 lbs/hr (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = 4.00 kWh; Preheat energy (Ref. 2)

E_pre_EE = 2.00 kWh; (Ref. 2)

Days = See Table 1

CF = 0.9 (Ref. 6)

Example:

A hospital installed a new ENERGY STAR Electric Griddle in its kitchen

Eday_base (kWh/day) = (100 lbs/day) x (0.139 kWh/lb) / (65%) + [2.5 kW x (12 hr/day - (100 lbs/day / 35 lb/hr) - (15 min / 60 min/hr))] + 4.00 kWh = 47.6 kWh/day

Eday_EE (kWh/day) = (100 lbs/day) x (0.139 kWh/lb) / (70%) + [2.13 kW x (12 hr/day - (100 lbs/day / 40 lb/hr) - (15 min / 60 min/hr))] + 2.00 kWh = 41.6 kWh/day

Unit kWh Savings per Year = (47.6 kWh/day - 41.6 kWh/day) x 365 days/yr = 2,212 kWh

Unit Peak kW Savings = 2,212 kWh / (12 hrs/day x 365 days/yr) x 0.90 = 0.454 kW

Deemed Input Tables

Table 1. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Methodology and Assumptions

Savings assumes a 3' x 2' griddle size and a Tier 1 idle rate.

Notes

There is no code requirement for this technology.

ENERGY STAR requires that Tier 1 Electric Griddles have a cooking energy efficiency ≥ 70% and a normalized idle energy rate ≤ 355 Watts per ft^2 (Ref. 4)

ENERGY STAR requires that Tier 2 Electric Griddles have a cooking energy efficiency ≥ 70% and a normalized idle energy rate ≤ 320 Watts per ft^2 (Ref. 4)

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. *Commercial Griddles,* Food Service Equipment Workpaper PGECOFST103 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. *Commercial Griddles Key Product Criteria,* Accessed August, 15, 2012. http://www.energystar.gov/index.cfm?c=griddles.pr_crit_comm_griddles.
5. *Technology Assessment: Griddles,* Food Service Technology Center, 2002. Page 3-22. http://www.fishnick.com/equipment/techassessment/3_griddles.pdf
6. 2004-05 Database for Energy Efficiency Resources (DEER) Update Study Final Report, pp. 3-15 to 3-18. http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/24/2012
1.1	Renamed measure	Joe Plummer	2/8/2013
1.2	Fixed preheat energy labels	Joe Plummer	10/30/13
1.3	Hours of use changed to 365.25	Franklin Energy Services	1/13/2016

Commercial Food Service - ENERGY STAR Electric Hot Food Holding Cabinet

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type, cabinet volume
Version No.	1.3
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	See Table 1 (Ref. 2)

Measure Description

This measure includes installation of high efficiency ENERGY STAR electric hot food holding cabinets (HFHCs) instead of standard efficiency units. Energy efficient commercial HFHCs reduce energy consumption primarily through better insulation, magnetic door electric gaskets, auto-door closures, or Dutch doors.

Algorithms

Unit kWh Savings per Year = (kW_base - kW_ee) x Hours x Days

Unit Peak kW Savings = (kW_base - kW_ee) x CF

Where:

kW_base	=	Wattage of baseline unit. See Table 1. (Ref. 6)
kW_ee	=	Wattage of ENERGY STAR unit. See Table 1 (Ref. 4)
Hours	=	15 hrs/day (Ref. 7)
Days	=	See Table 2
CF	=	0.9 (Ref. 5)

Example:

A sit-down food restaurant installed a new full-size ENERGY STAR Electric HFHC:

Unit kWh Savings per Year = (2.0 kW - 0.294 kW) x 15 hrs/day x 365 days/yr = 9,347 kWh

Unit Peak kW Savings = (2.0 kW - 0.294 kW) x 0.9 = 1.54 kW

Deemed Input Tables

Table 1. Hot Food Holding Cabinet Performance Characteristics

Size	Volume (ft^3)	kW_base	kW_ee	Incremental Cost
Full-Size	20	2.000	0.294	$1,891
3/4-Size	12	1.200	0.258	$707
Half-Size	8	0.800	0.172	$1,497

Table 2. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Methodology and Assumptions

The baseline energy usage is assumed to be 100 W/ft^2 based on the FSTC Life Cycle Cost Calculator

Notes

There is no code requirement for this technology.

The ENERGY STAR Version 3.0 specification revision for commercial HFHCs is under development as of August 2016. The previous version's standards are listed below, italicized.

> *ENERGY STAR requires that Electric HFHCs (28 $ft^3 \leq$ Volume) have an idle rate defined by: Watts $\leq$ 3.8 x Volume (ft^3) + 203.5*
>
> *ENERGY STAR requires that Electric HFHCs (13 $ft^3 \leq$ Volume < 28 ft^3) have an idle rate defined by: Watts $\leq$ 2.0 x Volume (ft^3) + 254.0*
>
> *ENERGY STAR requires that Electric HFHCs (Volume $\leq$ 13 ft^3) have an idle rate defined by: Watts $\leq$ 21.5 x Volume (ft^3)*

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. *Insulated Holding Cabinet,* Food Service EquipmentWorkpaper PGECOFST105 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. *Commercial Hot Food Holding Cabinets Key Product Criteria,* http://www.energystar.gov/index.cfm?c=hfhc.pr_crit_hfhc. Accessed 8/24/12.
5. 2004-2005 Database for Energy Efficiency Resources (DEER) Update Study Final Report, pp. 3-15 to 3-18. http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf
6. *Hot-Food Holding Cabinet Life-Cycle Cost Calculator*, Food Service Technology Center, http://www.fishnick.com/saveenergy/tools/calculators/holdcabcalc.php. Accessed on 8/27/12.

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/24/2012
1.1	Update sizes	Franklin Energy Services	8/27/2012
1.2	Hours of use changed to 365.25	Franklin Energy Services	1/13/2016
1.3	Updated notes regarding ES Version 3.0	Franklin Energy Services	8/19/2016

Commercial Food Service - ENERGY STAR Electric Steamer

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type, number of pans
Version No.	3.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$2,490 (Ref. 2)

Measure Description

This measure includes replacement of commercial electric steamers with new 5 or 6-pan ENERGY STAR electric steamers.

Algorithms

Unit kWh Savings per Year = (Eday_base - Eday_EE) x Days

Unit Peak kW Savings = Unit kWh Savings per Year / (OpHrs x Days) x CF

Where:

Eday_base (kWh/day) = LBFood x Efood / Eff_base + (IdleRate_base + Res_Rate_base) x (OpHrs - LBFood / PC_base - T_pre / 60) + E_pre

Eday_EE (kWh/day) = LBFood x Efood / Eff_EE + (IdleRate_EE + Res_Rate_EE) x (OpHrs - LBFood / PC_EE - T_pre / 60) + E_pre

LBFood = See Table 1; Pounds of food cooked per day (Ref. 2)

Efood = 0.0308 kWh/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 26%; Heavy load cooking energy efficiency (Ref. 2)

Eff_EE = 50% (Ref. 2)

IdleRate_base = See Table 1; Idle Energy Rate (Ref. 2)

IdleRate_EE= See Table 1; (Ref. 2)

OpHrs = 12 hrs/day; Daily operating hours (Ref. 2)

PC_base = See Table 1; Production Capacity (Ref. 2)

PC_EE = See Table 1 (Ref. 2)

Res_Rate_base = 1.910 kW; Residual Energy Rate (Ref. 2)

Res_Rate_EE = 0.120 kW; Residual Energy Rate (Ref. 2)

T_pre	=	15 min/day; PYreheat Time (Ref. 2)
E_pre	=	1.50 kWh; Preheat energy (Ref. 2)
Days	=	See Table 2
CF	=	0.9 (Ref. 1)

Example:

A health clinic cafeteria installed a new 6-pan ENERGY STAR Electric Steam Cooker

Eday_base (kWh/day) = (192 lbs/day) x (0. 0308 kWh/lb) / (26%) + (2.00 kW + 1.91 kW) x (12 hrs/day - (192 lbs/day / 120 lbs/hr) - (15 min / 60 min/hr)) + 1.50 kWh/day = 63.9 kWh/day

Eday_EE (kWh/day) = (192 lbs/day) x (0. 0308 kWh/lb) / (50%) + (0.80 kW + 0.120 kW) x (12 hrs/day - (192 lbs/day / 100 lbs/hr) - (15 min / 60 min/hr)) + 1.50 kWh/day = 22.4 kWh/day

Unit kWh Savings per Year = (63.9 kWh/day - 22.4 kWh/day) x 365 days/yr = 15,158 kWh

Unit Peak kW Savings = 15,147 kWh / (12 hr/day x 365 days/yr) x 0.9 = 3.113 kW

Deemed Input Tables

Table 1. Steamer Characteristics

	3-Pan Steamer	4-Pan Steamer	5-Pan Steamer	6-Pan Steamer
LBFood (lbs/day)	100	128	160	192
Efood (kWh/lb)	0.0308	0.0308	0.0308	0.0308
Eff_base (%)	26%	26%	26%	26%
Eff_EE (%)	50%	50%	50%	50%
IdleRate_base (kW)	1.000	1.325	1.675	2.000
IdleRate_EE (kW)	0.400	0.530	0.670	0.800
OpHrs (hrs/day)	12	12	12	12
PC_base (lbs/hr)	70	87	103	120
PC_EE (lbs/hr)	50	67	83	100
Res_Rate_base (kW)	1.910	1.910	1.910	1.910
Res_Rate_EE (kW)	0.120	0.120	0.120	0.120
T_pre (minutes)	15	15	15	15
E_pre	1.5	1.5	1.5	1.5

Table 2. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Notes

There is no code requirement for this technology.

Table 3. ENERGY STAR requires that Electric Steam Cookers have the following efficiencies (Ref. 4):

Pan Capacity	Cooking Energy Efficiency	Idle Rate (Watts)
3-Pan	50%	400
4-Pan	50%	530
5-Pan	50%	670
6-Pan	50%	800

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. *Commercial Steam Cookers,* Food Service Equipment Workpaper PGECOFST104 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. *Commercial Steam Cookers Key Product Criteria,* http://www.energystar.gov/index.cfm?c=steamcookers.pr_crit_steamcookers. Accessed August, 27, 2012.

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/27/2012
2.0	Updated OpHrs in table	Franklin Energy Services	11/11/2015
3.0	Updated the Energy-to-Food value to 0.0308 kWh/lb	Franklin Energy Services	11/11/2015

Commercial Food Service - ENERGY STAR Gas Combination Oven

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type
Version No.	1.3
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$5,717 (Ref. 2)

Measure Description

This measure includes the replacement of a gas combination oven with an ENERGY STAR gas combination oven, or installation of an ENERGY STAR combination oven in new construction.

ENERGY STAR combination ovens incorporate timesaving features via sophisticated control packages.

Algorithms

Unit Dth Savings per Year = (Eday_base - Eday_prop) / Conversion Factor x Day

Where:

Eday_base (Btu/day) = LBFood x Efood / Eff_base + IdleRate_base x [OpHrs - LBFood / PC_base - T_pre / 60] + E_pre_base

Eday_EE (Btu/day) = LBFood x Efood / Eff_EE + IdleRate_EE x [OpHrs - LBFood / PC_EE - T_pre / 60] + E_pre_EE

LBFood = 200 lbs/day; Pounds of food cooked per day (Ref. 2)

Efood = 250 Btu/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 35%; Heavy load cooking energy efficiency (Ref. 6)

Eff_EE = 48.5% (Ref. 6)

IdleRate_base = 28,000 Btu/hr; Idle Energy Rate (Ref. 2)

IdleRate_EE= 14,000 Btu/hr (Ref. 7)

OpHrs = 8 hrs/day; Daily operating hours (Ref. 5)

PC_base = 80 lbs/hr; Production Capacity (Ref. 2)

PC_EE = 120 lbs/hr (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = 18,000 Btu/day; Preheat energy (Ref. 2)

E_pre_EE = 13,000 Btu/day (Ref. 2)

Days = See Table 1

ConversionFactor = 1,000,000 Btu/Dth

Example:

A hospital cafeteria installed a new ENERGY STAR gas combination oven.

Eday_base (Btu/day) = (200 lbs/day) x (250 Btu/lb) / (35%) + [28,000 Btu/hr x (8 hrs/day - (200 lbs/day / 80 lb/hr) - (15 min / 60 min/hr))] + 18,000 Btu/day = 307,857 Btu/day

Eday_prop (Btu/day) = (200 lbs/day) x (250 Btu/lb) / (48.5%) + [14,000 Btu/hr x (8 hrs/day - (200 lbs/day / 120 lb/hr) - (15 min / 60 min/hr))] + 13,000 Btu/day = 201,259 Btu/day

Unit Dth Savings per Year = (307,857 Btu/day - 201,259 Btu/day) / 1,000,000 Btu/Dth x 365 days/yr = 38.9 Dth

Deemed Input Tables

Table 1. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Methodology and Assumptions

Table 2. ENERGY STAR Gas Combination Oven Criteria (Ref. 6, 7)

Operation	Idle Rate, Btu/h	Cooking-Energy Efficiency, %
Steam Mode	≤ 200P+6,511	≥ 41
Convection Mode	≤ 150P+5,425	≥ 56
Average (assuming 6-pan unit)	14,000	48.5

Notes

There is no code requirement for this technology.

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. Commercial Combination Ovens, Food Service Equipment Workpaper PGECOFST100 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. 2008 Database for Energy-Efficient Resources Version 2008.2.05 December 16, 2008; www.deeresources.com / DEER 2005 / DEER 2005 Version Reports and Notifications/ DEER 2005 Version 2.01 Enhancements and Notifications
5. Technology Assessment: Ovens, Food Service Technology Center, 2002. Page 7-22. http://www.fishnick.com/equipment/techassessment/7_ovens.pdf
6. Average of steam and convection cooking efficiencies listed in ENERGY STAR Commercial Ovens Key Product Criteria, Version 2.1. http://www.energystar.gov/index.cfm?c=ovens.pr_crit_comm_ovens. Accessed 7/9/14.
7. Sum of steam and convection oven idle rates (summed because they can be used simultaneously), assuming 6-pans to be conservative, rounded to nearest tenth. Ref. 5.

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/27/2012
1.1	Renamed measure	Joe Plummer	2/8/2013
1.2	Updated to include ENERGY STAR version 2.1 specification	Franklin Energy Services	7/31/2014
1.3	Updated description to include new construction, changed 365 to 365.25 for consistency with other measures, put Table 2 in Methodology & Assumptions section	Joe Plummer	7/31/2014

Commercial Food Service - ENERGY STAR Gas Convection Oven

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type
Version No.	2.1
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$1,886 (Ref. 2)

Measure Description

This measure includes installation of high efficiency ENERGY STAR gas convection ovens instead of standard efficiency units. Energy efficient commercial gas ovens reduce energy consumption primarily through sophisticated control package.

Algorithms

Unit Dth Savings per Year = (Eday_base - Eday_EE) / Conversion Factor x Days

Where:

Eday_base (Btu/day) = LBFood x Efood / Eff_base + IdleRate_base x [OpHrs - LBFood / PC_base - T_pre / 60] + E_pre_base

Eday_EE (Btu/day) = LBFood x Efood / Eff_EE + IdleRate_EE x [OpHrs - LBFood / PC_EE - T_pre / 60] + E_pre_EE

LBFood = 100 lbs/day; Pounds of food cooked per day (Ref. 2)

Efood = 250 Btu/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 30%; Heavy load cooking efficiency, standard efficiency equipment (Ref. 2)

Eff_EE = 46%; Heavy load cooking efficiency, ENERGY STAR equipment (Ref. 4)

IdleRate_base = 18,000 Btu/hr; Idle energy rate, standard efficiency equipment (Ref. 2)

IdleRate_EE= 12,000 Btu/hr; Idle energy rate, ENERGY STAR equipment (Ref. 4)

OpHrs = 8 hrs/day; Daily operating hours (Ref. 5)

PC_base = 70 lbs/hr; Production capacity, standard efficiency equipment (Ref. 2)

PC_EE = 80 lbs/hr; Production capacity, ENERGY STAR equipment (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = 19,000 Btu/day; Preheat energy (Ref. 2)

E_pre_EE = 11,000 Btu/day (Ref. 2)

Days = See Table 1

ConversionFactor = 1,000,000 Btu/Dth

Example:

A sit-down restaurant installed a new ENERGY STAR Gas Convection Oven

Eday_base (Btu/day) = (100 lbs/day) x (250 Btu/lb) / (30%) + [18,000 Btu/hr x (8 hrs/day - (100 lbs/day / 70 lb/hr) - (15 min / 60 min/hr))] + 19,000 Btu/day = 216,119 Btu/day

Eday_EE (Btu/day) = (100 lbs/day) x (250 Btu/lb) / (46%) + [12,000 Btu/hr x (8 hrs/day - (100 lbs/day / 80 lb/hr) - (15 min / 60 min/hr))] + 11,000 Btu/day = 143,348 Btu/day

Unit Dth Savings per Year = (216,119 Btu/day – 143,348 Btu/day) / 1,000,000 Btu/Dth x 365 days/yr = 26.6 Dth

Deemed Input Tables

Table 1. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Notes

There is no code requirement for this technology.

ENERGY STAR requires that Full Size Gas Convection Ovens have a cooking energy efficiency ≥ 46% and an idle energy rate ≤ 12,000 Btu/h (Ref. 4).

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. Commercial Convection Ovens, Food Service Equipment Workpaper PGEOFST101 R1, PG&E. June 1, 2009.

3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. Commercial Ovens Key Product Criteria. https://www.energystar.gov/sites/default/files/Commercial%20Ovens%20Final%20Version%202.2%20Specification.pdf. Accessed August, 19, 2016.
5. Technology Assessment: Ovens, Food Service Technology Center, 2002. Page 7-22. http://www.fishnick.com/equipment/techassessment/7_ovens.pdf

Revision History

Version	Description	Author	Date
2.0	Updated ENERGY STAR efficiency requirements	Franklin Energy Services	11/11/2015
2.1	Updated values to new ES requirements, updated example	Franklin Energy Services	8/19/2016

Commercial Food Service - ENERGY STAR Gas Fryer

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type, fryer type (standard or large vat)
Version No.	1.2
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$1,873 for Large Vat Fryers (Ref. 5), $1,219 for Standard Fryers (Ref. 2)

Measure Description

This measure includes installation of high efficiency Standard and Large Vat ENERGY STAR gas fryers instead of standard efficiency units. Energy efficient commercial gas fryers reduce energy consumption primarily through advanced burner and heat exchanger design and the application of advanced controls and insulation.

Algorithms

Unit Dth Savings per Year = (Eday_base - Eday_EE) / ConversionFactor x Days

Where:

Eday_base (Btu/day) = LBFood x Efood / Eff_base + IdleRate_base x [OpHrs - LBFood / PC_base - T_pre / 60] + E_pre_base

Eday_EE (Btu/day) = LBFood x Efood / Eff_EE + IdleRate_EE x [OpHrs - LBFood / PC_EE - T_pre / 60] + E_pre_EE

LBFood = 150 lbs/day; Pounds of food cooked per day (Ref. 2)

Efood = 570 Btu/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 35% for Large Vat Fryers (Ref. 5), 35% for Standard Fryers (Ref. 2); Heavy load cooking efficiency for standard efficiency equipment

Eff_EE = 50% for Large Vat Fryers, 50% for Standard Fryers (Ref. 4); Heavy load cooking efficiency for ENERGY STAR equipment

IdleRate_base = 20,000 Btu/hr for Large Vat Fryers (Ref. 5), 14,000 Btu/hr for Standard Fryers (Ref. 2); Idle Energy Rate for standard efficiency equipment

IdleRate_EE= 12,000 Btu/hr for Large Vat Fryers, 9,000 Btu/hr for Standard Fryers (Ref. 4); Idle Energy Rate for ENERGY STAR equipment

OpHrs = 12 hrs/day for Large Vat Fryers (Ref. 5), 16 hrs/day for Standard Fryers (Ref. 2); Daily operating hours

PC_base = 100 lbs/hr for Large Vat Fryers (Ref. 5), 60 lbs/hr for Standard Fryers (Ref. 4); Production capacity for standard efficiency equipment

PC_EE = 110 lbs/hr for Large Vat Fryers (Ref. 5), 65 lbs/hr for Standard Fryers (Ref. 4); Production capacity for ENERGY STAR equipment

T_pre = 15 min/day; Preheat Time (Ref. 2, 5)

E_pre_base = 21,000 Btu/day for Large Vat Fryers (Ref. 5), 16,000 Btu/day for Standard Fryers (Ref. 2); Preheat energy for standard efficiency equipment

E_pre_EE = 16,500 Btu/day for Large Vat Fryers (Ref. 5), 15,500 Btu/day for Standard Fryers (Ref. 2); Preheat energy for ENERGY STAR equipment

Days = See Table 1; Annual operating days

ConversionFactor = 1,000,000 Btu/Dth

Example:

A grocery store installed a new Standard-sized ENERGY STAR Gas Fryer

Eday_base (Btu/day) = (150 lbs/day) x (570 Btu/lb) / (35%) + [14,000 Btu/hr x (16 hr/day - (150 lbs/day / 60 lb/hr) - (15 min / 60 min/hr))] + 16,000 Btu/day = 445,786Btu/day

Eday_EE (Btu/day) = (150 lbs/day) x (570 Btu/lb) / (50%) + [9,000 Btu/hr x (16 hr/day - (150 lbs/day / 65 lb/hr) - (15 min / 60 min/hr))] + 15,500 Btu/day = 307,481 Btu/day

Unit Dth Savings per Year = (445,786 Btu/day - 307,481 Btu/day) / 1,000,000 Btu/Dth x 365 days/yr = 50.5 Dth

Deemed Input Tables

Table 1. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Notes

There is no code requirement for this technology.

ENERGY STAR defines a Standard Fryer as a fryer with a vat that measures ≥ 12 inches and < 18 inches wide, and a shortening capacity ≥ 25 pounds and ≤ 65 pounds (Ref. 4).

ENERGY STAR defines a Large Vat Fryer as a fryer with a vat that measures ≥ 18 inches and ≤ 24 inches wide, and a shortening capacity > 50 pounds (Ref. 4).

ENERGY STAR requires Standard Open Deep-Fat Gas Fryers have a heavy-load cooking efficiency ≥ 50% and an idle energy rate ≤ 9,000 Btu/h (Ref. 4)

ENERGY STAR requires Large Vat Open Deep-Fat Gas Fryers have a heavy-load cooking efficiency ≥ 50% and an idle energy rate ≤ 12,000 Btu/h (Ref. 4)

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. Commercial Fryer, Food Service Equipment Workpaper PGEOFST102 R1, PG&E. June 1, 2009.
3. Data from Table 1 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. ENERGY STAR Program Requirements: Product Specification for Commercial Fryers: Eligibility Criteria, Version 3.0, https://www.energystar.gov/sites/default/files/Commercial%20Fryers%20Program%20Requirements.pdf, accessed August, 19, 2016.
5. Commercial Large Vat Fryer, Food Service Equipment Workpaper PGECOFST114 R1, PG&E. June 1, 2009.

Revision History

Version	Description	Author	Date
1.0	Put together algorithm	Franklin Energy Services	8/14/2012
1.1	Changed measure name	Joe Plummer	2/8/2013
1.2	Added Large Vat Fryers	Franklin Energy Services	8/19/2016

Commercial Food Service - ENERGY STAR Gas Griddle

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type
Version No.	1.1
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$1,912 (Ref. 6)

Measure Description

This measure includes installation of high efficiency ENERGY STAR gas griddles instead of standard efficiency units. Energy efficient commercial gas griddles reduce energy consumption primarily through advanced burner design and controls.

Algorithms

Unit Dth Savings per Year = (Eday_base - Eday_EE) / Conversion Factor x Days

Where:

Eday_base (Btu/day) = LBFood x Efood / Eff_base + IdleRate_base x [OpHrs - LBFood / PC_base - T_pre / 60] + E_pre_base

Eday_EE (Btu/day) = LBFood x Efood / Eff_EE + IdleRate_EE x [OpHrs - LBFood / PC_EE - T_pre / 60] + E_pre_EE

LBFood = 100 lbs/day; Pounds of food cooked per day (Ref. 2)

Efood = 475 Btu/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 32%; Heavy load cooking energy efficiency (Ref. 2)

Eff_EE = 38% (Ref. 4)

IdleRate_base = 19,000 Btu/hr; Idle Energy Rate (Ref. 2)

IdleRate_EE= 16,000 Btu/hr (Ref. 2)

OpHrs = 12 hrs/day; Daily operating hours (Ref. 5)

PC_base = 25 lbs/hr; Production Capacity (Ref. 2)

PC_EE = 45 lbs/hr (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = 21,000 Btu/day; Preheat energy (Ref. 2)

E_pre_EE = 15,000 Btu/day (Ref. 2)

Days = See Table 1

ConversionFactor = 1,000,000 Btu/Dth

Example:

A sit-down restaurant installed a new ENERGY STAR Gas Griddle

Eday_base (Btu/day) = (100 lbs/day) x (475 Btu/lb) / (32%) + [19,000 Btu/hr x (12 hr/day - (100 lbs/day / 25 lb/hr) - (15 min / 60 min/hr))] + 21,000 Btu/day = 316,688 Btu/day

Eday_EE (Btu/day) = (100 lbs/day) x (475 Btu/lb) / (38%) + [16,000 Btu/hr x (12 hr/day - (100 lbs/day / 45 lb/hr) - (15 min / 60 min/hr))] + 15,000 Btu/day = 292,444 Btu/day

Unit Dth Savings per Year = (316,688 Btu/day - 292,444 Btu/day) / 1,000,000 Btu/Dth x 365 days/yr = 8.9 Dth

Deemed Input Tables

Table 1. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Methodology and Assumptions

Savings assumes a 3' x 2' griddle size and a Tier 1 idle rate.

Notes

There is no code requirement for this technology.

ENERGY STAR requires that Gas Griddles have a cooking energy efficiency ≥ 38% and a normalized idle energy rate ≤ 2,650 Btu/h per ft^2 (Ref. 4).

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. *Commercial Griddles,* Food Service Equipment Workpaper PGECOFST103 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. *Commercial Griddles Key Product Criteria,* http://www.energystar.gov/index.cfm?c=griddles.pr_crit_comm_griddles. Accessed August, 15, 2012.
5. *Technology Assessment: Griddles,* Food Service Technology Center, 2002. Page 3-22. http://www.fishnick.com/equipment/techassessment/3_griddles.pdf
6. Based on Vulcan-Hart pricing from KaTom.com, see Costs tab.

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	8/14/2012
1.1	Renamed measure	Joe Plummer	2/8/2013

Commercial Food Service - ENERGY STAR Gas Steamer

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type, number of pans (5 or 6)
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$3,732 (Ref. 2)

Measure Description

This measure includes replacement of commercial gas steamers with new 5 or 6-pan ENERGY STAR gas steamers.

Algorithms

Unit Dth Savings per Year = (Eday_base - Eday_EE) / Conversion Factor x Days

Where:

Eday_base (Btu/day) = LBFood x Efood / Eff_base + (IdleRate_base + Res_Rate_base) x (OpHrs - LBFood / PC_base - T_pre / 60) + E_pre_base

Eday_EE (Btu/day) = LBFood x Efood / Eff_EE + (IdleRate_EE + Res_Rate_EE) x (OpHrs - LBFood / PC_prop - T_pre / 60) + E_pre_EE

LBFood = See Table 1; Pounds of food cooked per day (Ref. 2)

Efood = 105 Btu/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 15%; Heavy load cooking energy efficiency (Ref. 2)

Eff_EE = 38% (Ref. 2)

IdleRate_base = See Table 1; Idle Energy Rate (Ref. 2)

IdleRate_EE= See Table 1 (Ref. 2)

OpHrs = 12 hrs/day; Daily operating hours (Ref. 2)

PC_base = See Table 1; Production Capacity (Ref. 2)

PC_EE = See Table 1 (Ref. 2)

Res_Rate_base = 45,080 Btu/h; Residual Energy Rate (Ref. 2)

Res_Rate_EE = 1,658 Btu/h; Residual Energy Rate (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = 18,000 Btu/day; Preheat energy (Ref. 2)

E_pre_EE = 9,000 Btu/day (Ref. 2)

Days = See Table 2

ConversionFactor = 1,000,000 Btu/Dth

Example:

A fast-food restaurant installed a new 5-pan ENERGY STAR Gas Steamer

Eday_base (Btu/day) = (100 lbs/day) x (105 Btu/lb) / (15%) + (16,000 Btu/hr + 45,080 Btu/h) x (12 hrs/day - (100 lbs/day / 117 lb/hr) - (15 min / 60 min/hr)) + 18,000 Btu/day = 721,014 Btu/day

Eday_EE (Btu/day) = (100 lbs/day) x (105 Btu/lb) / (38%) + (12,500 Btu/hr + 1,658 Btu/h) x (12 hrs/day - (100 lbs/day / 100 lb/hr) - (15 min / 60 min/hr)) + 9,000 Btu/day = 163,608 Btu/day

Unit Dth Savings per Year = (721,014 Btu/day - 163608 Btu/day) / 1,000,000 Btu/Dth x 365 days/yr = 203.6 Dth

Deemed Input Tables

Table 1. Steamer Characteristics

	5-Pan Steamer	6-Pan Steamer
LBFood (lbs/day)	83	100
Efood (Btu/lb)	105	105
Eff_base (%)	15%	15%
Eff_EE (%)	38%	38%
IdleRate_base (Btu/hr)	13,333	16,000
IdleRate_EE (Btu/hr)	10,400	12,500
OpHrs (hrs/day)	12	12
PC_base (lbs/hr)	117	140
PC_EE (lbs/hr)	100	120
Res_Rate_base (Btu/h)	45,080	45,080
Res_Rate_EE (Btu/h)	1,658	1,658
T_pre (minutes)	15	15
E_pre_base (Btu)	18,000	18,000
E_pre_EE (Btu)	9,000	9,000

Table 2. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Notes

There is no code requirement for this technology.

ENERGY STAR requires that Gas Steam Cookers have the following efficiencies (Ref. 4):

Table 3. Cooking Efficiency and Idle Rate by Pan Capacity

Pan Capacity	Cooking Energy Efficiency	Idle Rate (Btu/h)
3-Pan	38%	6,250
4-Pan	38%	8,350
5-Pan	38%	10,400
6-Pan	38%	12,500

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. Commercial Steam Cookers, Food Service Equipment Workpaper PGECOFST104 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. Commercial Steam Cookers Key Product Criteria, http://www.energystar.gov/index.cfm?c=steamcookers.pr_crit_steamcookers. Accessed August 27, 2012.

Revision History

Version	Description	Author	Date
1.0	Put together alogrithm	Franklin Energy Services	8/27/2012

Commercial Food Service - Gas Conveyor Oven

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type, width of conveyor (≤ 25"or > 25")
Version No.	1.1
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$1,751 for small; $4,731 for large (Ref. 2)

Measure Description

This measure includes the replacement of a standard efficiency gas conveyor oven with a high efficiency model. High-efficiency conveyor ovens can achieve higher efficiencies through use of independently controlled temperature zones and air curtains at the ends of the oven.

Algorithms

Unit Dth Savings per Year = (Eday_base - Eday_EE) / Conversion Factor x Days

Where:

Eday_base (Btu/day) = nPizza x Efood / Eff_base + IdleRate_base x [OpHrs - nPizza / PC_base - T_pre / 60] + E_pre_base

Eday_EE (Btu/day) = nPizza x Efood / Eff_EE + IdleRate_EE x [OpHrs - nPizza / PC_EE - T_pre / 60] + E_pre_EE

nPizza = See Table 1; Pizzas cooked per day (Ref. 2)

Efood = 190 Btu/pizza; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 20%; Heavy load cooking energy efficiency (Ref. 2)

Eff_EE = 42% (Ref. 2)

IdleRate_base = See Table 1; Idle Energy Rate (Ref. 2)

IdleRate_EE= See Table 1 (Ref. 2)

OpHrs = 10 hrs/day; Daily operating hours (Ref. 4)

PC_base = See Table 1; Production Capacity (Ref. 2)

PC_EE = See Table 1 (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = See Table 1; Preheat energy (Ref. 2)

E_pre_EE = See Table 1 (Ref. 2)

Days = See Table 2

ConversionFactor = 1,000,000 Btu/Dth

Example:

A fast-food pizzeria installed a new 25-in. high efficiency gas conveyor oven.

Eday_base (Btu/day) = (75 pizzas/day) x (190 Btu/pizza) / (20%) + [45,000 Btu/hr x (10 hrs/day - (75 pizzas/day / 55 pizzas/hr) - (15 min / 60 min/hr))] + 16,000 Btu/day = 464,636 Btu/day

Eday_EE (Btu/day) = (75 pizzas/day) x (190 Btu/pizza) / (42%) + [29,000 Btu/hr x (10 hrs/day - (75 pizzas/day / 75 pizzas/hr) - (15 min / 60 min/hr))] + 8,000 Btu/day = 295,679 Btu/day

Unit Dth Savings per Year = (464,636 Btu/day - 295,679 Btu/day) / 1,000,000 Btu/Dth x 365 days/yr = 61.7 Dth

Deemed Input Tables

Table 1. Conveyor Characteristics

	Small Conveyor (≤ 25-in. width)	Large Conveyor Oven (> 25-in. width)
nPizza (pizzas/day)	75	150
Efood (Btu/pizza)	190	190
Eff_base (%)	20%	20%
Eff_EE (%)	42%	42%
IdleRate_base (Btu/hr)	45,000	70,000
IdleRate_EE (Btu/hr)	29,000	57,000
OpHrs (hrs/day)	10	10
PC_base (pizzas/hr)	55	150
PC_EE (pizzas/hr)	75	225
T_pre (minutes)	15	15
E_pre_base (Btu)	16,000	35,000
E_pre_EE (Btu)	8,000	18,000

Table 2. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Notes

There is no code requirement for this technology.

Small conveyor ovens are defined as having a conveyor width of 25-in. or less

Large conveyor ovens are defined as having a conveyor width of greater than 25-in.

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. *Commercial Conveyor Ovens,* Food Service Equipment Workpaper PGECOFST117 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. *Technology Assessment: Ovens,* Food Service Technology Center, 2002. Page 7-22. http://www.fishnick.com/equipment/techassessment/7_ovens.pdf

Revision History

Version	Description	Author	Date
1.0	Put together alogrithm	Franklin Energy Services	8/27/2012
1.1	Replaced LBFood in algorithms with nPizza, changed measure name	Joe Plummer	2/8/2013

Commercial Food Service - Gas Oven, Broiler, Pasta Cooker

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Input Btu/h of new equipment, new equipment type
Version No.	3.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	See Table 1

Measure Description

This measure includes replacement of failed or working gas food service equipment with new high efficiency food service equipment.

Algorithms

Unit kWh Savings per Year = HVAC_Savings_Factor x BTUH_In / 1,000 kWh/Wh

Unit Dth Savings per Year = BTUH_In x BTU_Savings_Factor / 1,000,000

Where:

BTUH_In = Nameplate input Btu/h of equipment meeting installation standard (provided by the customer/contractor)

BTU_Savings_Factor = Deemed annual Btu savings per nameplate Btu/h input rating

HVAC_Savings_Factor = Deemed annual electricity savings from HVAC interactive effects (Watt-hours per installed Btu/h input)

Example:

A fast-food restaurant installed a new high efficiency 48,000 Btu/h Pasta Cooker

Unit Dth Savings per Year = 48,000 Btu/h x (1,689 Btu/ (Btu/h*yr)) / 1,000,000 Btu/Dth = 81.0 Dth

Deemed Input Tables

Table 1. Pre- and Post-retrofit Equipment, Savings Factors, and Incremental Costs

Baseline Equipment	Efficient Equipment	BTU Savings Factor (Btu / ((Btu/h)-yr)) (Ref. 1)	HVAC Savings Factor (Watt-hours / ((Btu/h)-yr) (Ref. 1)	Incremental Cost ($/unit) (Ref. 3)
Open Flame Rotisserie Oven	Efficient Rotisserie Oven	554	15	$2,665
Range	Pasta Cooker	1,689	46	$2,413
Standard Charbroiler	Efficient Charbroiler	1,078	29	$2,173
Standard Radiant Broiler	Efficient Upright Broiler	1,041	30	$4,413
Standard Salamander Broiler	Efficient Salamander Broiler	885	28	$1,006

Notes

The following technologies have been removed from Table 1 because they now have their own measure:

- Convection Oven, Rack Oven, Conveyor Oven, Fryer, Griddle and Combination Oven

References

1. Savings per installed BTU derived from the Arkansas Food Service Deemed Savings table
2. Measure life for similar food service equipment, 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
3. Incremental costs confirmed using "Commercial Cooking Appliance Technology Assessment, FSTC Report #5011.02.2, Food Service Technology Center, 2002" and product manufacturer Web sites

Revision History

Version	Description	Author	Date
1.0	Original from Nexant with extraneous tabs hidden	Nexant	
2.0	Cleaned up; removed extraneous fields, clarified that BTUH_In is specified by customer, added incremental costs, corrected HVAC effects formula to convert to kWh, added lifetime	Joe Plummer	
2.1	Corrected algorithm to add conversion factor from Btu to MMBtu	Joe Plummer	
2.2	Corrected algorithm to add conversion factor from Btu to kWh/yr (multiply by 1e-3 to divide by 1,000)	SK	
3.0	Removed measures per note above and reformatted	Franklin Energy Services	8/29/2012
3.1	Renamed measure	Joe Plummer	2/8/2013

Commercial Food Service - Gas Rack Oven

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Food Service
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Building type, single or double rack
Version No.	1.1
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	12 (Ref. 1)
Unit Participant Incremental Cost	$4,933 for single-rack; $5,187 for double-rack (Ref. 2)

Measure Description

This measure includes replacement of commercial gas rack ovens with new high efficiency rack ovens. High efficiency rack ovens achieve higher efficiencies by incorporating timesaving features via sophisticated control packages.

Algorithms

Unit Dth Savings per Year = (Eday_base - Eday_EE) / Conversion Factor x Days

Where:

Eday_base (Btu/day) = LBFood x Efood / Eff_base + IdleRate_base x [OpHrs - LBFood / PC_base - T_pre / 60] + E_pre_base

Eday_EE (Btu/day) = LBFood x Efood / Eff_EE + IdleRate_EE x [OpHrs - LBFood / PC_EE - T_pre / 60] + E_pre_EE

LBFood = See Table 1; Pounds of food cooked per day (Ref. 2)

Efood = 235 Btu/lb; ASTM Energy-to-Food value (Ref. 2)

Eff_base = 30%; Heavy load cooking energy efficiency (Ref. 2)

Eff_EE = 50% (Ref. 2)

IdleRate_base = See Table 1; Idle Energy Rate (Ref. 2)

IdleRate_EE = See Table 1 (Ref. 2)

OpHrs = 8 hrs/day; Daily operating hours (Ref. 4)

PC_base = See Table 1; Production Capacity (Ref. 2)

PC_EE = See Table 1 (Ref. 2)

T_pre = 15 min/day; Preheat Time (Ref. 2)

E_pre_base = See Table 1; Preheat energy (Ref. 2)

E_pre_EE = See Table 1 (Ref. 2)

Days = See Table 2

ConversionFactor = 1,000,000 Btu/Dth

Example:

A high school cafeteria installed a new high efficiency double-rack oven.

Eday_base (Btu/day) = (1,200 lbs/day) x (235 Btu/lb) / (30%) + [65,000 Btu/hr x (8 hrs/day - (1,200 lbs/day / 250 lb/hr) - (15 min / 60 min/hr))] + 100,000 Btu/day = 1,231,750 Btu/day

Eday_EE (Btu/day) = (1,200 lbs/day) x (235 Btu/lb) / (50%) + [35,000 Btu/hr x (8 hrs/day - (1,200 lbs/day / 280 lb/hr) - (15 min / 60 min/hr))] + 85,000 Btu/day = 770,250 Btu/day

Unit Dth Savings per Year = (1,231,750 Btu/day - 770,250 Btu/day) / 1,000,000 Btu/Dth x 200 days/yr = 92.3 Dth

Deemed Input Tables

Table 1. Oven Characteristics

	Single-Rack Oven	Double-Rack Oven
LBFood (lbs/day)	600	1200
Efood (Btu/lb)	235	235
Eff_base (%)	30%	30%
Eff_EE (%)	50%	50%
IdleRate_base (Btu/hr)	43,000	65,000
IdleRate_EE (Btu/hr)	29,000	35,000
OpHrs (hrs/day)	8	8
PC_base (lbs/hr)	130	250
PC_EE (lbs/hr)	140	280
T_pre (minutes)	20	20
E_pre_base (Btu)	50,000	100,000
E_pre_EE (Btu)	44,000	85,000

Table 2. Operation Days by Building Type (Ref. 3)

Building Type	Days Per Year
Large Office	250
Fast Food Restaurant	365
Sit-Down Restaurant	365
Grocery	365
Elementary School	200
Jr. High/High School/College	200
Health	365
Hotel	365
Other Commercial	250

Notes

There is no code requirement for this technology.

References

1. 2008 Database for Energy Efficient Resources, Version 2008.2.05, EUL/RUL Values, October 10, 2008.
2. *Commercial Rack Ovens,* Food Service Equipment Workpaper PGECOFST109 R1, PG&E. June 1, 2009.
3. Data from Table 2 in Technology Data Characterizing Water Heating in Commercial Buildings: Application to End-Use Forecasting, Osman Sezgen and Jonathan G. Koomey, Lawrence Berkeley National Laboratory, December 1995.
4. *Technology Assessment: Ovens,* Food Service Technology Center, 2002. Page 7-22. http://www.fishnick.com/equipment/techassessment/7_ovens.pdf

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	8/27/2012
1.1	Changed measure name, added single or double rack as required input from customer/contractor	Joe Plummer	9/12/2013

Commercial Food Service - Kitchen Demand Control Ventilation

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Commercial kitchens
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Confirmation of gas heat for make-up air, project location (county), fan hp, and hours of operation for the kitchen
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$1,988 per fan for retrofit applications or $1,000 per fan for new construction applications (Ref. 1)

Measure Description

This measure includes installing controls for commercial kitchen hoods to vary the ventilation rate based upon cooling load, which varies throughout the day. By reducing the kitchen exhaust rate, fan energy savings are possible, and less make-up air is needed which results in heating savings.

Algorithms

Unit kWh Savings per Year = Usage_Save_Per_HP x HP x Actual_Hours / Tested_Hours

Unit Peak kW Savings = Demand_Save_Per_HP x HP

Unit Dth Savings per Year = CFM_Reduction x HP x Annual_Heating_Load x Actual_Hours / (Heat_Eff * Conversion_Factor)

Where:

Usage_Save_Per_HP = kWh savings per exhaust fan HP = 4,486 (Ref. 1)

Demand_Save_Per_HP = kW demand savings per exhaust fan HP = 0.76 (Ref. 1)

Actual_Hours = hours of operation. If unknown, use 4,745, which is 7 AM to 8 PM (per Appendix D) for 365 days per year.

Tested_Hours = annual hours of operation from PGE Workpaper, which was based on measured data. Average operation was 17.8 hours per day for 330 days per year, or 5,874 hours (Ref. 1)

CFM_Reduction = Average airflow reduction per exhaust fan HP with demand control ventilation = 611 CFM / HP (Ref. 2)

HP = horsepower of the exhaust fan for the ventilation system

Annual_Heating_Load = Annual Btu / CFM of outside air per hour needed as make-up for exhaust fan, value depends on location, see Table 1 below

Heat_Eff = heating efficiency of the make-up air unit, if unknown use typical value of 80%

Conversion_Factor = 1,000,000 Btu per Dth

Example:

Retrofit of a 3 HP kitchen exhaust fan with kitchen demand control ventilation in Climate Zone 2. The heating efficiency of the make-up air unit is unknown.

HP = 3.0

Annual_Heating_Load = 135,000 Btu per CFM

Heat_Eff = 80%

Unit kWh Savings per Year = 4,486 kWh per HP x 3.0 HP x 4,745 Hours / 5,874 Hours = 10,871 kWh

Unit Peak kW Savings = 0.76 kW per HP x 3.0 HP = 2.28 kW

Unit Dth Savings per Year = 611 CFM per HP x 3.0 HP x 135,000 Btu per CFM / (80% efficiency * 1,000,000 Btu per Dth) = 309.3 Dth

Deemed Input Tables

Table 1. Annual Heating Load by Location (Ref. 3)

Location	Annual Heating Load (Btu/CFM per hour of Operation)
Zone 1 (Northern MN)	32.23
Zone 2 (Central MN)	28.63
Zone 3 (Twin Cities/Southern MN)	25.66

Zone 1 is the average of data for International Falls and Duluth

Zone 2 is the average of data for Duluth and Minneapolis

Zone 3 is the average of data for Minneapolis and Rochester

Hours of operation included in the calculator were 7 AM to 8 PM, consistent with energy model inputs listed in Appendix D. Two additional hours of operation (5 AM to 10 PM and 10 AM to 8 PM) were also used, representing shorter and longer hours of operation than Appendix D, to confirm that normalizing Btu/CFM by hours of operation would be consistent for a variety of start and end times.

Methodology and Assumptions

Uses algorithms from IL TRM (Ref. 2) for gas savings.

Uses algorithms from PGE Workpaper (Ref. 1) for electric savings.Note that IL TRM appears to incorrectly list the 4,486 kWh/hp and 0.76 kW/hp electric savings from the PGE Workpaper as 4,486 kWh/fan and 0.76 kW.

Notes

This measure requires installation of a VFD to provide the variable speed capability of the exhaust fan. Savings associated with the VFD are included in the kitchen demand control ventilation measure. Projects should not be eligible for both kitchen demand control ventilation and VFD measures for the same equipment.

References

1. PGE Workpaper PGECOFST116, Commercial Kitchen Demand Ventilation Controls, December 21, 2007.
2. State of Illinois Energy Efficiency Technical Reference Manual, Version 5.0, Volume 2: Commercial and Industrial Measures, Page 74-76. February 11, 2016. www.ilsag.info/il_trm_version_5.html
3. Food Service Technology Center Outside Air Load Calculator, with inputs of 1 CFM and hours of operation from 7 AM to 8 PM. No inputs in calculator for days/week or days/year, so this is for 365 days/year. www.fishnick.com/ventilation/oalc/oac.php

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/26/16

Plug Load

Commercial Plug Load - Beverage Machine Controls

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Plug Loads
Applicable To	Commercial facilities with vending machines
Actions	Replace Working (addition to working equipment)
Required from Customer/Contractor	n/a
Version No.	4.1
Unit kWh Savings per Year	See algorithm (Ref. 1)
Unit Peak kW Savings	See algorithm (Ref. 1)
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 3)
Unit Participant Incremental Cost	$180 (Ref. 4)

Measure Description

Installation of automatic shutoff control on refrigerated vending machines. Controls must include a passive infrared sensor to shut off lighting and compressor. Controls must be capable of periodically powering up the machine to maintain product temperature and provide compressor protection.

Algorithms

Unit kWh Savings per Year = Wbase / 1000 x Hours x SavingsFactor

Unit Peak kW Savings = Unit kWh Savings per Year / Hours x CF

Where:

Wbase = 400 W; connected Wattage of the controlled equipment (Ref. 2)

Hours = 8,760 (average hours per year)

SavingsFactor = 46% (Ref. 2)

CF = 0.27 (Ref. 5)

Example:

A customer installed Vending Miser controls on their cold beverage vending machine.

Unit kWh Savings per Year = 400W / 1000 x (8,760 hours) x 46% = 1,613 kWh

Unit Peak kW Savings = 1,613 kWh / 8,760 hours x 0.27 = 0.050 kW

Notes

There are no energy code requirements for this technology

References

1. Energy and demand savings from Illinois Statewide Technical Resource Manual, pages 279-281.
2. USA Technologies Energy Management Product Sheets, July 2006; cited September 2009. http://www.usatech.com/energy_management/energy_productsheets.php
   *The SavingsFactor value is supported by the Focus on Energy's Deemed Savings Evaluation Report 2010, which references several studies in their defense of the figure.
3. 2008 Database for Energy-Efficiency Resources (DEER), Version 2008.2.05, "Effective/Remaining Useful Life Values", California Public Utilities Commission, December 16, 2008
4. 2005 Database for Energy Efficiency Resources (DEER) Update Study Final Report - Residential and Commercial Non-Weather Sensitive Measures
5. Northwest Power and Conservation Council, 2001. Accessed 1/4/13. www.nwcouncil.org/rtf/supportingdata/VendingMiser.XLS

Revision History

Version	Description	Author	Date
.1.0	Original from Nexant with extraneous tabs hidden	Nexant	
2.0	Reformatted	Joe Plummer	
3.0	Added algorithm per the IL TRM	Franklin Energy Services	7/23/2012
3.1	Adjusted savings; increased kWh and eliminated kW savings	Franklin Energy Services	7/23/2012
3.2	Added example	Franklin Energy Services	7/23/2012
3.3	Revised Product Description	Franklin Energy Services	7/23/2012
4.0	Updated the CF to 0.27 per Reference 5	Franklin Energy Services	1/4/2013
4.1	Changed Action from Retrofit to Replace Working; Changed Target End Use from Specialty to Plug loads; Changed annual hours from 8,760 to 8,760 for consistency with other measures	Joe Plummer	4/3/2013

Commercial Plug Load - Computer Power Management

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Electric
Applicable To	Commercial office and computer lab workstations; direct install/energy audit programs
Actions	Modify
Required from Customer/Contractor	Computer type (desktop or laptop), monitors per workstation
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 1)
Unit Participant Incremental Cost	$0 (does not include labor costs)

Measure Description

This measure characterizes average savings from adjustment of computer power management settings by a direct install technician. Computer power management settings, when properly enabled, automatically put the computer and monitor in a low power state when no activity is detected for a certain period of time.

Average per unit savings are provided in Table 5.

Algorithms

Annual Unit kWh savings = $((UEC_{CompBase} - UEC_{CompEff}) + (UEC_{MonBase} - UEC_{MonEff}))$ x HVAC_cooling_factor

Unit Peak kW Savings = (Unit kWh Savings per Year)/8,760 x HVAC_cooling_factor

Unit Dth Savings per Year= $((UEC_{CompBase} - UEC_{CompEff}) + (UEC_{MonBase} - UEC_{MonEff}))$ x HVAC_heating_factor

Where:

Unit = One Workstation

$UEC_{ComBase}$ = $(\sum_{State} Power_{State} \times Hours_{Base,State}) / 1{,}000$, energy consumption of computer before adjusting power settings

UEC_{ComEff} = $(\sum_{State} Power_{State} \times Hours_{Eff,State}) / 1{,}000$,energy consumption of computer after adjusting power settings

$UEC_{MonBase}$ = $(\sum_{State} MpW \times Power_{State} \times Hours_{Base,State}) / 1{,}000$, energy consumption of monitor before adjusting power settings

UEC_{MonEff} = $(\sum_{State} MpW \times Power_{State} \times Hours_{Eff,State}) / 1{,}000$, energy consumption of monitor after adjusting power settings

$Hours_{Base,State}$ = 8,760 x BaseDutyCycle(%), annual hours in each power state, see Table 1 for computers and Table 2 for monitors

$Hours_{Eff,State}$ = 8,760 x EfficientDutyCycle(%), annual hours in each power state, see Table 1 for duty cycle, see Table 1 for computers and Table 2 for monitors

MpW = Monitors per Workstation

$Power_{State}$ = Power (W) consumption in each power state,See Table 2

HVAC_cooling_factor = 1.095 (Ref. 4)

HVAC_heating_factor = -0.0023 Dth/kWh (Ref. 4)

Example:

A direct install technician adjusts power management settings in a desktop computer workstation with two monitors.

Computer savings:

Computer kWh savings = ($UEC_{CompBase}$ -$UEC_{CompEff}$)

kWh savings = ($UEC_{CompBase}$ -$UEC_{CompEff}$)

UECCompBase = 0 x 5% x 8,760+0.9 x 55% x 8,760+2.1 x 2% x 8,760+39.9 x 35% x 8,760+72.2 x 3% x 8,760=146.2kWh

UECCompEff = 0 x 5% x 8760+0.9 x 77% x 8760+2.1 x 2% x 8760+39.9 x 13% x 8760+72.2 x 3% x 8760=70.5kWh

Computer kWh savings = (146.2-70.5) = 75.7kWh

Computer peak kW savings = 75.7/8760 = 0.009 kW

Monitor savings:

Monitor kWh savings = ($UEC_{MonBase}$ - UEC_{MonEff})

$UEC_{MonBase}$ = (2 x 0 x 22% x 8,760+2 x 0.23 x 50% x 8,760+2 x 0.32 x 2% x 8,760+2 x 14.43 x 26% x 8,760)/1,000=67.9kWh

UEC_{MonEff} = (2 x 0 x 22% x 8760+2 x 0.23 x 57% x 8,760+2 x 0.32 x 2% x 8,760+2 x 14.43 x 19% x 8,760)/1,000=50.5kWh

Monitor kWh savings = (67.9-50.5) = 17.4kWh

Monitor peak kW savings=17.4/8760 = 0.002 kW

Total kWh Savings = (75.7+17.4) x 1.095 = 101.9 kWh

Total kW Savings = (0.009 + 0.002) x 1.095 = 0.012 kW

Deemed Input Tables

Table 1. Average baseline and efficient duty cycle for computers by power state (Ref. 2)

Computer Power State	Duty Cycle, as %	
	Base	Efficient
Unplugged	5%	5%
Off	55%	77%
Sleep	2%	2%
Idle	35%	13%
Active	3%	3%
Total	**100%**	**100%**

Table 2. Average baseline and efficient duty cycle for monitors by power state (Ref. 2)

Monitor Power State	Duty Cycle, as %	
	Base	Efficient
Unplugged	22%	22%
Off	50%	57%
Sleep	2%	2%
On	26%	19%
Total	**100%**	**100%**

Table 3. Average power draw by state for desktop and laptop computers (Ref. 3)

Power Draw, W		
Power State	Desktop Computer	Laptop Computer
Unplugged	0.0	0.0
Off	0.9	0.5
Sleep	2.1	0.9
Idle	39.9	8.9
Active	72.2	60.0

Table 4. Average power draw by state for monitors (Ref. 3)

Monitor Power State	Power Draw, W	
	Base	Measure
Unplugged	0.00	0.00
Off	0.23	0.23
Sleep	0.32	0.32
On	14.43	14.43

Table 5. Average Savings per Unit

Average Savings per unit		
Device	**kWh**	**kW**
Desktop Computer	75.7	0.009
Laptop* Computer	16.4	0.002
Monitor	8.7	0.001

* Laptop savings includes built in display

Methodology and Assumptions

Adapted from Northwest Regional Technical Forum Non-Res Network Computer Power Management measure.

Incremental cost does not include labor costs.

References

1. Measure life of a computer, 2016 IRS Publication 946, Page 30
2. RTF NonResNetCompPwrMgt_v4_1.xlsm which analyzed data from several sources
3. Updated RTF NonResNetCompPwrMgt_v4_1.xlsm with new values for Desktop, Laptop and Monitor power consumption per current ENERGY STAR information and market penetration
4. HVAC cooling and heating interactive factor data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes (see http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf), and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Revision History

Version	Description	Author	Date
1.0	Created document	Franklin Energy Services	12/5/17

Commercial Plug Load - Snack Machine Controls

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Plug Loads
Applicable To	Commercial facilities with vending machines
Actions	Plug-in addition to working equipment (or replace working machine)
Required from Customer/Contractor	n/a
Version No.	1.0
Unit kWh Savings per Year	See algorithm (Ref. 1)
Unit Peak kW Savings	See algorithm (Ref. 1)
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 3)
Unit Participant Incremental Cost	$80 (Ref. 4)

Measure Description

Installation of automatic shutoff control on non-refrigerated snack vending machines. Controls must include a passive infrared sensor to shut off lighting when the area surrounding the vending machine is unoccupied for fifteen (15) minutes. Controls must be capable of powering up the machine on IR activation to highlight the product offerings.

Algorithms

Unit kWh Savings per Year = W_{base} / 1000 x Hours x SavingsFactor

Unit Peak kW Savings = Unit kWh Savings per Year / Hours x CF

Where:

W_{base} = 85 W; connected Wattage of the controlled equipment (Ref. 2)

Hours = 8,760 (average hours per year)

Savings Factor = 46% (Ref. 2)

CF = 0.27 (Ref. 5)

Example:

A customer installed Vending Miser controls on their non-refrigerated vending machine.

Unit kWh Savings per Year = 85W / 1000 x (8,760 hours) x 46% = 343 kWh

Unit Peak kW Savings = 343 kWh / 8,760 hours x 0.27 = 0.01 kW

Notes

There are no energy code requirements for this technology

References

1. Energy and demand savings from Illinois Statewide Technical Resource Manual, pages 279-281. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_4/2-13-15_Final/Updated/Illinois_Statewide_TRM_Effective_060115_Final_02-24-15_Clean.pdf. Accessed 08/24/16.
2. State of Wisconsin Focus on Energy Evaluation Deemed Savings Manual V1.0, cited April 2007, pages 106-107. https://www.focusonenergy.com/sites/default/files/bpdeemedsavingsmanuav10_evaluationreport.pdf. Accessed 08/24/16.
3. 2008 Database for Energy-Efficiency Resources (DEER), Version 2008.2.05, "Effective/Remaining Useful Life Values", California Public Utilities Commission, December 16, 2008. http://www.deeresources.com/files/deer0911planning/downloads/EUL_Summary_10-1-08.xls. Accessed 08/24/16.
4. Regional Technical Forum, Vending System Controls. http://rtf.nwcouncil.org/supportingdata/VendingMiser.XLS. Accessed 08/24/16.

Revision History

Version	Description	Author	Date
1.0	Original issue (based from Commercial Beverage)	Franklin Energy Services	7/19/2016

Commercial Plug Load – Tier 1 Advanced Power Strips

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Misc. Electric Loads
Applicable To	Commercial office and computer lab workstations
Actions	Modify, New Construction
Required from Customer/Contractor	n/a
Version No.	2.0
Unit kWh Savings per Year	134.1 kWh (see Methodology and Assumptions)
Unit Peak kW Savings	0 (Ref. 2)
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 3)
Unit Participant Incremental Cost	$40 or use actual cost per unit (Ref. 1)

Measure Description

This measure relates to Advanced Power Strips – Tier 1 which are multi-plug power strips with the ability to automatically disconnect specific connected loads depending upon the power draw of a control load, also plugged into the strip. Power is disconnected from the switched (controlled) outlets when the control load power draw is reduced below a certain adjustable threshold, thus turning off the appliances plugged into the switched outlets. By disconnecting, the standby load of the controlled devices, the overall load of a centralized group of equipment (e.g. a desk workstation) can be reduced. In a commercial office space, savings generally occur during off-hours, when connected equipment continues to consume electricity while in standby mode or when off. Uncontrolled outlets are also provided that are not affected by the control device and so are always providing power to any device plugged into it.

Methodology and Assumptions

The estimated electric energy savings for this measure represent typical savings per workstation calculated from an average of savings from two studies (Ref. 4, 5).

Unit kWh Savings = (145.6 kWh + 134 kWh) / 2 = 139.8 kWh (Ref. 4, 5)

The BPA Ross Complex study (Ref. 4) compiled energy savings data from a total of 45 tier 1 APS units installed in office cubicles in three separate facilities, finding an average of 145 kWh of annual savings per power strip. The ACEEE and University of Idaho study (Ref. 5) surveyed the energy savings from 88 tier 1 APS units controlling 77 separate devices in an office facility and found an average of 134 kWh of annual savings per power strip.

Example:

Advanced Tier 1 Power Strips are installed in ten workstations in a small commercial office site.

kWh Savings per Year = 139.8 kWh x 10 units = 1,398 kWh

References

1. MEMD attachment FES-C18 Advanced Power Strips Michigan.xls
2. IL TRM V6.0 page 498 – No coincidence factor due to no savings attributable to standby losses between 1:00 p.m. and 5:00 p.m.
3. Ohio Technical Reference Manual: Technical Reference Manual (TRM) for Ohio Senate Bill 221" Energy Efficiency and Conservation Program" and 09-512-GE-UNC, October 15, 2009, Pages 149-150
4. Bonneville Power Administration. *Smart Power Strip Energy Savings Evaluation (Ross Complex)*. 2011. https://studylib.net/doc/8460015/smart-strip-energy-savings-evaluation-%E2%80%93-ross-complex--van
5. Acker, B., C. Duarte, K. Van Den Wymelenberg. *Office Space Plug Load Profiles and Energy Saving Interventions*. 2012. https://aceee.org/files/proceedings/2012/data/papers/0193-000277.pdf

Revision History

Version	Description	Author	Date
1.0	Document Created	Franklin Energy Services	9/7/17
2.0	Updated savings based on more recent data	Cadmus	10/30/2018

Commercial Plug Load – Tier 2 Advanced Power Strips

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Misc. Electric Loads
Applicable To	Commercial office and computer lab workstations; compatibility with the host site's IT protocols should be considered
Actions	Modify, New Construction
Required from Customer/Contractor	n/a
Version No.	1.0
Unit kWh Savings per Year	125 (Ref. 4)
Unit Peak kW Savings	0.011 (Ref. 4)
Unit Dth Savings per Year	-0.0023 * (Unit kWh Savings per Year) = -0.29 (Ref. 3)
Measure Lifetime (years)	8 years (Ref. 2)
Unit Participant Incremental Cost	$65 or use actual cost per unit (Ref. 1)

Measure Description

Tier 2 Advanced Power Strips (APS) used in commercial workstation applications manage both active and standby power loads for controlled devices in a complete system. Tier 2 APS may operate either with or without a software installation on the workstation computer. Those without a software installation use localized motion detection as a proxy for user engagement; those with a software installation on the workstation computer track mouse movement and keyboard strokes as a proxy for user engagement. Both versions of commercial-use, Tier 2 Advanced Power Strips will put the workstation computer into a standby/sleep mode after a period absent of user engagement; this manages the active power usage of the workstation computer. Both versions also remove power to a number of switched outlets to turn off peripheral devices; this manages the standby power usage of attached peripheral devices. Commercial-use, Tier 2 Advanced Power Strips also have a number of "always-on" outlets intended for those workstation devices that always need power supplied such as a wireless router or internet hub/switch.

Example:

Advanced Tier 2 Power Strips are installed throughout a small commercial office site.

Unit kWH Savings per Year = 125 kWh

Unit kW Peak Savings = 0.011 kW

Unit Dth Savings per Year = -0.0023 * 125 = -0.29 Dth

Methodology and Assumptions

The estimated electric energy savings for this measure are based on the results of a 2016 Minnesota Conservation Applied Research and Development (CARD) study (Ref. 4). The study included detailed monitoring of eight workstations found to consume an average of 332 kWh per year. The savings for Tier

2 Advanced Power Strips are thought to be comparable to the savings from enabling Computer Power Management (CPM) in the study, which produced an average savings of 106 kWh per year (29 percent of total workstation energy). A savings range of 100-150 kWh for Tier 2 APS was suggested by the study author.

The peak demand savings for this measure are also based on metering results from the CARD study. Enabling CPM was found to produce an average demand savings of 9W between 1pm-5pm on weekdays in summer months. This figure was scaled to 11W using the ratio of deemed APS savings to CPM savings (125 kWh/106 kWh).

The gas savings reflect the additional heating energy required due to the reduction in electrical energy consumption resulting from implementation of this measure. The heating penalty factor (-0.0023 Dth/kWh) is consistent with the factor used in the Commercial Lighting End Use measure (Ref. 3).

References

1. "Tier 2 Advanced Power Strips in Residential and Commercial Applications" San Diego Gas & Electric Emerging Technologies Program Technology Assessment Report, Alternative Energy Systems Consulting Inc., April 2015
2. 2008 DEER Effective Useful Life (EUL) for Plug Load Occupancy Sensors
3. HVAC cooling and heating interactive factor data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes (see http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf), and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3)
4. *Impacts of Office Plug Load Reduction Strategies.* Conservation Applied Research and Development (CARD) Final Report. Seventhwave et al, October 2016.

Revision History

Version	Description	Author	Date
1.0	Document Created	Franklin Energy Services	12/2/16

Misc

C/I - Building Operator Certification

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial, Public
Target End Uses	HVAC, Lighting
Applicable To	Commercial, Industrial, and Public Buildings
Actions	Modify
Required from Customer/Contractor	Completion of Level I of Level II BOC training
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	5 years (See Ref. 2)
Unit Participant Incremental Cost	$1,200 per participant (Ref. 3)

Measure Description

This measure evaluates the impact of training and certifying building operators under the Building Operator Certification (BOC) program. BOC trains facility operators and managers to make informed decisions on energy efficient building management.

Eligible candidates for BOC training include building engineers, stationary engineers, maintenance supervisors, maintenance workers, facility coordinators, HVAC technicians, electricians, operations supervisors, operations techs, and others in the facility operation and maintenance field. However, work experience, education, and completion of BOC classes, exams, and on-the-job projects are also considered.

Energy is saved by influencing building operators and managers to pursue energy efficient projects and to make energy conscious decisions. Energy savings are captured on a per participant basis.

Algorithms

BOC Attributable Savings = Gross Savings x BOC Influence (varies by participant)
= See Below

Net BOC Attributable Savings = Savings Net of Utility Rebated
= BOC Attributable Savings x Rebate Factor
= See table below

Proposed Savings = [(Net BOC Attributable Savings – O&M Savings) x 0.35 + O&M Savings]
= See table below

Where:

Rebate Factor = 0 for incentivized projects, 1 for no incentive paid

Table 1. Building Operator Certification Program Savings

BOC Annual Savings Description	kWh	therm
Gross Savings (per participant)	188,599	4,641.2
BOC Attributable	130,746	3224.7
Net BOC Attributable	42,936	2,279.8
Gross per Square Foot*	1.040	0.0257
BOC Attributable per Square Foot*	0.721	0.0185
Net BOC Attributable per Square Foot*	0.237	0.0134
O&M per Square Foot*	0.058	0.00519
Proposed Net BOC Attributable per Square Foot*	0.121	0.00806

*Based on average facility size of 194,500 square feet

Example:

Certified building operator of a 240,000 square foot building serviced by gas and electric utilities.

Building kWh savings per year = 240,000 sq. ft. * 0.121 kWh/sq. ft.= 29,040 kWh/yr.

Building therm savings per year = 240,000 sq. ft. * 0.00806 therm/sq. ft = 1,934.4 therm/yr.

Methodology and Assumptions

Savings here are derived from analysis of 22 Consumers Energy BOC graduate organizations, where pre- and post-training data was collected. Additionally the analysis contains data from a similar study done in Minnesota programs by Navigant Consulting.

Assumes successful completion of Level I or Level II BOC training by eligible building operator or manager; savings are not dependent on which level is completed. The level of influence BOC training had on each participant's decision-making was captured in a survey released after training, which contributed to the BOC influence rate. Impacts by utility offered incentives were also considered in the influence rate by eliminating projects where rebates were offered from the pool of influence. The influence rate was applied to gross savings to determine the amount of energy savings specifically attributed to BOC training.

References

1. Building Operator Certification (Electric/Gas), 2012. Prepared by Consumers Energy Business Solutions, pages 1-9
2. The Impact and Process Evaluation Building Operator Training and Certification (BOC) Program Final Report, Section 1.4, page 4
3. The 2010 Building Operator Certification Pilot Summary Report, Section 2, page 3

Revision History

Version	Description	Author	Date
1.0	Document created	Franklin Energy Services	11/12/2015

C/I Motors

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Fans, Pumps, Motors, HVAC, Process
Applicable To	Motors in industrial and HVAC applications
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	New Motor Enclosure Type (ODP/TEFC), RPM, Horsepower, Efficiency; Action Type (Replace on Fail, Replace Working, or New Construction); Building Type and Application (see Table 2)
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	6 years (Replace Working), 20 years (Replace on Fail, New Construction) (Ref. 1, 2, 4)
Unit Participant Incremental Cost	Incr. Cost for EPACT to NEMA Premium Efficiency or EPACT to Enhanced NEMA Premium (Replacing Working); Incr. Cost for NEMA Premium Efficiency to Enhanced NEMA Premium (Replace on Fail and New Construction). See Appendix C. (Ref. 6)

Measure Description

This measure includes one-for-one replacement of working or failed/near-failure 1-200 hp motors with motors that meet or exceed NEMA Premium Efficiency levels in industrial and non-industrial applications, as well as installation of motors in new construction.

For replacement of working motors, the new motor efficiency must be at least NEMA Premium Efficiency. For replacement of failed/near-failure motors or new construction, the new motor efficiency must exceed NEMA Premium Efficiency.

Algorithms

Unit kWh Savings per Year = HP x LF x Conversion x (1/Eff_base – 1/Eff_EE) x Hrs

Unit Peak kW Savings = HP x LF x Conversion x (1/Eff_base – 1/Eff_EE) x CF

Where:

Hrs	=	Deemed annual operating hours by end use (non-industrial applications, see Table 2) or motor HP (industrial applications, see Table 1.)
LF	=	Motor load factor, deemed at 75% (Ref. 1, 4)
HP	=	Rated horsepower of new motor
Eff_EE	=	Efficiency of new motor. Eff_EE = NEMA Premium Efficiency or NEMA Premium Efficiency + 1%. See Appendix C.

Eff_base	=	Baseline motor efficiency. Eff_base = EPACT efficency (Replace Working), NEMA Premium Efficiency (Replace on Fail, New Construction). See Appendix C.
Conversion	=	Standard conversion from hp to kW = 0.746 kW/hp
CF	=	Coincidence Factor = 0.78 (Ref. 1, 2)

Deemed Input Tables

Table 1. Deemed annual operating hours by motor horsepower for industrial applications (Ref. 3)

Motor HP	Hrs
5	2,745
7.5	3,391
10	3,391
15	3,391
20	3,391
25	4,067
30	4,067
40	4,067
50	4,067
60	5,329
75	5,329
100	5,329
125	5,200
150	5,200
200	5,200

Table 2. Deemed annual operating hours by building type and application (Ref. 4)

Building Type and Application	Hrs
Office HVAC Pump	2,000
Retail HVAC Pump	2,000
Hospitals HVAC Pump	2,754
Elem/Sec Schools HVAC Pump	2,190
Restaurant HVAC Pump	2,000
Warehouse HVAC Pump	2,241
Hotels/Motels HVAC Pump	4,231
Grocery HVAC Pump	2,080
Health HVAC Pump	2,559
College/Univ HVAC Pump	3,641
Office Ventilation Fan	6,192
Retail Ventilation Fan	3,261
Hospitals Ventilation Fan	8,374
Elem/Sec Schools Ventilation Fan	3,699

Building Type and Application	Hrs
Restaurant Ventilation Fan	4,155
Warehouse Ventilation Fan	6,389
Hotels/Motels Ventilation Fan	3,719
Grocery Ventilation Fan	6,389
Health Ventilation Fan	2,000
College/Univ Ventilation Fan	3,631
Office Other Non-Industrial Application	4,500
Retail Other Non-Industrial Application	4,500
Hospitals Other Non-Industrial Application	4,500
Elem/Sec Schools Other Non-Industrial Application	4,500
Restaurant Other Non-Industrial Application	4,500
Warehouse Other Non-Industrial Application	4,500
Hotels/Motels Other Non-Industrial Application	4,500
Grocery Other Non-Industrial Application	4,500
Health Other Non-Industrial Application	4,500
College/Univ Other Non-Industrial Application	4,500
Industrial/Manufacturing	See Table 1

Methodology and Assumptions

Measure lives for replacement of failed motors or motors in new construction was 15-20 years in most TRMs prior to the EISA standard for motors taking effect in December 2010. No sources were found for lifetime of early replacement motors since most states have disallowed rebates for industrial Premium Efficiency motors. However, a review of several TRMs showed that for other measures, the lifetime of early replacements is typically about one-third of the full measure life. Therefore, the lifetime of this measure was set to 6 years (approximately one-third of 15-20 years.)

Notes

According to the EISA standard, general purpose motors (subtype I) manufactured after December 19, 2010, with a power rating of at least 1 horsepower but not greater than 200 horsepower, shall have a nominal full-load efficiency that is not less than as defined in NEMA MG– 1 (2006) Table 12–12 (aka "NEMA Premium®" efficiency levels).

References

1. NYSERDA (New York State Energy Research and Development Authority); NY Energy $mart Programs Deemed Savings Database - Source for coincidence factor, measure life, and motor load factor
2. Franklin Energy Services review, November 2013
3. United States Industrial Electric Motor Systems Market Opportunities Assessment, EERE, US DOE, Dec 2002 - Source for operating hours for industrial motors and source for motor load factor data (Tables 1-18 and 1-19)

4. Efficiency Vermont's Technical Reference User Manual, 2004 - Source for operating hours for commercial motors (p.15) and source for measure life and source for existing motor efficiencies and source for motor load factor default value
5. CEE (Consortium for Energy Efficiency) Premium Efficiency Motors Initiative – source for premium motor efficiencies
6. Xcel Energy Minnesota Electric and Natural Gas Conservation Improvement Program Plan for 2013-2015 (Docket No. E,G002/CIP-12-447) – source for incremental costs.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Joe Plummer	11.13.13
2.0	Design changes to accommodate Replace on Fail and New Construction in addition to Replace Working, corrected incremental cost information	Joe Plummer	5.9.14

Industrial - High Frequency Battery Chargers

Measure Detail	Measure Value
Target Market Segments	Industrial
Target End Uses	Industrial Process
Applicable To	Industrial customers with battery-powered motive equipment. See Methodology and Assumptions for charger requirements
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Operation shifts per day with forklift usage (1, 2, or 3)
Version No.	1.0
Unit kWh Savings per Year	ΔkWh
Unit Peak kW Savings	0 (see Methodology and Assumptions)
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 years (Ref. 1)
Unit Participant Incremental Cost	$872.50 per charger (Ref. 1)

Measure Description

Industrial battery-powered motive equipment is widely utilized in warehouses, ports, airports, and manufacturing for decades. Large battery chargers are used with forklifts, transport equipment, electric vehicles, and golf carts. The most common technologies in use today are ferroresonant and silicon controlled rectifier (SCR). These technologies tend to be less efficient than high frequency chargers. There are three areas of inefficiency in battery charging:

1. Power Conversion Efficiency – the ratio of energy out of the charger versus the energy into the charger.
2. Charge Return – the ratio of energy out of the battery versus the energy into the battery.
3. Standby Losses – the energy used when no battery is connected to the charger.

Algorithms

Unit kWh Savings per Year = ΔkWh

Where:

N = number of chargers.

ΔkWh = deemed kWh savings per charger, varies by number of shifts with forklift use (Table1)

Example:

A manufacturer installs a high frequency battery charger in a facility with two shifts involving forklift usage.

Unit kWh Savings per Year = 2,688 kWh

Deemed Input Tables

Table 1. Deemed kWh savings (Ref. 1)

	8-hour shift	16-hour shift	24-hour shift
ΔkWh	1,460	2,688	3,638

Methodology and Assumptions

New 3-phase high frequency charger(s) shall have a minimum power conversion efficiency of 92 percent, and a minimum 8-hour shift operation for five days per week. The new charge return factor should be no greater than 1.10 at 100 percent or 80 percent depth of charge, and no greater than 1.15 at 40 percent depth of charge (Ref. 2). The new standby loss should be less than 10W (Ref. 2). The new battery charger must replace either a ferroresonant or silicon controlled rectifier (SCR) charger. This measure is only applicable to battery charging for forklifts, golf carts and other non-road electric vehicles.

It is assumed that charging occurs during off-peak hours with the existing and proposed chargers, resulting in zero peak kW savings. There may be peak kW impacts if opportunity charging is performed during peak hours.

References

1. Pacific Gas and Electric Company, Application Assessment Report #0808, ''Industrial Battery Charger Energy Savings Opportunities", May 29, 2009.
2. California Energy Commission, 2014 Appliance Efficiency Regulations, Page 167. http://www.energy.ca.gov/2014publications/CEC-400-2014-009/CEC-400-2014-009-CMF.pdf

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	8/30/2017

Commercial - Modulating Gas Clothes Dryer

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Misc. gas loads
Applicable To	Commercial customers
Actions	Modify
Required from Customer/Contractor	Building type
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	14 (Ref. 1)
Unit Participant Incremental Cost	$525 (Ref. 2)

Measure Description

This measure involves the retrofit of a 30 to 200 pound commercial gas dryer with a two-stage modulating gas valve kit. This kit allows the dryer to reduce its firing rate during the latter stages of the drying cycle, when less heat is needed because there is not as much moisture remaining in the clothes.

Algorithms

Unit Dth Savings per Year = SF * N_{CYCLES}

Where:

SF = Savings factor, 0.006 Dth per cycle (Ref. 2, see below)

N_{CYCLES} = Number of cycles per year, refer to Table 1

Example:

A customer installed a modulating gas valve kit on a dryer in a laundromat.

Unit Dth Savings per Year = 0.006 * 1,483 = 8.9 Dth

Deemed Input Tables

Table 1. Yearly Cycle Count vs. Site Type

Site Type	Cycles Per Year
Coin-operated laundromats	1,483 (Ref. 3)
Multifamily dryers	1,074 (Ref. 3)
On-premise laundromats (dry cleaner, hospital, hotel, nursing home, etc.)	2,683 (Ref. 2)

Methodology and Assumptions

The CARD study (Ref. 2) is a small pilot study examining savings produced by the installation of two-stage modulating gas valve kits on 12 dryers at 6 sites: a laundromat, a dry cleaner, a university, two hotels, and a health care facility. It shows average savings of 161 therms for each modulating valve kit installed.

It also notes that savings appeared to be more dependent on the number of cycles than on dryer size. Therefore the algorithm here makes an effort to accommodate that. The CARD study's Appendix B showcases the number of cycles for each dryer tested. Averaging the baseline and efficient number of cycles for each produces an average cycle count of 2,610. This indicates average per-cycle savings of 161 / 2,610 = 0.06 therms = 0.006 Dth.

This value can be used with DOE-estimated number of cycles for coin-operated and multifamily laundromats seen in Table 1 (Ref. 3). For on-premise cycle count, findings from the CARD study are used. Averaging the baseline and efficient number of cycles for non-laundromat sites produces an average cycle count of 2,683 for these sites.

References

1. Zhang, Y. and Wei, J. *Commercial Clothes Dryers. Codes and Standards Enhancement (CASE) Initiative for PY2013: Title 20 Standards Development.* July 2013. https://efiling.energy.ca.gov/GetDocument.aspx?tn=71757
   Life of retrofit kit is assumed to match that of a commercial dryer.
2. Gas Technology Institute. *Advanced Commercial Clothes Dryer Technologies Field Test.* January 15, 2018. http://mn.gov/commerce-stat/pdfs/card-dryer-retrofit.pdf
3. Illinois Energy Efficiency Stakeholder Advisory Group. Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 6.0. Volume 2: Commercial and Industrial Measures. February 8, 2017. http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_6/Final/IL-TRM_Effective_010118_v6.0_Vol_2_C_and_I_020817_Final.pdf

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Cadmus	10/2018

C/I Lubricants - Hydraulics

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Lubricants
Applicable To	Commercial and industrial customers
Actions	Replace on Failure, Replace Working
Required from Customer/Contractor	Motor horsepower, yearly hours of operation, cost of efficienct lubricant, cost of baseline lubricant
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (see Notes)
Unit Participant Incremental Cost	Actual cost should be used

Measure Description

Industrial hydraulic systems use hydraulic oil to transfer input energy to output power. Hydraulic oils also protect critical components from premature wear. Energy efficient hydraulic oil lubricants meet these requirements and reduce hydraulic system energy consumption. Energy efficient hydraulic oils have a lower coefficient of friction which reduces the friction between two moving parts (rotating pump equipment and hydraulic oil). This lower coefficient of friction reduces the energy required to produce output power. These oils also have a high viscosity index which reduces the effect temperature has on the viscosity of the hydraulic oil. The high viscosity index reduces viscosity changes over varied operating temperatures, which optimizes volumetric and mechanical efficiency at the pumps rated output. Additionally, energy efficient hydraulic oils reduce the operating temperature of the hydraulic system.

This is applicable for manufacturers using electric motors to power their hydraulic system both inside and outside conditioned areas, or for hydraulic systems on mobile equipment. The baseline equipment is hydraulic systems using non-energy efficient industrial hydraulic oils.

Savings are calculated based on a reduced coefficient of friction and the shear-stable high viscosity index value associated with energy-efficient hydraulic oils in hydraulic systems.

Algorithms

$kWh_{SAVED} = (HP * 0.746 * LF / \eta_{MOTOR}) * HOU * SF$

Where:

HP	=	Rated power consumption of electric motor, summed when pumps are in series
0.746	=	Conversion from horsepower to kW
LF	=	Motor load factor, 65% (Ref. 1)

η_{motor}	=	Motor efficiency. Actual, or see Appendix C and use the EPACT efficiency for the motor type and size. If unsure use a 93% estimate.
HOU	=	Annual hours of operation, user provided
SF	=	Savings factor, 3% (see Notes)

Example:

A 75 horsepower, 1200 RPM, ODP enclosure motor runs hydraulic equipment for 3,000 hours a year. The load factor is unknown.

kWh_{SAVED} = (75 HP * 0.746 * 65% / 93.6%) * 6000 * 3% = 6,127 kWh

Notes

The useful life of the lubricant is deemed to be 10 years when properly maintained. This is based on several factors:

- Customer experience with the product
- Results gained during hydraulic durability testing
- The Mobil DTE 20s Ultra series of products have a 6-year warranty (Ref. 2)
- Near-future Mobil DTE products will have a 10-year warranty

Incremental costs should equal the price difference between an energy-efficient hydraulic oil and a standard hydraulic oil which will vary across the state of Minnesota. Users should determine this for each project. Typically roughly one gallon per horsepower is required, and energy efficient oil will cost roughly $10 more per gallon.

The savings factor value of 3% was deemed based on several references. Various applications of energy-efficient hydraulic oils have produced measured energy savings from 3.3% to 7.1% (Ref. 3, Ref. 4, Ref. 5, Ref. 6, Ref. 7). A conservative savings factor of 3% is deemed.

To qualify as an energy efficient lubricant, the lubricant must:

- Have a viscosity Index ≥ 156 as determined by ASTM D2270, ensuring the oil maintains optimal efficiency across a wide temperature range
- Have a shear stability (kinematic viscosity loss) ≤ 11% as determined by CEC L-45-A-99, ensuring the efficiency benefits will not diminish much as the oil shears, and ensuring performance for the full measure life
- ISO 32 and ISO 46 oils must pass the JCMAS HK VG32W and VG46W specifications, ensuring oxidation stability across the full measure life
- Base oils not in the API Group IV or V as defined in API 1509 must pass the Bosch Rexroth 90245 specification, ensuring the oil protects from equipment wear.

References

1. U.S. Department of Energy. *Improving Motor and Drive System Performance; A Sourcebook for Industry*. 2008. Page 18. https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_sourcebook_web.pdf
2. ExxonMobil. Mobil DTE 20 Ultra Series Limited Warranty. 2020.
3. Lev A. Bronshteyn and Jesa H. Kreiner. *Energy Efficiency of Industrial Oils*. March 25, 2008. Page 775 concludes: "Approximately five-to-eight percent energy are achievable by using energy-efficient industrial lubricants compared with current typical products." https://www.tandfonline.com/doi/abs/10.1080/10402009908982281
4. ExxonMobil. *Energy Saving Strategies for Plastics Injection Molding: Lubrication*. April 2020. https://ilsag.s3.amazonaws.com/Exxon-Mobil-EE-Idea-Attachments_April-2020.pdf
5. ExxonMobil. Mobil DTE 10 Excel™ 46 helps Volkswagen AG enhance energy efficiency on plastic injection molding machines. 2013. https://www.mobil.com/en/lubricants/for-businesses/industrial/lubricant-expertise/resources/plastic-injection-molding-machine-hydraulic-oil-efficiency
6. R.I. Taylor et al. *Lubricants & Energy Efficiency: Life-Cycle Analysis*. 2005. https://www.sciencedirect.com/science/article/abs/pii/S0167892205800586
7. ExxonMobil. Performance Summary. MPact Plastics, Pinetown KZN, South Africa. September 29, 2017.

Revision History

Version	Description	Author	Date
1.0	Initial version		9/2021

C/I Lubricants - Gearbox

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Lubricants
Applicable To	Commercial and industrial customers
Actions	Replace on Failure, Replace Working
Required from Customer/Contractor	Motor horsepower, yearly hours of operation, cost of efficienct lubricant, cost of baseline lubricant
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (see Notes)
Unit Participant Incremental Cost	Actual cost should be used

Measure Description

Industrial gear reduction systems use gear oil to transfer input energy to output power. Gear oils also protect critical components from premature wear. Energy efficient gear oil lubricants meet these requirements and provide reduced energy consumption. Energy efficient gear oils have a lower coefficient of friction which reduces the friction between two moving parts (two gears meshing together covered in gear oil). This lower coefficient of friction reduces the energy required to yield output power. Second, these oils have a high viscosity index which reduces the effect temperature has on the viscosity of the gear oil. The high viscosity index reduces viscosity changes over varied operating temperatures, which optimizes volumetric and mechanical efficiency at the pumps rated output. Additionally, energy efficient gear oils reduce the operating temperature of the hydraulic system.

This is applicable for manufacturers using electric motors to power their gear reduction equipment both inside and outside conditioned areas, or for gear reduction systems on mobile equipment. The baseline equipment is gearboxes using non-energy efficient industrial gear lubricants

Algorithms

$kWh_{SAVED} = (HP * 0.746 * LF / \eta_{motor}) * HOU * SF * n$

Where:

HP	=	Rated power consumption of electric motor, summed when pumps are in series
0.746	=	Conversion from horsepower to kW
LF	=	Motor load factor, 65% (Ref. 1)
η_{motor}	=	Motor efficiency. Actual, or see Appendix C and use the EPACT efficiency for the motor type and size. If unsure use a 93% estimate.

HOU	=	Annual hours of operation, user provided
SF	=	Savings factor, 1% per gear mesh (Ref. 2, Ref. 3)
n	=	Number of gear reductions served by the efficient gear lubricant

Example:

A 100 horsepower, 1200 RPM, ODP enclosure motor runs a 4-reduction gearbox for 2,000 hours a year. The load factor is unknown.

kWh_{SAVED} = (100 * 0.746 * 65% / 94.1%) * (2,000) * 1% * 4 = 4,122 kWh

Notes

The useful life of the lubricant is deemed to be 10 years when properly maintained. This is based on several factors:

- Customer experience with the product
- Results gained during hydraulic durability testing
- The Mobil DTE 20s Ultra series of products have a 6-year warranty (Ref. 2)
- Near-future Mobil DTE products will have a 10-year warranty

Incremental costs should equal the price difference between an energy-efficient gear oil and a standard gear oil which will vary across the state of Minnesota. Users should determine this for each project. Typically roughly one gallon per horsepower is required, and energy efficient oil will cost roughly $10 more per gallon.

The savings factor value of 1% was deemed based on several references. Various applications of energy-efficiency gear oils have produced measured energy savings from 3.3% to 7.1% (Ref. 3, Ref. 4). One study of gearboxes specifically showed savings of 0.9% (Ref. 5). A conservative savings factor of 1% is deemed.

To qualify as an energy efficient lubricant, the lubricant must:

- Have a viscosity Index ≥ 156 as determined by ASTM D2270, ensuring the oil maintains optimal efficiency across a wide temperature range
- Have a shear stability (kinematic viscosity loss) ≤ 11% as determined by CEC L-45-A-99, ensuring the efficiency benefits will not diminish much as the oil shears, and ensuring performance for the full measure life
- ISO 32 and ISO 46 oils must pass the JCMAS HK VG32W and VG46W specifications, ensuring oxidation stability across the full measure life
- Base oils not in the API Group IV or V as defined in API 1509 must pass the Bosch Rexroth 90245 specification, ensuring the oil protects from equipment wear.

References

1. U.S. Department of Energy. *Improving Motor and Drive System Performance; A Sourcebook for Industry*. 2008. Page 18. https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_sourcebook_web.pdf
2. ExxonMobil. Mobil DTE 20 Ultra Series Limited Warranty. 2020.
3. Lev A. Bronshteyn and Jesa H. Kreiner. *Energy Efficiency of Industrial Oils*. March 25, 2008. Page 775 concludes: "Approximately five-to-eight percent energy are achievable by using energy-efficient industrial lubricants compared with current typical products." https://www.tandfonline.com/doi/abs/10.1080/10402009908982281
4. R.I. Taylor et al. *Lubricants & Energy Efficiency: Life-Cycle Analysis*. 2005. https://www.sciencedirect.com/science/article/abs/pii/S0167892205800586
5. ExxonMobil. Performance Summary. ArcerlorMittal – Minorca Mine. Virginia, MN. May 16, 2017.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper		9/2021

Agriculture

Agriculture - Dairy Farm Long Daylighting

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Lighting
Applicable To	Agricultural customers
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Baseline lamp or fixture wattage and quantity, efficient lamp or fixture wattage and quantity
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	Refer to Appendix B for costs or use actual fixture costs.

Measure Description

This measure includes making energy efficient upgrades to fixtures or lamps used for long day lighting in dairy applications. Typically baseline fixtures will be metal halide or pulse start metal halide, with upgrades to linear fluorescent or LED. This measure uses the same baseline and energy efficient fixture wattages as described in Appendix B, but operates the fixtures for longer hours.

Long day lighting involves operating lighting for longer hours to simulate longer days, which increases milk production from the cows.

Algorithms

$kWh_{SAVED} = (kW_{BASE} * Qty_{BASE} – kW_{EE} * Qty_{EE}) * HOURS$

$kW_{SAVED} = (kW_{BASE} * Qty_{BASE} – kW_{EE} * Qty_{EE}) * CF$

Where:

kW_{BASE} = Wattage of baseline lamp/fixture in kW. Refer to Appendix B or use actual wattage.

kW_{EE} = Wattage of efficient lamp/fixture in kW. Refer to Appendix B or use actual wattage.

Qty_{BASE} = if unknown, assume equal to Qty_EE. Number of baseline lamps being replaced.

Qty_{EE} = Number of lamps or fixtures being installed

HOURS = 6,205 (Ref. 2, Ref. 3)

CF = 1.0 Coincidence factor

Example:

A dairy farm is looking to install ten 190W LED fixtures to replace ten 400W Metal Halide fixtures in a long day lighting application.

kW_{BASE}	0.455 kW
kW_{EE}	0.190 kW
Qty_{BASE}	10
Qty_{EE}	10

kWh_{SAVED} = (0.455 * 10 – 0.190 * 10) * 6,205 = 27,054 kWh

kW_{SAVED} = (0.455 * 10 – 0.190 * 10) * 1.0 = 4.36 kW

Methodology and Assumptions

Long day lighting studies (Ref. 3, Ref. 4) have determined that for long day lighting to work, the lights must deliver a minimum of 15 foot-candles at the eye level of the cows for 16 to 18 hours per day. Using a midpoint of 17 hours, 17 x 365 = 6,205 hours per year.

References

1. Public Service Commission of Wisconsin. Focus on Energy Evaluation Business Programs: Measure Life Study Final Report. August 25, 2009. Available online: https://focusonenergy.com/sites/default/files/bpmeasurelifestudyfinal_evaluationreport.pdf
2. Dahl, Geoffrey E. Photoperiod Management of Dairy Cattle for Performance and Health. Available Online: www.wcds.ca/proc/2003/Manuscripts/Chapter%2027%20Dahl.pdf
3. University of Wisconsin-Madison. Long Day Lighting in Dairy Barns. Healthy Farmers, Healthy Profits Project. Second Edition (August 2000). Available Online: http://bse.wisc.edu/HFHP/tipdairy.htm

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	9/29/16

Agriculture - Engine Block Heater Timer

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Misc. Electric Loads
Applicable To	Agricultural customers
Actions	Modify
Required from Customer/Contractor	Heater size
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 1)
Unit Participant Incremental Cost	$20 (Ref. 2)

Measure Description

This measure involves the installation of a plug-in timer that controls the operation of an engine block heater timer to modulate its operation.

Algorithms

$kWh_{SAVED} = P_{HEATER} * (t_{HEATER} - t_{CONTROL}) * Days * UF / C$

Where:

P_{HEATER}	=	1,000 W, if unknown. Avg. power of engine block heater. (Ref. 2)
t_{HEATER}	=	10 hours/day. Time that heater will operate if uncontrolled. (Ref. 1 and Ref. 2)
$t_{CONTROL}$	=	2 hours/day. Time that heater will operate if controlled. (Ref. 3)
Days	=	90 days. Days the heater timer will be operating. (Ref. 4)
UF	=	0.8. Usage Factor. (Ref. 5)
C	=	1,000 W/kW. Conversion factor.

Example:

A customer installed a new timer control on a 1,200 W engine heater.

kWh_{SAVED} = 1,200 W * (10 hrs/day – 2 hrs/day) * 90 days * 0.8 / 1,000 W/kW = 691 kWh

Methodology and Assumptions

The incremental cost is the full cost of the timer since the base case is a block heater with no timer. Purchase costs typically start at $20. Timers for heaters over 1,800 Watts or heaters that operate on 240 volts will cost $40 to $60 plus installation. (Ref. 2)

References

1. Franklin Energy Services estimate.
2. Focus on Energy fact sheet: Engine Block Heaters Make Diesel Start-up a Snap http://www.focusonenergy.com/files/document_management_system/business_programs/engineblockheaters_factsheet.pdf (Accessed September 19, 2012). This document is no longer available online.
3. Vehicle Warm-Up, Natural Resources Canada (NRCAN). http://www.nrcan.gc.ca/energy/efficiency/communities-infrastructure/transportation/idling/4423. Accessed 5/21/15.
4. Franklin Energy Services estimate. This is based on operating for the three coldest months: December, January, and February.
5. Franklin Energy Services estimate. This reflects the reality that not all installed timers will be used or scheduled appropriately.
6. Heater is not going to be operating during the peak season (summer) when cold temperatures are not a concern.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	11/12/2015

Agriculture - High Efficiency Fans

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	HVAC
Applicable To	Agricultural customers
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Fan diameter, model number, VER
Version No.	1.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	7 (Ref. 1)
Unit Participant Incremental Cost	$150 (Ref.1)

Measure Description

This measure involves the installation of high efficiency, high-speed ventilation/exhaust fans that provide ventilation to destratify air, reduce animal heat stress, control insects or dry surfaces.

Algorithms

$kWh_{SAVED} = (CFM_{BASE} / VER_{BASE} - CFM_{EE} / VER_{EE}) / C * HOURS$

$kW_{SAVED} = (CFM_{BASE} / VER_{BASE} - CFM_{EE} / VER_{EE}) / C * CF$

Where:

CFM_{BASE}	=	Airflow (CFM) of baseline unit @ 0.10" static pressure (See Table 1)
VER_{BASE}	=	Ventilating Efficiency Ratio (CFM/Watt) of baseline unit @ 0.10" static pressure (See Table 1)
CFM_{EE}	=	Airflow (CFM) of efficient unit @ 0.10" static pressure (See Table 1)
VER_{EE}	=	Ventilating Efficiency Ratio (CFM/Watt) of efficient unit @ 0.10" static pressure (See Table 1 if Unknown)
HOURS	=	2,935 hours per year (Ref. 1)
C	=	1,000 W/kW. Conversion factor.
CF	=	1.0 (Ref. 1)

Example:

A cattle barn installed a new 36” circulation fan with a VER of 17.9 CFM/Watt.

kWh_{SAVED} = (9,780 CFM / 15.5 CFM/W – 9,780 CFM / 17.9 CFM/W) / 1,000 W/kW * 2,935 hours = 248 kWh

kW_{SAVED} = (9,780 CFM / 15.5 CFM/W – 9,780 CFM / 17.9 CFM/W) / 1,000 W/kW *1.0 = 0.0906 kWh

Methodology and Assumptions

Table 1. Average Fan Performance Characteristics (Ref. 2)

Fan Diameter (in)	CFM_base	VER_base (cfm/W)	CFM_EE	VER_EE (cfm/W)
24" through 35"	5,647	11.9	5,647	15.0
36" through 47"	9,780	15.5	9,780	17.9
48" though 71"	21,130	17.7	21,130	22.8

References

1. Act on Energy Commercial Technical Reference Manual No. 2010-4, Pages 318-320.
2. BESS Labs Agricultural Ventilation Fan Testing Data, http://bess.illinois.edu/oldSearchResults.asp#. Accessed 5/21/15.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	11/12/2015
1.1	Added Table 1, Average Fan Characteristics	Franklin Energy Services	12/11/2015

Agriculture - High Efficiency Grain Dryers

Measure Detail	Measure Value
Target Market Segments	Commercial, Industrial
Target End Uses	Industrial Process
Applicable To	Natural gas-fired grain dryers; input values provided are for corn
Actions	Replace Working, Replace on Fail
Required from Customer/Contractor	Installed cost of proposed dryer; documentation demonstrating existing and proposed dryer efficiencies, average bushels per year processed
Version No.	1.0
Unit kWh Savings per Year	0
Unit Peak kW Savings	0
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	20 (Ref. 3)
Unit Participant Incremental Cost	Installed cost of new dryer, provided by customer/contractor. $45,000 can be used as a planning estimate (Ref. 4.). Actual costs vary based on dryer capacity and other factors

Measure Description

This measure characterizes the efficiency gains from replacing existing grain dryers with high efficiency grain dryers. High efficiency grain dryers include features such as automated control, improved airflow, grain turners, and exhaust heat recapture and recycle, all of which serve to reduce the thermal energy required to evaporate a unit of water. Installing a high efficiency dryer often involves a desire to increase processing speed as measured in bushels per hour; a customer may be switching from an in-bin dryer to a higher capacity continuous flow or batch dryer (Ref. 5).

Algorithms

Unit Dth Savings per Year = Bushels/yr * (M_{pre} - M_{post}) * (e_b - e_{ee})/1,000,000

Where:

M_{pre} = pre-dryer water mass per bushel of grain; at a typical moisture content of 22% for corn at harvest (Ref. 1), M_{pre} equals 60.66 lb/bushel (Ref. 2).

M_{post} = post-dryer water mass per bushel of grain; at a typical moisture content of 15% for corn post-drying (Ref. 1), Mpost equals 55.67 lb/bushel

e_b = Existing (baseline) dryer efficiency; typical value is 2,241 Btu/lb H_2O (Ref. 1)

e_{ee} = Proposed dryer efficiency; typical value is 1,625 Btu/lb H_2O (Ref. 1)

Example:

A grain storage facility replaces its existing grain dryer with a more efficient natural gas-fired unit. The dryer is expected to process 100,000 bushels of corn per month from October through December annually.

Unit Dth Savings per Year = (100,000*3)*(60.66-55.67)*(2,241-1,625)/1,000,000 = 922

Methodology and Assumptions

Before and after dryer efficiencies were obtained from recent grain dryer projects in the Wisconsin Focus on Energy program (13 projects in total). Wisconsin grain drying efficiencies were adjusted based on average monthly air enthalpy values for the period of October through December, the primary drying season. The effective adjustment was 96.6%. Moisture content removal is assumed to be from 22% moisture content to 15% moisture content, which is slightly conservative compared to the project data (23.5% to 15.2%).

Use of the typical input values provided will generate the energy savings per bushel of corn expected on average for installing an energy efficient grain dryer. Actual dryer efficiency is dependent on grain moisture content, ambient air temperature and humidity, and processing speed. A custom approach should be used where greater accuracy is desired.

References

1. Wisconsin Focus on Energy project data; 13 recent grain dryer projects in Wisconsin were used as the source of average pre- and post- moisture content (22% and 15%, respectively) and baseline and proposed dryer efficiency.
2. "Tables for Weights and Measurement: Crops". University of Missouri Extension, http://extension.missouri.edu/publications/DisplayPub.aspx?P=G4020. Accessed September 28, 2016.
3. Wisconsin Technical Reference Manual, October 2015. Midpoint of three sources:
    a. 10-12 years: "Computing a Grain Storage Rental Rate." Iowa State University Ag Extension, October 10, 2013. http://www.extension.iastate.edu/agdm/wholefarm/pdf/c2-24.pdf, accessed 9/28/16.
    b. 10-12 years: "Grain Drying Systems." Paper presented at the Facility Design Conference of the Grain Elevator & Processing Society, St. Charles, Illinois, July 28-31, 2002. http://www.uwex.edu/energy/pubs/GrainDryingSystems_GEAPS2002.pdf, accessed 9/28/16.
    c. 30 years: *Fundamentals of Engineering Thermodynamics.* Shapiro and Moran, 1995. Washington DC: McGraw Hill.

4. Based on a review of grain dryer projects in Iowa, which showed a cost between $80-100 per bu/hr for 5% moisture removal per hour. Typical dryer capacity is 500 Bu/hr; therefore estimated average cost is $90 * 500 = $45,000.
5. "Sizing Up Grain Dryers". Farm Industry News, May 1998. http://farmindustrynews.com/sizing-grain-dryers, accessed 9/28/16.

Revision History

Version	Description	Author	Date
1.0	New measure	Franklin Energy Services	9/28/2016

Agriculture - Livestock Waterer

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Livestock
Applicable To	Agricultural customers
Actions	Replace on Failure, New Construction
Required from Customer/Contractor	Retrofit or new, County
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 1)
Unit Participant Incremental Cost	$787.50 (Ref. 2)

Measure Description

This measure involves the installation of insulated or energy free livestock waterers to replace electric livestock waterers.

Algorithms

$kWh_{SAVED} = (Watts_{BASE} - Watts_{EE}) * HOURS / C$

Where:

$Watts_{BASE}$ = 1,100 W for retrofit, 500 W for new installation. Power of baseline waterer (Ref. 1)

$Watts_{EE}$ = 250 W, if unknown. Power of efficient waterer (Ref. 1)

HOURS = Hours of heater operation, See Table 1. (Ref. 3)

C = 1,000 W/kW. Conversion factor.

Example:

A customer in Zone 2 installed a new energy efficient livestock waterer to replace a standard unit.

kWh_{SAVED} = (1,100 W - 250 W) * 2,934 hours / 1,000 W/kW = 2,494 kWh

Methodology and Assumptions

Table 1. Annual Hours Below Freezing

Zone	Hours < 32°F
Zone 1	3,325
Zone 2	2,934
Zone 3	2,692

Table 2. Average Annual Deemed Savings

Type	kWh
Energy Efficient Livestock Waterer	2,826
Energy Free Retrofit Livestock Waterer	2,494
Energy Free New Construction Livestock Waterer	2,288

Table 3. Temperature Data

Zone	City	Hours Below < 32°F	Zone Average
Zone 1	Int'l Falls	3,371	3,325
	Duluth	3,278	
Zone 2	Duluth	3,278	2,934
	Minneapolis	2,590	
Zone 3	Minneapolis	2,590	2,692
	Rochester	2,794	

References

1. Focus on Energy Technical Reference Manual, Page 2. https://focusonenergy.com/sites/default/files/Wisconsin%20Focus%20on%20Energy%20Technical%20Reference%20Manual%20August%202014.pdf
2. Act On Energy Technical Reference Manual (TRM), Pages 342-344.
3. A survey of TMY3 data for various locations in MN. http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html#M
4. Heater is not going to be operating during the peak season (summer) when cold temperatures are not a concern.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	11/12/2015

Agriculture – Milk Pre-Cooler

Measure Detail	Measure Value
Target Market Segments	Agriculture
Target End Uses	Dairy
Applicable To	Commercial customers
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	Number of cows
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$2,500 (Ref. 2)

Measure Description

Dairy farms store milk at 38ºF in refrigerated storage tanks. A milk pre-cooler can be used to utilize well water to pre-cool the milk before it enters the storage tank. This results in energy savings by reducing

Algorithms

$kWh_{SAVED} = N_{COWS} * Mdot_{MILK} * Cp_{MILK} * Delta_T * Days / EER / C$

$kW_{SAVED} = CF * (kWh_{SAVED}) / HOURS$

Where:

N_{COWS}	=	Number of cows milked, assume 303 (Ref. 9), unless known
$Mdot_{MILK}$	=	56 lbs. of milk/cow/day. Milk production, per cow, per day (Ref. 6)
Cp_{MILK}	=	0.93 Btu/lb. - °F. Heat capacity of whole milk (Ref. 4)
$Delta_T$	=	98ºF – 57ºF = 41ºF. Temperature drop of milk across pre-cooler (Ref. 5)
Days	=	365 days. Days, per year, the cows will be milked (Ref. 6)
EER	=	8.4 EER, if unknown. Efficiency of refrigeration system (Ref. 3)
C	=	1,000 W/kW. Conversion Factor
CF	=	1.0
HOURS	=	2,920 hours (Ref. 7)

Example:

A customer with a 130-cow farm, installed a new milk pre-cooler.

kWh_{SAVED} = 130 cows * 56 lbs. milk/cow/day * 0.93 Btu/lb.-F * 41°F * 365 day/yr. / 8.4 EER / 1,000 W/kW
= 12,062 kWh/year

kW_{SAVED} = 12,062 kWh / 2,920 hours = 4.13 kW

References

1. Focus on Energy Evaluation Business Programs Measure Life Study: Final Report August 25, 2009, Public Service Commission of Wisconsin.
2. Efficiency Maine – Commercial Technical Reference Manual, Version 2014.1. http://www.efficiencymaine.com/docs/EMT-Commercial-TRM.pdf. Accessed 07/01/15.
3. Sanford, Scott. "Milk Bulk Tank Refrigeration Condenser Cleaning Study Summary." University of Wisconsin-Madison, 2005.
4. *2014 ASHRAE Handbook - Refrigeration, page 19.4*.
5. Minnesota Department of Commerce – Division of Energy Resources, Dairy Cooperative Partnerships for Improved Efficiency Program Adoption, http://mn.gov/commerce-stat/pdfs/card-report-tmp-dairy-ee.pdf, accessed 8/23/17.
6. Product of 6.5 gallons and 8.6 lbs./gallon. Purdue University: Dairy Facts. http://www.ansc.purdue.edu/faen/dairy%20facts.html Accessed 8/15.
7. Raw milk for pasteurizing must be cooled within 4 hours (Ref. 8). Assuming two milkings, per day, the annual hours of operation is at most 2,920. (Ref. 6)
8. Dairy Farm Energy Management Guide: California, Ludington, Johnson, Kowalski, & Mage, Southern California Edison, 2004.
9. 2011 Michigan Dairy Farm Business Analysis Summary, Wittenberg, Eric and Wolf, Christopher. – pg. 3. Accessed 8/7/2017.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/21/17

Agriculture - Poultry Farm LED Lighting

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Lighting
Applicable To	Agricultural customers
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Baseline fixture wattage and quantity, LED lamp wattage and quantity, poultry farm type
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	7 years (Ref.1)
Unit Participant Incremental Cost	$30 (Ref. 2)

Measure Description

This measure includes the replacement of high-intensity discharge (HID), incandescent, and fluorescent fixtures with light emitting diode (LED) fixtures in poultry farms.

Algorithms

$kWh_{SAVED} = (Watts_{BASE} * Qty_{BASE} - Watts_{EE} * Qty_{EE}) / C * HOURS * Days$

$kW_{SAVED} = (Watts_{BASE} * Qty_{BASE} - Watts_{EE} * Qty_{EE}) / C * CF$

Where:

$Watts_{BASE}$	=	60 W, if unknown. Wattage of baseline lamp/fixture. (Ref. 3)
$Watts_{EE}$	=	10 W, if unknown. Wattage of LED lamp/fixture (Ref. 3)
Qty_{BASE}	=	if unknown, assume equal to Qty_EE. Number of baseline lamps being replaced.
Qty_{EE}	=	Number of LED lamps being installed
HOURS	=	16, if unknown; Refer to Table 1 for daily hours
C	=	1,000 W/kW. Conversion factor.
CF	=	1.0

Example:

A chicken broiler facility replacing 60 watt incandescent lamps with 10 watt LEDs.

kWh_{SAVED} = (60 W * 14 - 10 W * 14) / 1,000 W/kW * 16 hr/day * 365 days/yr = 4,088 kWh

kW_{SAVED} = (60 W * 14 - 10 W * 14) / 1,000 W/kW * 1.0 = 0.700 kW

Methodology and Assumptions

Table 1. Suggested Lighting Guide for Poultry Production (Ref. 4)

Type of Poultry	Age (Weeks)	Minimum Light Intensity Lux (foot-candles)	Photo Period (hours of light per day)
Chicken			
Chicken Broilers	0 to 0.4	20 to 30 (2 to 3)	24
	0.4 to 4	5 to 10 (0.5 to 1)	20 to 12
	4 to Market	6 to 10 (0.5 to 1)	20 to 24
Broiler Breeders	0 to 3	30 to 50 (3 to 5)	18
	4 to 20	10 to 30 (1 to 3)	9
	20 to 64	30 to 50 (3 to 5)	15
Chicken Layers	0 to 2	10 to 30 (1 to 3)	22 to 16
	2 to 6	10 to 30 (1 to 3)	16 to 8
	6 to 18	5 to 10 (0.5 to 1)	8 to 10
	18 to 80	5 to 10 (0.5 to 1)	15
Turkey			
Brooder – Commercial Turkey Hens or Toms	0 to 0.4	90 to 100 (9 to 10)	22 to 24
	0.4 to 1.2	30 to 50 (3 to 5)	16 to 22
Grow Out, Turkey Hens or Toms	1.2 to Market	10 to 30 (1 to 3)	16
Turkey Breeder Hens	0 to 5	20 (2)	24
	5 to 30	20 (2)	8
	30 and Up	20 (2)	13 to 15
Turkey Breeder Toms	0 to 5	20 (2)	24
	5 and Up	30 (3)	13 to 15
Average			**16**

References

1. Engineering estimate based on survey of manufacturer's rated life and the life extending effect of dimming. Typical rated life ranges from 35,000 - 60,000 hours (4 - 7 years). See "Info" tab for more details.
2. Average cost of LED fixtures based on Once Agricultural Lighting pricing. See "Info" tab for more details.

3. Field Demonstration of Advanced Lighting Technologies for Poultry Houses; Dr. Susan Watkins, Susan Sullivan, and Dr. H.L. Goodwin, University of Arkansas System's Division of Agriculture; 2011. Research shows that a majority of facility use 60 watt incandescent lamps. A majority of the facilities in the study went with 10 LED lamps. Accessed 07-16-15. http://poultryscience.uark.edu/Energy_Grant_Phase_1_Report.pdf
4. Energy Efficient Poultry Lighting Fact Sheet; Ontario Ministry of Agriculture, Food and Rural Affairs; Order No. 06-009; January 2006. The LED lamps used in the study range from 60,000 to 100,000 hours in Table 1, going with 60,000 hours for year round use is close to seven years. Referencing document Table 3 for daily hours. Accessed 07-16-15. http://www.omafra.gov.on.ca/english/engineer/facts/06-009.pdf

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	11/12/2015

Agriculture - VSD for Vacuum Dairy Pumps

Measure Detail	Measure Value
Target Market Segments	Agricultural
Target End Uses	Pumps
Applicable To	Dairy farms
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Vacuum pump motor horsepower
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 (Ref. 4)
Unit Participant Incremental Cost	$356/hp (Ref. 5)

Measure Description

This measure is for installing a variable speed drive (VSD) on a vacuum pump motor. The vacuum systems used for milking dairy cows rely on air pumps to continuously remove air from the milking system to reduce the vacuum pressure. A conventional vacuum system runs the vacuum pump motor at a constant speed while admitting air through the vacuum regulator to maintain a constant vacuum pressure as operational loads shift. A VSD saves energy by reducing the motor speed to maintain vacuum pressure.

Algorithms

$kWh_{SAVED} = (kW_{CS} – kW_{VSD}) * t_{PUMP}$

$kW_{SAVED} = CF * (kW_{CS} – kW_{VSD})$

Where:

kW_{CS}	=	Average Input kW of constant speed unit = HP * 0.746 * LF / eff_{MOTOR}
kW_{VSD}	=	Average Input kW of variable speed unit = C_1 * (2 * MU) + C_2
t_{PUMP}	=	Vacuum pump annual hours of operation = Qty_{COWS} * $Qty_{MILKINGS\ PER\ COW}$ * $Qty_{MILKING\ DAYS}$ /($hrs_{PER\ STALL}$ * qty_{STALLS})
HP	=	Nominal motor horsepower, from customer
0.746	=	Conversion factor from HP to kW (0.746 kW/HP)
LF	=	Motor load factor = 75% (Ref. 1)
Eff_{MOTOR}	=	Efficiency of vacuum pump motor, assumed to be 90% (Ref. 2)
C_1	=	0.0495, Regression Coefficient (Ref. 1)
C_2	=	1.7729, Regression Coefficient (Ref. 1)

MU = Quantity of milk units (teat positioner) = 3.2 * HP; estimated to be 64 MU (4 per stall, 16 total stalls) for a 20-hp vacuum pump; 1 MU = 1 Teat Positioner (Ref. 6)

Qty_{COWS} = Total quantity of cows being milked; assume 303 or customer-provided (Ref. 3)

$Qty_{MILKINGS\ PER\ COW}$ = Quantity of milking sessions, per day, per cow, assumed to be 2 (Ref. 1)

$Qty_{MILKING\ DAYS}$ = Quantity of milking days per year, assumed to be 365

$hrs_{PER\ STALL}$ = Duration of time spent during one milking session, assumed to be 5 hours (Ref. 6)

Qty_{STALLS} = Quantity of stalls per farm = MU/4, or customer-provided (Ref. 6)

CF = Coincidence Factor = 0.9 (Ref. 6)

Example:

A customer installed a new 20-hp VSD Vacuum Pump

kW_{CS} = 20 * 0.746 * 75% / 90% = 12.43 kW

kW_{VSD} = 0.0495 * (2 * 64 MU) + 1.7729 = 8.11 kW

t_{PUMP} = 303 cows * 2 milkings/cow/day * 365 days/yr /(5 cows/hrs/stall * 16 stalls) = 2,765 hrs./year

kWh_{SAVED} = (12.43 kW – 8.11 kW) * 2,765 hrs./year = 11,956 kWh/year

kW_{SAVED} = 0.9 * (12.43 – 8.11) = 3.89 kW

References

1. Efficiency of Maine – Commercial TRM. Version 2016. Pg. 86. Accessed 8/7/17. https://www.efficiencymaine.com/docs/EMT-TRM_Commercial_v2017_1.pdf
2. US DOE – Premium Efficiency Motor Selection and Application Guide, Pg. 2-4. Rough estimate based on NEMA Premium efficiencies of motors less than 20 hp. https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_handbook_web.pdf Accessed 8/7/2017.
3. 2011 Michigan Dairy Farm Business Analysis Summary, Wittenberg, Eric and Wolf, Christopher. – pg. 3. https://www.msu.edu/user/steind/2011%20Michigan%20Dairy%20Farm%20Business%20Analysis.pdf Accessed 8/7/2017.
4. Focus on Energy Evaluation. Business Programs: Measure Life Study Appendix B (page 45 of PDF). https://focusonenergy.com/sites/default/files/bpmeasurelifestudyfinal_evaluationreport.pdf Accessed 8/7/2017.

5. Incremental cost determined by average installed price from Reference 1, divided by an assumed motor size of 15 hp (based on the range of 7.5 hp to 20 hp): $5,322 / 15 hp = $355.80/hp.
6. Internal Franklin Energy Services estimates.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	8/22/2017

Agriculture - VSD Milk Pump

Measure Detail	Measure Value
Target Market Segments	Commercial
Target End Uses	Dairy
Applicable To	Commercial customers
Actions	Replace on Failure, Replace Working, New Construction
Required from Customer/Contractor	Number of cows
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref.1)
Unit Participant Incremental Cost	$4000 (Ref. 2)

Measure Description

This measure involves the installation of a variable speed driven milk transfer pump.

Algorithms

$kWh_{SAVED} = N_{COWS} * Mdot_{MILK} * Cp_{MILK} * Delta_T * Days / EER / C$

$kW_{SAVED} = kWh_{SAVED} / HOURS$

Where:

EER	=	8.4 EER, if unknown. Efficiency of refrigeration system. (Ref. 3)
Cp_{MILK}	=	0.93 Btu/lb-°F. Heat capacity of whole milk. (Ref. 4)
Delta_T	=	15°F. Temperature drop of milk exiting pre-cooler. (Ref. 5)
N_{COWS}	=	Number of Cows Milked
$Mdot_{MILK}$	=	56 lbs of milk/cow/day. Milk production per cow per day. (Ref. 6)
Days	=	365 days. Days the cows will be milked. (Ref. 6)
C	=	1,000 W/kW. Conversion Factor
HOURS	=	2,920 hours (Ref. 7)

Example:

A customer with a 130-cow farm, installed a new VSD milk transfer pump.

kWh_{SAVED} = 130 cows * 56 lbs milk/cow/day * 0.93 Btu/lb-F * 15°F * 365 day/yr / 8.4 EER / 1,000 W/kW = 4,413 kWh/year

kW_{SAVED} = 4,413 kWh / 2,920 hours = 1.511 kW

References

1. Focus on Energy Evaluation Business Programs Measure Life Study: Final Report August 25, 2009, Public Service Commission of Wisconsin.
2. Assumed the average of VFD costs for 5-hp, 7.5-hp and 10-hp motor sizes. See VFD measure for the full table of costs. ($3,420, $4,200 and $4,300)
3. Sanford, Scott. "Milk Bulk Tank Refrigeration Condenser Cleaning Study Summary." University of Wisconsin-Madison, 2005.
4. 2014 ASHRAE Handbook - Refrigeration, page 19.4.
5. Sanford, Scott. 2004c. Variable Speed Milk Pumps. University of Wisconsin - Cooperative Extension Publication (A3784-7). Madison, Wisconsin: University of Wisconsin. https://attra.ncat.org/attra-pub/viewhtml.php?id=198. Accessed 5/21/15.
6. Product of 6.5 gallons and 8.6 lbs/gallon. Purdue University: Dairy Facts. http://www.ansc.purdue.edu/faen/dairy%20facts.html. Accessed 5/21/15.
7. Raw milk for pasturing must be cooled within 4 hours (Ref. 8). Assuming 2 milkings per day the annual hours of operation at most 2920 (Ref. 6)
8. Dairy Farm Energy Management Guide: California, Ludington, Johnson, Kowalski, & Mage, Southern California Edison, 2004.

Revision History

Version	Description	Author	Date
1.0	Created new workpaper	Franklin Energy Services	11/12/2015

Electric Utility Infrastructure

Lighting

Electric Utility Infrastructure - Lighting - General Measure

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Actions	Replace Working, Replace on Fail, Modify, New Construction
Required from Customer/Contractor	Existing fixtures and quantities (retrofits only), installed fixtures and quantities, operating hours estimate, HVAC system (heating only, heating & cooling, exterior/unconditioned)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	See Table 3
Unit Participant Incremental Cost	See Appendix B (Values originally developed for C/I applications, but apply to Infrastructure/Utility-owned projects as well)

Measure Description

Electric Utility Infrastructure lighting measures use a standard set of variables for hours of use, HVAC cooling interaction effects, and coincident factors. The following section provides the algorithms used for energy savings and the tables of supporting information. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities. Wattage references in Appendix B apply to Infrastructure projects the same as C/I projects.

Algorithms

Unit kWh Savings per Year = (kW_Base - kW_EE) x Hrs x HVAC_cooling_kWhsavings_factor

Unit Peak kW Savings = CF x (kW_Base - kW_EE) x HVAC_cooling_kWsavings_factor

Unit Dth Savings per Year = (kW_Base - kW_EE) x Hrs x HVAC_heating_penalty_factor

Where:

kW_Base = Baseline fixture wattage (kW per fixture): see Appendix B

kW_EE = High Efficiency fixture wattage (kW per fixture): see Appendix B

Hrs = Annual operating hours. An estimate for actual operating hours should be used. Project documentation should include a justification for the chosen estimate. If an estimate is impossible to produce, use the

building type from Table 2 most similar to the proposed install space to determine hours.

CF = Coincidence Factor, the probability that peak demand of the lights will coincide with peak utility system demand. If data is tracked at the site that would allow a project-specific CF to be calculated, that value should be used (for example, if lighting is tracked as a parasitic load at generation facilities). If an actual CF is not available, use the building type from Table 2 most similar to the proposed install space to determine CF.

HVAC_cooling_kWhsavings_factor = Cooling system energy savings factor resulting from efficient lighting from Table 1. Reduction in lighting energy results in a reduction in cooling energy. It only applies if the proposed installation site uses mechanical cooling (use a value of 1.0 otherwise).

HVAC_cooling_kWsavings_factor = Cooling system demand savings factor resulting from efficient lighting from Table 1. Reduction in lighting demand results in a reduction in cooling demand. It only applies if the proposed installation site uses mechanical cooling (use a value of 1.0 otherwise).

HVAC_heating_penalty_factor = Heating system penalty factor resulting from efficient lighting from Table 1. It only applies if the installation site uses gas space heating (use a value of 0 otherwise).

Example:

Replace (1) 60W incandescent with a 9W LED lamp in a utility-owned office space with gas heating and mechanical cooling.

kWh Savings = (0.043-0.009)*4,439*1.095 = 165.23 kWh

kW Savings = 0.7*(0.043-0.009)*1.254 = 0.0.298 kW

Heating Penalty = (0.043-0.009)*4,439*-0.0023 = -0.347 Dth/year

Deemed Input Tables

Table 1. HVAC Interactive Factors by HVAC System (Ref. 2)

Lighting Measures	HVAC Cooling kW Savings Factor		HVAC Cooling kWh Savings Factor		HVAC Heating Penalty Factor (Dth/kWh)
	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only	HVAC System: Heating & Cooling	HVAC System: Heating Only or Heating & Cooling
All Except Exterior/ Unconditioned	1.00	1.254	1.00	1.095	-0.0023
Exterior/ Unconditioned Space	1.00	1.00	1.00	1.00	0

Table 2. Deemed Peak Demand Coincidence Factors (Ref. 3) and Annual Operating Hours by Building Type (Ref. 4)

Building Type	CF	Hrs
Office	70%	4,439
Warehouse	70%	4,746
Other/Misc.	66%	4,576
24-Hour Facility	100%	8,760
Safety or Code Required	100%	8,760
Exterior lighting	0%	4,903

Table 3. Measure Life

Installed Technology	Measure Life (yrs)	Reference
Ceramic Metal Halide	13	8
Ceramic Metal Halide - Integrated Ballast	13	8
High Bay Fluorescent	15	6
High Bay LED	11.3	20
LED Exterior Canopy	10.2	7
LED Exterior (Wall & Area)	10.2	7
Low wattage plug in CFL	1.8	16
Low wattage T8	15	6
Pin based CFL	2.3	17
Pulse Start Metal Halide	15	9
CFL Standard to Low Wattage	2.3	1
Controls	8	6
Exit Sign Retrofit with LED/LEC	16	6
Exterior Canopy/Soffit Retrofit with LEDs	10.2	7

Installed Technology	Measure Life (yrs)	Reference
Exterior Wall Pack Retrofit with LEDs	10.2	7
Parking Garage Fluorescent	15	6
High Pressure Sodium	15	18
Interior LED Screw-in Lamps	3.4	14
Interior LED Luminaire	11.3	15
Pin-Based CFL	2.3	9
Pin-Based LED	11.3	21
T5 fixtures	15	6
T8 fixtures	15	6
Refrigerator/Freezer Case LEDs	10	10
Stairwell Fixtures with Integral Occupancy	14.4	11
T8 Standard to Low Wattage Retrofit	8.1	12
Energy Standard Exempt T12 HO ballasts for outdoor signs and electronic ballast T12s	15	6
Nonexempt 8 foot magnetic ballast T12s are 4 years in 2013, 3 years in 2014, 2 years in 2015, and 1 year in 2016, 1 year in 2017, TBD in 2018	1	13
T8 Optimization	15	6

Methodology and Assumptions

HVAC cooling and heating interactive factor data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes (see http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf), and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

References

1. CFL lamp rated hours of 10,000 is divided by the average operating hours (except safety, 24 hr, and exterior) of 4,431 hours to arrive at 2.3 years for measure life
2. HVAC cooling and heating interactive factor data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes (see http://www.deeresources.com/deer2005/downloads/DEER2005UpdateFinalReport_ItronVersion.pdf), and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).
3. Database of Energy Efficient Resources 2008 Measure Energy Analysis Revisions Version 2008.2.05-09-11 Planning/Reporting Version
4. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 Section 6.5. Illinois TRM summarizes recent studies including: DEER 2005, DEER 2008, ComEd FY1 and FY2 evaluations, AmerEn Missouri Final

Report: Evaluation of Business Energy Efficiency Program Custom and Standard Incentives, and Focus on Energy Evaluation, ACES Deemed Savings Desk Review, November 2010

5. Lighting Efficiency input wattage guide, Xcel Energy, July, 2008, kW
6. Database of Energy Efficient Resources 2008 Effective Useful Life Summary 10-1-08
7. Product life based on 50,000 minimum rated life from Design Lights Consortium V4.0 Specification https://designlights.org/resources/file/TRT_V40_Final_FULLTABLE_FINAL_highlights 50,000 divided by the exterior hours of 4,903 arrives at 10.2 years.
8. State of Wisconsin Public Service Commission of Wisconsin Focus on Energy Evaluation *Business Programs: Measure Life Study* Final Report: August 25, 2009
9. Residential and Commercial/Industrial Lighting and HVAC Measures for use as Energy Efficiency Measures/Programs Reference Document for the ISO Forward Capacity Market (FCM) June 2007 GDS Associates, Inc.
10. Assumes 6,205 hrs per year operation (17 hrs/day) and a lifetime of approximately 62,082 hours (this is the average rated life from DLC qualified product list). Accessed 7/31/12.
11. Xcel Energy 2013-2015 Triennial CIP Plan (Docket No. E,G002/CIP-12-447). Average of fixture lifetime (20 years) and control lifetime (~8 years).
12. Product life assumption of 36,000 hours determined from survey of on-line retailers, July 2012. 36,000 hours is divided by the average operating hours (except safety, 24 hr, and exterior) of 4,431 hours to arrive at 8.1 years for measure life.
13. Measure life reduction due to legislation and market. See T12 Up to 4-Foot Retrofit section for more information.
14. LED lamp rated hours of 15,000 (ENERGY STAR qualified minimum) is divided by the average operating hours (except safety, 24 hr, and exterior) of 4,431 hours to arrive at 3.4 years for measure life
15. Product life based on 50,000 minimum rated life from Design Lights Consortium V4.0 Specification https://designlights.org/resources/file/TRT_V40_Final_FULLTABLE_FINAL_highlights LED luminaire rated hours of 50,000 is divided by the average operating hours (except safety, 24 hr, and exterior) of 4,431 hours to arrive at 11.3 years for measure life
16. Measure life for plug in low wattage CFL lamps is based on 8,000 hours of life divided by the average annual operating hours of 4,431 to arrive at 1.81 years
17. CFL lamps rated hours of 10,000 is divided by the average operating hours (except safety, 24 hr, and exterior) of 4,431 hours to arrive at 2.3 years for measure life.
18. Xcel Energy uses 20 years in 2013-2015 Minnesota CIP Triennial Plan (Docket No. E,G002/CIP-12-447), per communication with Commerce staff. Fixture may be considered permanent once installed. However, life was decreased to 15 years for consistency with maximum lifetimes for other technologies.
19. ANSI/ASHRAE/IES Standard 90.1-2010 edition

20. LED highbay rated hours of 50,000 is divided by the average operating hours (except safety, 24 hr, and exterior) of 4,431 hours to arrive at 11.3 years
21. DLC is expected to adopt this category of lamps in late 2016; minimum rate lifetime will be 50,000 hours. 50,000 is divided by the average operating hours (except safety, 24 hr, and exterior) of 4,431 hours to arrive at 11.3 years.
22. C/I Lighting – Lighting End Use Measure. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs Version 2.0. Effective: January 1, 2017 – December 31, 2019.

Revision History

Version	Description	Author	Date
1.0	New EUI measure based on existing C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - CFL Standard to Low Wattage Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working, Replace on Fail
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure replaces standard wattage plug-in CFL lamps with lower wattage plug-in CFL lamps, nominally 40 watt lamps replaced by 28 watt or 25 watt lamps. These lamps plug into the fixture and can be used with the existing ballast and base. Commonly referred to as Dulux, Biax, or PL lamps. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Controls

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Modify
Required from Customer/Contractor	Control type/quantity, connected load (kW) to each control, estimated annual operating hours, HVAC system (heating only, heating & cooling, exterior/unconditioned)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	See algorithm
Measure Lifetime (years)	8 years (Ref. 1)
Unit Participant Incremental Cost	See Table 3

Measure Description

Occupancy sensors represent an energy-efficient way to control lighting use in low occupancy areas such as halls, storage rooms, and restrooms. Instead of relying on people to remember to switch lights off when they leave a space, occupancy sensors perform this task. They measure the movement of people within a space. When movement is detected, the lights turn on automatically; they then shut off when they no longer sense movement. Each unit's shut-off time can be preset, given the needs of the space being controlled.

Systems use daylight sensor lighting controls to take advantage of available daylight in perimeter building spaces (open spaces within 10' to 15' of windows) or other areas that have access to daylight infiltration. Daylight sensor lighting controls can be used to turn lights on or off, stepped dimming (high/low or inboard/outboard), or continuous dimming based on light levels from available daylight. Especially useful in common spaces where task lighting is not critical (malls, warehouses, atriums, etc.) This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithms

Unit kWh Savings per Year = kW_connected x (1-PAF) x Hrs xHVAC_cooling_kWhsavings_factor

Unit Peak kW Savings = CF x kW_connected x(1-PAF)x HVAC_cooling_kWsavings_factor

Unit Dth Savings per Year = kW_connected x (1-PAF) x Hrs x HVAC_heating_penalty_factor

Where:

kW_connected = Total connected fixture load, determined as the sum of stipulated fixture wattages from the Retrofit Tables in the C/I Lighting Measure.

Hrs = Annual operating hours. An estimate for actual operating hours should be used. Project documentation should include a justification for the chosen estimate. If an estimate is impossible to produce, use the building type from Table 2 in the Lighting – General Measure most similar to the proposed install space to determine hours.

PAF = Deemed Power Adjustment Factor per Table 3.

CF = Coincidence Factor, the probability that peak demand of the lights will coincide with peak utility system demand. If data is tracked at the site that would allow a project-specific CF to be calculated, that value should be used (for example, lighting parasitic loads at generation facilities). If an actual CF is not available, use the building type from Table 2 in the Lighting – General Measure most similar to the proposed install space to determine CF.

HVAC_cooling_kWhsavings_factor = C ooling system energy savings factor resulting from efficient lighting from Table 1 in the Lighting – General Measure. Reduction in lighting energy results in a reduction in cooling energy. It only applies if the proposed installation site uses mechanical cooling.

HVAC_cooling_kWsavings_factor = Cooling system demand savings factor resulting from efficient lighting from Table 1 in the Lighting – General Measure. Reduction in lighting demand results in a reduction in cooling demand. It only applies if the proposed installation site uses mechanical cooling.

HVAC_heating_penalty_factor = Heating system penalty factor resulting from efficient lighting from Table 1 in the Lighting – General Measure. It only applies if the installation site uses gas space heating.

Example:

Install a wall mounted occupancy sensor with a connected load of 0.560 kW (10 - 2L 32W T8 fixtures) in a utility-owned office space.

kWh = 0.560kW * (1-0.70) * 4,439 * 1.095 = 816.6 kWh

kW = 0.7 * 0.560 * (1-0.70) * 1.254 = 0.15 kW

Deemed Input Tables

Table 1. Deemed Power Adjustment Factors (Ref. 1) and Incremental Costs (Ref. 4)

Control Type	PAF	Incremental Cost
Occupancy Sensor - Wall Mount	0.700	$55
Occupancy Sensor - Ceiling Mount	0.700	$125
Daylighting - Continuous Dimming	0.567	$65
Daylighting - Multiple Step Dimming	0.648	$65
Daylighting - On/Off	0.729	$65

Codes and Legislation

Adoption of ASHRAE Standard 90.1-2010 will require occupancy sensors in many spaces for new construction.

Automatic Lighting Shutoff – interior lighting in buildings shall be controlled with an automatic control device to shut off building lighting in all spaces. This automatic control device shall function on either: a) a scheduled basis using a time-of-day operated control device that turns lighting off at specific programmed times – an independent program schedule shall be provided for areas of no more than 25,000 ft2 but not more than one floor – or b) an occupant sensor that shall turn lighting off within 30 minutes of an occupant leaving a space, or c) a signal from another control or alarm system that indicates the area is unoccupied.

Exceptions include: a) lighting required for 25-hour operation b) lighting in spaces where patient care is rendered and c) lighting in spaces where an automatic shutoff would endanger the safety or security of the room or building occupant(s).

Display/Accent Lighting – shall have a separate control device

Case Lighting – lighting in case for display purposes shall have a separate control device

Guest Room Lighting – Guestrooms in hotels, motels, boarding houses, or similar buildings shall have one or more control device(s) at the entry door that collectively control all permanently installed luminaires and switched receptacles, except those in the bathroom(s).

Task Lighting – Supplemental task lighting, including permanently installed undershelf or undercabinent lighting, shall have a control device integral to the luminaires or be controlled by a wall mounted control device provided the control device is readily accessible and located so that the occupant can see the controlled lighting.

Nonvisual Lighting – lighting for nonvisual applications, such as plant growth and food warming, shall have a separate control device.

Demonstration Lighting – lighting equipment that is for sale or for demonstrations in lighting education shall have a separate control device.

Stairwell Lighting – lighting in stairwells shall have on or more control devices to automatically reduce lighting power in any one controlled zone by at least 50% within 30 minutes of all occupants leaving that controlled zone.

Refer to Table 9.6.2 Control Factors Used in Calculating Additional Interior Lighting Power Allowance for more information. (Ref 6).

Notes

Adoption of ASHRAE Standard 90.1-2007 or 90.1-2010 will require occupancy sensors in many spaces for new construction.

References

1. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 Section 6.5. Illinois TRM summarizes recent studies including: DEER 2005, DEER 2008, ComEd FY1 and FY2 evaluations, AmerEn Missouri Final Report: Evaluation of Business Energy Efficiency Program Custom and Standard Incentives, and Focus on Energy Evaluation, ACES Deemed Savings Desk Review, November 2010
2. ANSI/ASHRAE/IES Standard 90.1-2010 edition
3. C/I Lighting – Controls Measure. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs Version 2.0. Effective: January 1, 2017 – December 31, 2019.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Exit Sign Retrofit with LED/LEC

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working, Replace on Fail
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure evaluates the retrofit and replacement of incandescent exit signs with energy efficient LED and LEC exit signs. ENERGY STAR labeled exit signs operate on five watts or less per sign, compared to the standard signs, which use as much as 40 watts per sign. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Notes

EPA suspended the ENERGY STAR Exit Sign specification effective May 1, 2008. In EPAct 2005, Congress passed a new minimum federal efficiency standard for electrically-powered, single-faced exit signs with integral light sources that are equivalent to ENERGY STAR levels for input power demand. EPAct 2005 references the ENERGY STAR Version 2.0 specification. All exit signs manufactured on or after January 1, 2006 must have an input power demand of 5 watts or less per face.

References

1. Database of Energy Efficient Resources 2008 Effective Useful Life Summary 10-1-08
2. Calculated through energy modeling be FES 2012

3. Lighting Efficiency input wattage guide, Xcel Energy, July, 2008, kW
4. NYSERDA Deemed Savings Database, Labor cost assumes 25 minutes @ $18/hr taken from the State of Illinois Technical Reference Manual 2012 and 2012 manufacturer product survey and project data.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Exterior Canopy/Soffit Retrofit with LEDs

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Exterior canopy/soffit lighting within Electric Utility Infrastructure
Actions	Replace Working, Replace on Fail
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

Exterior high pressure sodium, metal halide, mercury vapor, and pulse start metal halide fixtures can all be replaced with energy efficient LED exterior light fixtures in canopy and soffit applications. Utilizing LED lighting, a large energy savings can be accomplished without a great lumen reduction in the area. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Exterior Wall Pack Retrofit with LEDs

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Exterior wall pack lighting within Electric Utility Infrastructure
Actions	Replace Working, Replace on Fail
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

Exterior high pressure sodium, metal halide, mercury vapor, and pulse start metal halide fixtures can all be replaced with energy efficient LED exterior wall pack fixtures. Utilizing LED lighting, a large energy savings can be accomplished without a great lumen reduction in the area. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Fluorescent to LED High Bay Systems

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

LED high bay fixtures offer increased efficiency with nearly equivalent light output as compared to linear fluorescent high bay systems. Integrated LED high bays also offer advanced controllability leading to an even greater increase in efficiency.

LED systems are often utilized in high bay ceiling applications over 15 feet. LED fixtures also offer an increased life time, reduced maintenance, and no decreased in operational performance in colder temperatures.

This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that LED High Bay fixtures appear on the Design Lights Consortium Qualified Product List under the High Bay category.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - High Pressure Sodium Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Replace Working
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure evaluates high pressure sodium fixtures replaced by pulse start metal halides, high bay fluorescent fixtures, parking garage fluorescent, and ceramic metal halides.

Pulse start metal halide systems typically consume 20 percent less energy than high pressure sodium systems, produce the same light at lower wattages, and can often use more efficient ballasts depending on the application.

High bay fluorescent systems are often utilized in high bay ceiling applications over 15 feet. High bay fluorescent and parking garage fluorescent systems offer lower depreciation rates, better dimming options, virtually instant start-up and re-strike, better color rendition, and reduced glare.

Ceramic metal halides can be utilized to replace high pressure sodium in lower wattage applications and result in better color rendition, lower wattage consumption, and improved color temperature.

This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Notes

New construction wattage tables are available in the CI Lighting New Construction file.

The Energy Independence and Security Act of 2007 legislation sets standards for ballasts used in new metal halide luminaires that operate lamps from 150 to 500 watts. New metal halide luminaires must contain ballasts that meet new efficiency standards. Pulse-start metal halide ballasts must have a minimum ballast efficiency of 88%, magnetic probe-start ballast a minimum efficiency of 94%. New

metal halides operating lamps of 150-500 watts manufactured on or after January 1, 2009 contain pulse-start, magnetic or electronic, metal halide ballasts with a minimum efficiency of 88%.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Incandescent Over 100W Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working, Retrofit
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure replaces Incandescent fixtures over 100 watts with various technologies including ceramic metal halides, high pressure sodium fixtures, integrated ballast ceramic metal halides, LED lamps, LED luminaire, pin-based CFL, pulse start metal halides, T5 fixtures, and T8 fixtures. The replacement fixture technology will depend on the specific application and environment. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org and LED and CFL lamps appear on the ENERGY STAR Qualified Product list available at www.energystar.gov.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Incandescent Up to 100W Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working, Retrofit
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure replaces Incandescent fixtures up to 100 watts with various technologies including ceramic metal halides, LED lamps, LED luminaire, pin-based CFL, pulse start metal halides, and T8 fixtures. The replacement fixture technology will depend on the specific application and environment. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org and LED and CFL lamps appear on the ENERGY STAR Qualified Product list available at www.energystar.gov.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting – LED Troffer Retrofit Kits

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

LED Troffers offer an energy efficient alternative to T8 linear fluorescent fixtures. Kits are available to convert an existing recessed troffer to LED without requiring removal of the fixture. LED integrated fixtures offer similar light output with a reduction of energy consumption. Integrated LED fixtures also offer controllability beyond capabilities of linear fluorescent technology and integration with many complex control systems. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting – LED Troffers

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

LED Troffers offer an energy efficient alternative to T8 linear fluorescent fixtures. The LED integrated fixtures offer similar light output with a reduction of energy consumption. Integrated LED fixtures also offer controllability beyond capabilities of linear fluorescent technology and integration with many complex control systems.

This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Mercury Vapor Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Replace Working
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure evaluates mercury vapor fixtures replaced by pulse start metal halides, high bay fluorescent fixtures, high pressure sodium fixtures, parking garage fluorescent fixtures, and ceramic metal halides.

Pulse start metal halide systems typically consume 20 percent less energy than mercury vapor systems, produce the same light at lower wattages, and can often use more efficient ballasts depending on the application.

High bay fluorescent systems are often utilized in high bay ceiling applications over 15 feet. High bay fluorescent and parking garage fluorescent systems offer lower depreciation rates, better dimming options, virtually instant start-up and re-strike, better color rendition, and reduced glare.

Ceramic metal halides can be utilized to replace mercury vapor systems in lower wattage applications and result in better color rendition, lower wattage consumption, and improved color temperature.

This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Metal Halide Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Replace Working
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure evaluates probe start metal halides replaced by pulse start metal halides, high bay fluorescent fixtures, and ceramic metal halides. Pulse start metal halide systems typically consume 20 percent less energy than standard metal halide systems, produces the same light at lower wattages, and can often use more efficient ballasts depending on the application.

High bay fluorescent and parking garage fluorescent systems are often utilized in high bay ceiling applications over 15 feet. High bay fluorescent and parking garage fluorescent systems offer lower depreciation rates, better dimming options, virtually instant start-up and re-strike, better color rendition, and reduced glare.

Ceramic metal halides can be utilized to replace probe start metal halides in lower wattage applications and result in better color rendition, lower wattage consumption, and improved color temperature. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Pulse Start Metal Halide Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Replace Working
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure evaluates pulse start metal halide fixtures replaced by lower wattage pulse start metal halides, high bay fluorescent fixtures, and ceramic metal halides.

Pulse start metal halide fixtures can be replaced by lower wattage pulse start metal halides when the space they are in is considered over lit.

High bay fluorescent and fluorescent systems are often utilized in high bay ceiling applications over 15 feet. High bay fluorescent and fluorescent systems offer lower depreciation rates, better dimming options, virtually instant start-up and re-strike, better color rendition, and reduced glare.

Ceramic metal halides can be utilized to replace pulse start metal halides in lower wattage applications and result in better color rendition, lower wattage consumption, and improved color temperature. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - Stairwell Fixtures with Integral Occupancy Sensors

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Replace Working
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure involves replacement of existing fluorescent stairwell fixtures with fluorescent or LED stairwell fixtures with integral occupancy sensors and step-dimming ballasts, allowing for automatic adjustment of light output based on stairwell occupancy.

This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Methodology and Assumptions

The efficient wattages in Appendix B include multipliers reflecting the rated level of dimming and an average duty cycle of 3% determined from M&V of a large installation sponsored by Xcel Energy.

Notes

In 2009 the Department of Energy announced new lamp rulemaking for general service fluorescent lamps. The efficiency standard requires general service fluorescent lamps covered in this rulemaking to meet minimum lumen per watt (LPW) requirements; products that do not meet the minimum LPW requirements as of July 14, 2012 can no longer be produced. 700 series T8 lamps affected by this rulemaking have been postponed for two years until July 2014. T12 lamps remain on the same timeline.

Requirements

It is suggested that all LED fixtures and retrofits appear on the Design Lights Consortium Qualified Product list available at www.designlights.org.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - T12 8-Foot Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working, Replace on Fail
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure evaluates the replacement of 8 foot T12 lamps and magnetic or electronic ballasts with energy efficient T8, T5, and T5HO lamps and ballasts. The replacements can be 8 foot or 4 foot lamps. Changing from T12 lamp and ballast systems to T8, T5, or T5HO systems will reduce the energy consumption of the system while maintaining similar light outputs. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Methodology and Assumptions

Measure Life is reduced based on remaining useful life of magnetic ballasts in the market place. Using the analysis completed in the Texas Docket 39146 Appendix C, a current remaining useful life of T12 magnetic ballasts at the end of 2012 is 4.1 years, or 4 years. The following documents were used in this analysis:

- "Fluorescent Lamp Ballasts Preliminary Analytical Tools: National Impact Analysis" (Ref. 7)
- "Fluorescent Lamp Ballast Technical Support Document for the Final Rule, 2000" (Ref. 8)

The Illinois Statewide Technical Reference Manual goes further to conclude the measure life should decrease from four years in 2012 to three years in 2013, two years in 2014, and one year in 2015. (Ref. 9)

Notes

EPAct 2005 and 2000 DOE Ballast Rule. 2000 DOE Ballast Rule no longer allows ballasts that do not pass the new requirements to be manufactured after July 1, 2010 and EPAct 2005 no longer allows ballasts that do not pass the new requirements to be sold after October 1, 2010.

Ballasts affected by the rulemaking are those that operate:

- T12 4-foot linear and 2-foot U-shaped Rapid Start lamps with medium bi-pin bases
- T12 8-foot Instant Start lamps with single pin bases
- T12 8-foot Rapid Start HO lamps with recessed double contact (RDC) bases

Exceptions to the ballast standards:

- Dimming ballasts that dim to 50% or less of maximum output
- T12 HO ballasts capable of starting at ambient temperatures as low as -20° F or less and for use in outdoor illuminated signs
- Ballasts having a power factor of less than 0.90 and designed and labeled for use only in residential applications.
- 2 foot and 3 foot lamp and ballast systems
- 2009 DOE Lamp Rulemaking for GSFL and IRL Lamps. New efficiency standards for General Service Fluorescent lamps (GSFLs), linear and U-shaped require these covered lamp types to meet minimum lumen per watt (LPW) requirements; products that do not meet the minimum LPW requirements as of July 14, 2012 can no longer be produced.

The following lamp types are affected by these standards:

- Lamp Type| Energy Conservation Standard (lm/W)
- 4-foot (T8-T12) Medium Bi-pin ≥25W 89/88
- 2-foot (T8-T12) U-Shaped ≥25W 84/81
- 8-foot (T8-T12) Single Pin Slimline ≥52W 97/93
- 8-foot (T8-T12) High Output 92/88
- 4-foot (T5) Miniature Bi-pin Standard Output ≥26W 86/81
- 4-foot (T5) Miniature Bi-pin high Output ≥49W 76/72
- New T12 lamps that meet the new standards are now available in the market allowing T12s to still be installed

References

1. DOE 2010b "Fluorescent Lamp Ballasts Preliminary Analytical Tools: National Impact Analysis" U.S. Department of Energy: 2010.
2. DOE 2000b. "Fluorescent Lamp Ballast Technical Support Document for the Final Rule, 2000." September 2000.

3. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 Section 6.5.
4. C/I Lighting – T12 8-Foot Retrofit Measure. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs Version 2.0. Effective: January 1, 2017 – December 31, 2019.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - T12 Up to 4-Foot Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace Working, Retrofit
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

This measure evaluates the replacement of T12 lamps and magnetic or electronic ballasts up to 4 feet in length with energy efficient T8, T5, and T5HO lamps and ballasts. The replacement of T12 lamps and ballasts with T8, T5, and T5HO lamp and ballast systems results in a lower wattage system with similar light output. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Methodology and Assumptions

Measure Life is reduced based on remaining useful life of magnetic ballasts in the market place and the July 14, 2012 Federal Standards eliminating standard T12 lamps.

Reviewing the market and a pending study of the T12s in the Minnesota market, the measure life is 1 year at full savings for T12s. The remaining 14 years of the measure life will utilize T8 baseline for savings.

This is set to be re-visited at the completion of the T12 market study.

Notes

EPAct 2005 and 2000 DOE Ballast Rule. 2000 DOE Ballast Rule no longer allows ballasts that do not pass the new requirements to be manufactured after July 1, 2010 and EPAct 2005 no longer allows ballasts that do not pass the new requirements to be sold after October 1, 2010.

Ballasts affected by the rulemaking are those that operate:

- T12 4-foot linear and 2-foot U-shaped Rapid Start lamps with medium bi-pin bases
- T12 8-foot Instant Start lamps with single pin bases
- T12 8-foot Rapid Start HO lamps with recessed double contact (RDC) bases

Exceptions to the ballast standards:

- Dimming ballasts that dim to 50% or less of maximum output
- T12 HO ballasts capable of starting at ambient temperatures as low as -20° F or less and for use in outdoor illuminated signs
- Ballasts having a power factor of less than 0.90 and designed and labeled for use only in residential applications.
- 2 foot and 3 foot lamp and ballast systems

2009 DOE Lamp Rulemaking for GSFL and IRL Lamps. New efficiency standards for General Service Fluorescent lamps (GSFLs), linear and U-shaped require these covered lamp types to meet minimum lumen per watt (LPW) requirements; products that do not meet the minimum LPW requirements as of July 14, 2012 can no longer be produced.

The following lamp types are affected by these standards:

- Lamp Type| Energy Conservation Standard (lm/W)
- 4-foot (T8-T12) Medium Bi-pin ≥25W 89/88
- 2-foot (T8-T12) U-Shaped ≥25W 84/81
- 8-foot (T8-T12) Single Pin Slimline ≥52W 97/93
- 8-foot (T8-T12) High Output 92/88
- 4-foot (T5) Miniature Bi-pin Standard Output ≥26W 86/81
- 4-foot (T5) Miniature Bi-pin high Output ≥49W 76/72
- New T12 lamps that meet the new standards are now available in the market allowing T12s to still be installed.

Requirements

It is suggested that high performance and reduced wattage T8 lamps appear on the Consortium for Energy Efficiency Qualified Product List available at www.cee1.org.

References

1. DOE 2010b "Fluorescent Lamp Ballasts Preliminary Analytical Tools: National Impact Analysis" U.S. Department of Energy: 2010.
2. DOE 2000b. "Fluorescent Lamp Ballast Technical Support Document for the Final Rule, 2000." September 2000.

3. State of Illinois Energy Efficiency Technical Reference Manual Final Technical Version as of July 18th, 2012 Effective June 1st, 2012 Section 6.5.
4. ANSI/ASHRAE/IES Standard 90.1-2010 edition
5. C/I Lighting – T12 Up to 4-Foot Retrofit Measure. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs Version 2.0. Effective: January 1, 2017 – December 31, 2019.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Lighting - T8 Standard to Low Wattage Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Lighting
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Replace Working, New Construction
Version No.	1.0
Unit kWh Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Peak kW Savings	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.
Unit Dth Savings per Year	Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for lamp wattages.

Measure Description

High performance T8 lighting with low wattage lamps incorporates improvements to lamp and ballast technologies. They deliver light levels comparable with standard 32 watt T8 systems at lower wattages and with improved lamp life. This measure replaces 32W standard T8 systems with low watt T8 systems. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithm and Assumptions

Refer to the Lighting – General Measure for appropriate algorithm and inputs. Refer to Appendix B for wattages.

Requirements

It is suggested that all low wattage T8 lamps appear on the Consortium for Energy Efficiency Qualified Product list available at www.cee1.org.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

HVAC

Electric Utility Infrastructure - HVAC - Chiller Systems

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	HVAC
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Replace Working or New Construction
Required from Customer/Contractor	New chiller type, nominal cooling capacity in tons, integrated part load value, full load value; EFLHcool estimate or building type (refer to Table 2), project location (county) Chilled water leaving temperature, condenser leaving temperature and condenser gpm; if water cooled centrifugal chiller is not designed to operate at standard AHRI conditions
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 years (Ref. 1)
Unit Participant Incremental Cost	See Table 1

Measure Description

This measure analyzes the space cooling savings potential of the installation of high efficiency chillers including; all air cooled chillers, water cooled screw, scroll, and centrifugal chillers. This measure is applicable to chillers with efficiencies provided at AHRI conditions, but also accommodates water cooled centrifugal chillers with efficiencies provided at other conditions. The incremental cost is associated with base equipment cost and does not include any installation costs. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithms

Unit kWh Savings per Year = Nominal Capacity x (IPLV_base - IPLV_EE) x $EFLH_{Cool}$

Unit Peak kW Savings = Nominal Capacity x (FLV_base - FLV_EE) x CF

Where:

Nominal Capacity = the nominal rating of the cooling capacity of the energy efficient chiller (tons)

$IPLV_{EE}$ = the integrated part load value (IPLV) of the energy efficient chiller (kW/ton) at AHRI standard conditions*

For efficiencies provided at other than AHRI conditions:

$IPLV_{EE}$ = $IPLV_{CS}$ / K_{ADJ} = the integrated part load value of energy efficient chiller at operating conditions divided by K_{ADJ} for water cooled centrifugal chillers if chiller designed not to operate at AHRI standard conditions

$IPLV_{Base}$ = the integrated part load efficiency of the baseline chiller (kW/ton), $IPLV_{Base}$ = $IPLV_{AHRI}$ per Table 1.

$EFLH_{Cool}$ = the equivalent full load hours of chiller operation. If the proposed project will serve a unique space type, an estimate for $EFLH_{cool}$ should be made and justification should be provided in the project documentation. If the space is similar to one of the building types listed in Table 2, the hours from that table can be used. If no estimate can be made and no building types in Table 2 match the proposed space, the Miscellaneous value from Table 2 should be used.

FLV_{EE} = the equivalent full load value of the energy efficient chiller (kW/ton), FLV at AHRI standard conditions*provided by the contractor/customer.

For efficiencies provided at other than AHRI conditions:

FLV_{EE} = FLV_{CS} / k_{ADJ} = the equivalent full load value of the energy efficient chiller at operating conditions divided by k_{ADJ} for water cooled centrifugal chillers if chiller not designed not to operate at AHRI standard conditions

FLV_{Base} = the full load efficiency of the baseline chiller (kW/ton), FLV_{Base} = FLV_{AHRI} per Table 1.

CF = Deemed coincident demand factor, equal to 0.90 (Ref. 2)

For Water Cooled Centrifugal Chillers not tested at AHRI Standard Conditions** (Ref. 3):

$IPLV_{CS}$ = for water cooled centrifugal chillers not designed to run at AHRI Standard test conditions*, the integrated part load value provided by customer/contractor at operating conditions (kW/ton)

FLV_{CS} = for water cooled centrifugal chillers not tested at AHRI Standard test conditions*, the equivalent full load value provided by customer/contractor at operating conditions (kW/ton)

k_{ADJ} = A x B

where:

A	=	$0.00000014592 \times (LIFT)^4 - 0.0000346496 \times (LIFT)^3 + 0.00314196 \times (LIFT)^2 - 0.147199 \times (LIFT) + 3.9302$
B	=	0.0015 * LvgEvap + 0.934
LIFT	=	LvgCond – LvgEvap
LvgCond	=	Full Load Condenser leaving fluid temperature (°F)
LvgEvap	=	Full Load Evaporator leaving fluid temperature (°F)

* Standard AHRI test conditions are 44°F leaving chilled water temperature, 85°F entering condenser water temperature with 3 gpm/ton condenser water flow.

** These adjustment factors are applicable to centrifugal chillers designed for a minimum leaving water temperature of at least 36°F and a maximum condenser entering water temperature of 115 °F and LIFT ≥ 20°F and ≤ 80°F.

Example:

Retrofit of an existing water cooled centrifugal chiller installed in a Generation Facility with an estimated 1,298 effective full load cooling hours, 600 ton cooling capacity not rated at AHRI conditions. Design FLV = 0.50 and Design IPLV of 0.45, Climate Zone 3. The new chiller is full-load optimized and designed to operate with a condenser water leaving temperature of 91.16°F and evaporator leaving temperature of 42°F.

Lift = 91.16°F - 42°F = 49.16°F

$A = 0.00000014592 \times (49.16)^4 - 0.0000346496 \times (49.16)^3 + 0.00314196 \times (49.16)^2 - 0.147199 \times (49.16) + 3.9302 = 1.0228$

$B = 0.0015 \times 42 + 0.934 = 0.997$

$K_{ADJ} = 1.0228 \times 0.997 = 1.02$

$FLV_{EE} = 0.50 / 1.02 = 0.49$

$IPLV_{EE} = 0.40 / 1.02 = 0.44$

Unit kWh Savings per Year = 600 x (0.539 - 0.44) x 1298 = 77,101 kWh

Unit Peak kW Savings per Year = 600 x (0.57 - 0.49) x 0.9 = 43.0 kW

Deemed Input Tables

Table 1. Deemed Full Load and Integrated Part Load Baseline Efficiencies per AHRI 550/590 and Incremental Costs (Ref. 4, 5)

Equipment	PATH A****		PATH B*****		Incremental Cost($/ton)
	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)	
Water Cooled Scroll or Screw Chiller < 75 tons	0.780	0.630	0.800	0.600	130
Water Cooled Scroll or Screw Chiller ≥ 75 and < 150 tons	0.775	0.615	0.790	0.586	90
Water Cooled Scroll or Screw Chiller ≥ 150 and < 300 tons	0.680	0.580	0.718	0.540	90
Water Cooled Scroll or Screw Chiller ≥ 300 tons	0.620	0.540	0.639	0.490	40
Water Cooled Centrifugal Chiller < 150 tons	0.634	0.596	0.639	0.450	130
Water Cooled Centrifugal Chiller ≥ 150 and < 300 tons	0.634	0.596	0.639	0.450	85
Water Cooled Centrifugal Chiller ≥ 300 and < 600 tons	0.576	0.549	0.600	0.400	85
Water Cooled Centrifugal Chiller ≥ 600 tons	0.570	0.539	0.590	0.400	40
Air Cooled Chiller with Condenser < 150 tons	1.255	0.96	NA	NA	110
Air Cooled Chiller with Condenser > 150	1.255	0.94	NA	NA	110

* Path A is for traditional applications and where the intended applications are expected to have significant operating times at full load conditions, typically a non VFD controlled unit.

** All Path B chillers must be equipped with demand limiting controls or VFD controlled units.

*** FLV_AHRI = 12 / EER and IPLV_AHRI = 12 / SEER

Table 2. Equivalent Full Load Hours of cooling ($EFLH_{Cool}$) per zone in Minnesota by building type (Ref. 6)

Building Type	Zone 1	Zone 2	Zone 3
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Methodology and Assumptions

$EFLH_{Cool}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Assumed ventilation rates complied with the requirements of ASHRAE standard 62.1 – 2004.

Notes

Savings are based upon AHRI rated chillers and those water cooled centrifugal chillers operating within the limits of the nonstandard conditions listed above.

Table 1 chiller sizes were expanded to cover the scope the 2015 MN Energy Code, Table C.403.2.3 (7), Minimum Efficiency Requirements: Water Chilling Packages

References

1. ASHRAE, 2007, Applications Handbook, Ch. 36, table 4, Comparison of Service Life Estimates
2. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, and primary data has not been identified.
3. 2015 Minnesota Energy Code, Section C403.2.3.1 Water-cooled centrifugal chilling packages. https://codes.iccsafe.org/public/document/code/357/5880017
4. 2015 Minnesota Energy Code, Table C.403.2.3 (7), Minimum Efficiency Requirements: Water Chilling Packages. https://codes.iccsafe.org/public/document/code/357/5880017
5. 2008 Deer www.deeresources.com - Average across Tier 1 equivalent equipment.
6. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012.

Revision History

Version	Description	Author	Date
1.0	New EUI measure based on existing C/I measure	GDS Associates	11/21/2016
2.0	Updated FLV and IPLV values	Mark Garofano	11/2018

Electric Utility Infrastructure - HVAC - Chiller Tune-up

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	HVAC
Applicable To	Electric Utility Infrastructure
Actions	O&M
Required from Customer/Contractor	Chiller type, nominal cooling capacity in tons, integrated part load value, full load value; building type (refer to Table 2), project location (county)
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	5 (Ref. 1)
Unit Participant Incremental Cost	$5/ton (default/planning figure; Use actual cost of tune-up) (Ref. 2)

Measure Description

This measure describes savings for air cooled or water chiller tune-up completed in accordance with the following recommended tune-up requirements:

- Clean condenser coil/tubes
- Check cooling tower for scale or buildup
- Check contactors condition
- Check evaporator condition
- Check low-pressure controls
- Check high-pressure controls
- Check filter, replace as needed
- Check belt, replace as needed
- Check crankcase heater operation
- Check economizer operation

This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithms

kWh_{SAVED} = Nominal Capacity x $IPLV_{BASE}$ x $EFLH_{Cool}$ x MF_E

kW_{SAVED} = Nominal Capacity x FLV_{BASE} x CF x MF_D

Where:

$EFLH_{Cool}$ = the equivalent full load hours of chiller operation. If the proposed project will serve a unique space, an estimate for $EFLH_{cool}$ should be made and justification should be provided in the project documentation. If the space is similar to one of the building types listed in Table 2, the hours from that table can be used. If no estimate can be made and no building types in Table 2 match the proposed space, the Miscellaneous value from Table 2 should be used.

Capacity = the nominal rating of the cooling capacity of the energy efficient chiller (tons)

Chiller efficiencies = because existing chiller efficiency typically cannot be determined without extensive testing, code minimum efficiencies are recommended for base efficiency.

$IPLV_{BASE}$ = the integrated part load efficiency of the baseline chiller (kW/ton), $IPLV_{BASE}$ = $IPLV_{AHRI}$ per Table 1. Alternatively, actual efficiency may be used if verified via testing.

FLV_{BASE} = the full load efficiency of the baseline chiller (kW/ton), FLV_{BASE} = FLV_{AHRI} per Table 1. Alternatively, actual efficiency may be used if verified via testing.

CF = Coincidence factor = 0.9(Ref. 3)

MF_E = Maintenance energy saving factor, MF_E = 5 % (Ref. 4)

MF_D = Maintenance demand saving factor, MF_D = 2.5 % (Ref. 4)

Example:

Tune up of a 200 ton air cooled chiller serving a utility-owned mid-rise office building in Zone 2:

kWh_{SAVED} = 200 x 0.94 x 529 x 0.05 =4,973 kWh

kW_{SAVED} = 200 x 1.26 x 0.9 x 0.025 = 5.67 kW

Deemed Input Tables

Table 1. Deemed Full Load and Integrated Part Load Baseline Efficiencies per AHRI 550/590 (Ref. 5)

Equipment	PATH A*		PATH B**	
	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)
Water Cooled Scroll or Screw Chiller < 75 tons	0.780	0.630	0.800	0.600
Water Cooled Scroll or Screw Chiller ≥ 75 and < 150 tons	0.775	0.615	0.790	0.586
Water Cooled Scroll or Screw Chiller ≥ 150 and < 300 tons	0.680	0.580	0.718	0.540
Water Cooled Scroll or Screw Chiller ≥ 300 tons	0.620	0.540	0.639	0.490
Water Cooled Centrifugal Chiller < 150 tons	0.634	0.596	0.639	0.450
Water Cooled Centrifugal Chiller ≥ 150 and < 300 tons	0.634	0.596	0.639	0.450

Equipment	PATH A*		PATH B**	
	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)	FLV_AHRI (kW/ton)	IPLV_AHRI (kW/ton)
Water Cooled Centrifugal Chiller ≥ 300 and < 600 tons	0.576	0.549	0.600	0.400
Water Cooled Centrifugal Chiller ≥ 600 tons	0.570	0.539	0.590	0.400
Air Cooled Chiller with Condenser < 150 tons	1.255	0.960	NA	NA
Air Cooled Chiller with Condenser > 150	1.255	0.940	NA	NA

* Path A is for traditional applications and where the intended applications are expected to have significant operating times at full load conditions, typically a non VFD controlled unit.

** All Path B chillers must be equipped with demand limiting controls or VFD controlled units.

Table 2. Equivalent Full Load Hours of cooling ($EFLH_{Cool}$) per zone in Minnesota by building type (Ref. 6)

Building Type	Zone 1	Zone 2	Zone 3
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Methodology and Assumptions

Measurements and corrections must be performed with standard industry tools and practices, and the results tracked by the efficiency program.

$EFLH_{Cool}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

References

1. Wisconsin Public Service Commission equipment useful life database, 2013
2. State of Wisconsin Public Service Commission, Focus on Energy Evaluation, Business Programs: Incremental Cost Study, 2009. This study is compile program project cost data. An average value from chiller types and sizes is roughly $5/ton the range is roughly $2 to 8$/ton
3. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, and primary data has not been identified.
4. United States Department of Energy, Building Technologies Program: Hospitals Benefit by Improving Inefficient Chiller systems white paper, August 2011. The paper found that coil cleaning, the primary savings measure associated with this cooling tune-up measure, reduces annual cooling energy consumption by 5-7%. Demand savings are conservatively assumed to be on half this, or 2.5%.

5. 2015 Minnesota Energy Code, Table C.403.2.3 (7), Minimum Efficiency Requirements: Water Chilling Packages. https://codes.iccsafe.org/public/document/code/357/5880017
6. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012

Revision History

Version	Description	Author	Date
1.0	New EUI measure based on existing C/I measure	GDS Associates	11/21/2016
2.0	Updated FLV and IPLV values	Mark Garofano	11/2018

Electric Utility Infrastructure - HVAC - Unitary Equipment Economizer Addition or Repair

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	HVAC
Applicable To	Electric Utility Infrastructure customers where air unitary equipment has been installed, or has failed closed
Actions	Modify
Required from Customer/Contractor	Existing equipment type, existing equipment nominal cooling capacity in tons, existing equipment EER/SEER, building type (refer to Table 1), project location (county)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 years (Ref. 1)
Unit Participant Incremental Cost	For economizer addition, see Table 2 (Ref. 2) For economizer repair, use actual cost

Measure Description

This measure includes the retro-fit of existing equipment or the optional addition of an air side economizer on new equipment where not required by code. This measure analyzes the cooling savings potential of the installation of an air side economizer on unitary equipment. This measure is applicable to dx and water cooled air systems. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

This measure also includes the repair of economizers that have failed closed, or been manually disabled in a closed position. This is a common occurrence that often costs less to rectify than installing a new economizer, while providing the same savings as that action. This measure does not apply to economizers that have failed open, cases of which are generally noticed and rectified soon after onset.

Algorithms

Unit kWh Savings per Year = Size x (12/SEER_EE) x $EFLH_{cool}$ x SF x SM Unit

Where:

Size = Nominal Cooling capacity in tons of the new equipment (1 ton = 12,000 btu/h)

$EFLH_{Cool}$ = the equivalent full load hours of HVAC equipment operation. If the proposed project will serve a unique space, an estimate for $EFLH_{cool}$ should be made and justification should be provided in the project documentation. If the space is similar to one of the building types listed

in Table 1, the hours from that table can be used. If no estimate can be made and no building types in Table 1 match the proposed space, the Miscellaneous value from Table 1 should be used. (Ref. 3)

SEER_EE = Energy efficiency ratio of the existing equipment, provided by the customer. If unknown, use SEER = EER/0.875 (Ref. 4) Assume SEER = 10.9 if unavailable. (Ref. 5)

SF = Deemed savings factor based upon zone. See Table 2. (Ref. 6)

SM = Deemed System Multiplier. SM = 1 for Constant Air Volume (CAV) Systems and SM = 1.4 for Variable Air Volume (VAV) systems. (Ref. 7)

Example:

Install an economizer by retrofitting a packaged rooftop installed in a utility-owned low-rise office building, 20 ton cooling capacity, SEER 14.4, VAV system, Climate Zone 1.

Unit KWh Savings per Year = 20 * (12 / 14.4) * 257 * 0.24 *1.4 = 1,439 KWh

Deemed Input Tables

Table 1. Equivalent Full Load Hours of cooling ($EFLH_{Cool}$) per zone in Minnesota by building type (Ref. 3)

Building Type	Zone 1	Zone 2	Zone 3
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Table 2. Deemed Savings Factor for Zone and incremental costs

Equipment	Savings Factor (Ref. 6)			Incremental Cost** (Ref. 2)
	Zone 1	Zone 2	Zone 3	
Units* less than or equal to 10 tons	0.240	0.130	0.100	$1,500
Units* 11-20 tons	0.240	0.130	0.100	$1,900
Units* 21-30 tons	0.240	0.130	0.100	$2,100
Units* 31-60 tons	0.240	0.130	0.100	$2,500
Units* 61-100 tons	0.240	0.130	0.100	$4,000

* Units include packaged and built up air-handler units.

** An additional $1000 should be included when retro-fitting existing units.

Methodology and Assumptions

$EFLH_{Cool}$ were determined from based prototypes building models on the California DEER study prototypes modified Illinois field data and scaled with Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Assumed ventilation rates complied with the requirements of ASHRAE standard 62.1 - 2004.

Methodology assumes 30% savings for VAV over CV systems. Savings were derived through energy modeling using fixed dry bulb control with a high temperature limit of 65˚F.

Incremental costs include controls and programming and assume similar cost between dx and water cooled equipment.

Savings assume economizer is given preference over demand control ventilation strategy.

Notes

Current code requires incorporation of economizer on all cooling systems 2.75 tons and greater for all three Minnesota weather zones with exceptions (Ref 8):

1. Where more than 25 percent of the air designed to be supplied by the system is to spaces that are designed to be humidified above 35°F (1.7 °C) dew-point temperature to satisfy process needs.
2. Systems expected to operate less than 20 hours per week.
3. Where the use of *outdoor air* for cooling will affect supermarket open refrigerated casework systems.

References

1. "Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures", by GDS Associates, Inc. June 2007, pg. 6
2. "Economizers for Packaged Air Systems", Energy Efficiency Office, Department of Natural Resources, Canada
3. Calculated through energy modeling by FES 2012
4. "ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment"
5. "Small Commercial HVAC, Surveying the Frontier of Energy Efficiency", by Lee DeBallie, PE – Energy Center of Wisconsin
6. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012
7. Calculated from the inverse of 0.7. Typical energy consumption of VAV systems are 70% of CV systems. Multiplier verified through energy modeling by FES 2012 and modeling results verified by "Energy Cost and IAQ Performance of Ventilation Systems and Controls - Project Report#2: Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies", pg. 7, by Indoor Environmental Division, EPA, January 2000

8. 2015 Minnesota Energy Code, Section C403.3.1 Economizers.

Revision History

Version	Description	Author	Date
1.0	New EUI measure based on existing C/I measure	GDS Associates	11/21/2016
2.0	Added option for economizer repair	Mark Garofano	11/2018

Electric Utility Infrastructure - HVAC - Unitary and Split Systems

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	HVAC
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Replace Working, New Construction
Required from Customer/Contractor	New equipment type, new equipment nominal cooling capacity in tons, new equipment EER/SEER, building type (refer to Table 1), project location (county)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	20 years (Ref. 1)
Unit Participant Incremental Cost	See Table 2

Measure Description

This measure includes installation of electric DX packaged, split, and condensing units; and PTACs in replacement and new construction applications. This measure analyzes the cooling savings potential of the installation of higher efficiency air-conditioning equipment. This measure is applicable to DX cooling only, DX cooling and electric heat, and DX cooling and gas heat units. The incremental cost is associated with base equipment cost and does not include any installation costs. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithms

Unit kWh Savings per Year = Size x (12/SEER_base - 12/SEER_EE) x (EFLH_cool) (for packaged, split units less than or equal to 5.4 tons, and PTAC units)

Unit kWh Savings per Year = Size x (12/IEER_base - 12/IEER_EE) x (EFLH_cool) (for packages and split units greater than 5.4 tons)

Unit Peak kW Savings = Size x (12/EER_base - 12/EER_EE) x CF

Where:

Size = Nominal cooling capacity in tons of the new equipment (1 ton = 12,000 btu/h)

SEER_base = Seasonal energy efficiency ratio of the baseline equipment, based on federal manufacturing requirements. See Table 2 for DX Packaged, Split and Condensing Units; for PTAC units, SEER_base = EER_base/0.875.

SEER_EE = Seasonal energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor. If unknown, use SEER = EER / 0.875 (Ref. 2)

IEER_base = Integrated energy efficiency ratio of the baseline equipment, based on federal manufacturing requirements. See Table 2 for DX Packaged, Split and Condensing Units.

IEER_EE = Integrated energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor.

EFLH_cool = the equivalent full load hours of HVAC equipment operation. If the proposed project will serve a unique space, an estimate for $EFLH_{cool}$ should be made and justification should be provided in the project documentation. If the space is similar to one of the building types listed in Table 1, the hours from that table can be used. If no estimate can be made and no building types in Table 1 match the proposed space, the Miscellaneous value from Table 1 should be used.

EER_base = Energy efficiency ratio of the baseline equipment, based on federal manufacturing requirements. See Table 2 for DX packaged, split, and condensing units; see Table 3 for PTAC units.

EER_EE = Energy efficiency ratio of the high efficiency equipment, provided by the customer/contractor. If unknown, use EER = .875 x SEER (Ref. 2)

CF = Deemed coincidence factor, equal to 0.9 (Ref. 3)

Example:

Retrofit packaged rooftop installed in a generation facility with estimated 865 effective full load run hours, 7.5 ton cooling capacity, IEER 12.5, EER 12, Climate Zone 3.

Unit kWh Savings per Year = 7.5 * (12 / 11.2 - 12 /12.5) * 865 = 723 KWh

Unit Peak kW Savings per Year = 7.5 * (12 /11 - 12 /12) * 0.9 = 0.614 KW

Deemed Input Tables

Table 1. Equivalent Full Load Hours of cooling per zone in Minnesota by building type (Ref. 4)

Building Type	Zone 1	Zone 2	Zone 3
Office-Low Rise	257	359	446
Office-Mid Rise	373	529	651
Office-High Rise	669	1061	1263
Warehouse	164	343	409
Other/Miscellaneous	443	612	729

Table 2. Deemed baseline efficiency and incremental costs for DX Packaged, Split, and Condensing Units (Ref. 5, 6, 7)

Equipment	SEER_base or IEER_base*	EER_base*	Incremental Cost
DX Condensing Units > 11.3 tons	14.0	10.5	$100/ton
DX Packaged and Split Units <= 5.4 tons	13.0	11.4	$165/ton
DX Packaged and Split Units 5.5-11.3 Tons	11.2	11.0	$150/ton
DX Packaged and Split Units 11.4-19.9 Tons	11.0	10.8	$140/ton
DX Packaged and Split Units 20-63.3 Tons	9.9	9.8	$125/ton
DX Packaged and Split Units > 63.3 tons	9.6	9.5	$110/ton

*Efficiency values take from ASHRAE 90.1-2010 Table C403.2.3(1) for units with gas heating, for units with no heating or electric resistance heating add 0.2 to the above values.

Table 3. Deemed baseline efficiency and incremental costs for PTAC Units (Ref. 5, 7)

Equipment	Cooling Capacity (Btu/h)	EER_base	Incremental Cost
PTAC, Standard Size (used for NewConstruction)	< 7,000	11.7	$250/ton
	7,000-15,000	13.8 - (0.300 *Cap/1000)	$250/ton
	> 15,000	9.3	$250/ton
PTAC, Non-Standard Size (used forReplacements* only)	< 7,000	9.4	$250/ton
	7,000-15,000	10.9 - (0.213 *Cap/1000)	$250/ton
	> 15,000	7.7	$250/ton

*Replacement unit shall be factory labeled as follows "MANUFACTURED FOR REPLACEMENT APPLICATIONS ONLY; NOT TO BE INSTALLED IN NEW CONSTRUCTION PROJECTS", Replacement efficiencies apply only to units with existing sleeves less than 16 inches (406mm) in height and less than 42 inches (1067 mm) in width.

Methodology and Assumptions

EFLH_Cool data based on DOE2/Equest building simulation. The prototypes building models are based on the California DEER study prototypes, and modified for local construction practices and code. Simulations were run using TMY3 weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3).

Assumed ventilation rates complied with the requirements of ASHRAE standard 62.1 - 2004.

References

1. ASHRAE Owning and Operating Equipment Data Base - Equipment Life/Maintenance Cost Survey
2. ANSI/AHRI 210/240-2008: 2008 Standard for Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment
3. 0.9 is a typical value used for central HVAC equipment in many programs, the range is 0.74 to 1.0 with most being very close to 0.9, primary data has not been identified.

4. Calculated through energy modeling of California DEER study prototypes modified by Illinois field data with TMY3 Minnesota weather data for the following cities in Minnesota: Duluth (Zone 1), St. Cloud (Zone 2), and Minneapolis-St. Paul (Zone3) by FES 2012
5. Title 10, Code of Federal Regulations, Part 431 - Energy Efficiency Program for Certain Commercial and Industrial Equipment, Subpart F - Commercial Air Conditioners and Heat Pumps. January 1, 2010.
6. Xcel MN Workpapers 2010
7. Based on a review of TRM incremental cost assumptions from Vermont, Wisconsin, and California. This assumes that baseline shift from IECC 2006 to IECC 2009 carries the same incremental costs.
8. C/I HVAC – Unitary and Split Systems Measure. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs Version 2.0. Effective: January 1, 2017 – December 31, 2019.

Revision History

Version	Description	Author	Date
1.0	New EUI measure based on existing C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - HVAC - Variable Speed Drives

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	HVAC
Applicable To	Electric Utility Infrastructure for space heating and cooling applications
Actions	Modify, Replace Working (Retrofit), New Construction (limited sizes, see Notes)
Required from Customer/Contractor	Horsepower, application type, motor efficiency, annual operating hours
Version No.	2.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	See Table 1 (Ref.2)

Measure Description

This measure applies to variable speed drives installed on HVAC systems including;

- HVAC Fans - supply fans, return fans, and cooling tower fans
- HVAC Pumps - hot water heating and chilled water cooling pumps

The VSD will vary the speed of the motor in a HVAC application with a diversified load.

In the applicable HVAC applications, the power of the motor is approximately proportional to the cube of the speed, providing significant energy savings.

Measure Cost

Actual costs should be used, if known. For smaller motors (< 20 HP), default project costs are given in the following table (Ref. 2). VSDs installed on larger motors must use actual costs.

Table 5. Incremental Cost by Motor Horsepower (Ref. 2)

HP	Cost
1 - 5 HP	$ 1,330
7.5 HP	$ 1,622
10 HP	$ 1,898
15 HP	$ 2,518
20 HP	$ 3,059

Algorithms

Annual kWh Savings = (0.746 x HP x LF / Eff x Hours x ESF

Where:

0.746 = Conversion from HP to kW

HP = Rated Motor horsepower. Actual value.

LF = Motor load factor at the pump or fan design flow rate. Use actual value if known. If unknown, use default value of 65% (Ref. 3).

Eff = Efficiency of motor. Use actual value if known. If unknown, use default NEMA premium efficiency rating by size and type of motor found in Table 4 (Ref. 4).

Hours = Annual operating hours. Actual run hours must be used; justification for run hours assumption must be included in project documentation.

ESF =

Energy Savings Factor. ESF is the sum product of DutyCycle and PLR_{BASE} across all flow rates, minus the sum product of DutyCycle and PLR_{EFF} across all flow rates. See Table 5 below for example ESF values.

$$= \sum_{0\%}^{100\%} (\text{DutyCycle} \times \text{PLR}_{\text{BASE}}) - \sum_{0\%}^{100\%} (\text{DutyCycle} \times \text{PLR}_{\text{EFF}})$$

DutyCycle = Percent of motor runtime at each flow rate. At generation facilities, it is expected that a duty cycle will be known with a reasonable degree of accuracy. Duty Cycle should be in the form of Table 2 below. See Table 3 for an example Duty Cycle.

Table 2. Duty Cycle Format

Flow Rate (Percent of design flow)	Duty Cycle (Percent of motor runtime at each flow rate)
0% to 10%	
10% to 20%	
20% to 30%	
30% to 40%	
40% to 50%	
50% to 60%	
60% to 70%	
70% to 80%	
80% to 90%	
90% to 100%	

PLR_{BASE} = Part Load Ratio for the baseline control strategy. The ratio of percent of peak power draw that occurs at each flow rate percentage. Consult Table 6 to find PLR_{BASE} values depending on the existing control strategy.

PLR_{EFF} = Part Load Ratio for the VSD. The ratio of percent of peak power draw that occurs at each flow rate percentage. Consult Table 6 to find PLR_{EFF} values. They should either be the Pump VSD or Fan VSD values.

Example:

A 100 HP boiler feedwater pump currently using a throttling valve is retrofitted with a VSD. The pump runs for 3,000 hours per year, the motor load factor is 90% and the motor efficiency is 95%. The motor duty cycle is found in Table 3 below.

ESF is calculated using example the duty cycle in Table 3, PLR_{BASE} (from Table 6 – pump throttling valve values), and PLR_{EFF} (from Table 6 – pump VSD values).

Table 3. Example ESF Calculation (Ref. 6)

Flow Rate (Percent of design flow)	Example Duty Cycle (Percent of motor runtime at each flow rate)	PLR_{BASE} (Throttling Valve)	PLR_{EFF} (VSD)
10% to 20%	6%	0.67	0.06
20% to 30%	11%	0.73	0.09
30% to 40%	13%	0.78	0.12
40% to 50%	17%	0.82	0.18
50% to 60%	24%	0.87	0.27
60% to 70%	17%	0.90	0.39
70% to 80%	9%	0.94	0.55
80% to 90%	2%	0.97	0.75
90% to 100%	1%	1.00	1.00

ESF = [(0.06 x 0.67) + (0.11 x .73) +(0.13 x 0.78) + (0.17 x 0.82) + (0.24 x 0.87) + (0.17 x 0.90) + (0.09 x 0.94) + (0.02 x 0.97) + (.01 x 1.0)] – [(0.06 x 0.06) + (0.11 x 0.09) + (0.13 x 0.12) + (0.17 x 0.18) + (0.24 x 0.27) + (0.17 x 0.39) + (0.09 x 0.55) + (0.02 x 0.75) + (0.01 x 1)] = 0.8371 – 0.2653 = 0.5718

Unit kWh Savings per Year = (0.746 x 100 x 0.90 / 0.95) x 3,000 x 0.5718 = 121,234 kWh

Deemed Input Tables

Table 4. Default NEMA Premium Motor Efficiencies (Ref. 4)

Size HP	Open Drip Proof (ODP)			Totally Enclosed Fan-Cooled (TEFC)		
	# of Poles			# of Poles		
	6	4	2	6	4	2
	Speed (RPM)			Speed (RPM)		
	1200	1800 Default	3600	1200	1800	3600
1	0.825	0.855	0.770	0.825	0.855	0.770
1.5	0.865	0.865	0.840	0.875	0.865	0.840
2	0.875	0.865	0.855	0.885	0.865	0.855
3	0.885	0.895	0.855	0.895	0.895	0.865
5	0.895	0.895	0.865	0.895	0.895	0.885
7.5	0.902	0.910	0.885	0.910	0.917	0.895
10	0.917	0.917	0.895	0.910	0.917	0.902
15	0.917	0.930	0.902	0.917	0.924	0.910
20	0.924	0.930	0.910	0.917	0.930	0.910
25	0.930	0.936	0.917	0.930	0.936	0.917
30	0.936	0.941	0.917	0.930	0.936	0.917
40	0.941	0.941	0.924	0.941	0.941	0.924
50	0.941	0.945	0.930	0.941	0.945	0.930
60	0.945	0.950	0.936	0.945	0.950	0.936
75	0.945	0.950	0.936	0.945	0.954	0.936
100	0.950	0.954	0.936	0.950	0.954	0.941
125	0.950	0.954	0.941	0.950	0.954	0.950
150	0.954	0.958	0.941	0.958	0.958	0.950
200	0.954	0.958	0.950	0.958	0.962	0.954
250	0.954	0.958	0.950	0.958	0.962	0.958
300	0.954	0.958	0.954	0.958	0.962	0.958
350	0.954	0.958	0.954	0.958	0.962	0.958
400	0.958	0.958	0.958	0.958	0.962	0.958
450	0.962	0.962	0.958	0.958	0.962	0.958
500	0.962	0.962	0.958	0.958	0.962	0.958

Table 5. HVAC Fan Run Hours for Various Building Types (Ref. 7, see Notes)

Building Type	Total HVAC Fan Run Hours	Heating Pump Run Hours	Cooling Pump and Cooling Tower Fan Run Hours
Large Office	6,704	5,346	2,456
Medium Office	6,534	3,537	2,337
Small Office	6,198	3,858	2,516
Warehouse	6,434	5,305	564

Table 6. Suggested Duty Cycle for HVAC Fans and Pumps (Ref. 8)

Flow Fraction (Percent of design flow)	Percent of Time at Flow Fraction
0% to 10%	0.0%
10% to 20%	1.0%
20% to 30%	5.5%
30% to 40%	15.5%
40% to 50%	22.0%
50% to 60%	25.0%
60% to 70%	19.0%
70% to 80%	8.5%
80% to 90%	3.0%
90% to 100%	0.5%

Table 7. Part Load Ratio for Flow rate bins Based on Control Types for Pumps (Ref. 5) and Fans (Ref. 6)

Control Type	Flow rate (percentage of design flow)								
	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Pump Baseline values ($PLR_{Baseline}$)									
No Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bypass Valve	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Throttling Valve	0.67	0.73	0.77	0.82	0.87	0.90	0.94	0.97	1.00
Pump VSD value (PLR_{EFF})									
VSD – pump	0.06	0.09	0.12	0.18	0.27	0.39	0.55	0.75	1.0

Control Type	Flow rate (percentage of design flow)								
	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Fan Baseline values ($PLR_{Baseline}$)									
No Control or Bypass Damper	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Discharge Dampers	0.55	0.63	0.7	0.77	0.83	0.88	0.93	0.97	1.00
Outlet Damper, Backward Inclined & Airfoil Fans	0.53	0.57	0.64	0.72	0.80	0.89	0.96	1.02	1.05
Inlet Damper Box	0.60	0.62	0.64	0.66	0.69	0.74	0.81	0.92	1.07
Inlet Guide Vane, Backward Inclined & Airfoil Fans	0.56	0.57	0.59	0.60	0.62	0.67	0.74	0.85	1.00
Inlet Vane Dampers	0.40	0.42	0.44	0.48	0.53	0.60	0.70	0.83	0.99
Outlet Damper, Forward Curved Fans	0.26	0.30	0.37	0.45	0.54	0.65	0.77	0.91	1.06
Eddy Current Drives	0.20	0.25	0.32	0.41	0.51	0.63	0.76	0.90	1.04
Inlet Guide Vane, Forward Curved Fans	0.22	0.23	0.26	0.31	0.39	0.49	0.63	0.81	1.04
Fan VSD value (PLR_{EFF})									
Fan - VSD	0.10	0.11	0.15	0.20	0.29	0.41	0.57	0.76	1.01

Notes

Hours of use for equipment come from the U.S. Department of Energy's Commercial Reference Buildings (Ref. 7). These standardized building models have typical HVAC systems, and were simulated with Minneapolis weather. This produced energy usage and run times for various HVAC equipment including fans and pumps. The run times are used for hours of use values. HVAC fans existed as discrete equipment for every building type. Pump heating hours were derived by summing the hours that both pumps and gas heat were in use. Pump cooling hours were derived by summing the hours that both pumps and electric cooling were in use. HVAC cooling tower fans are assumed to have the same hours of use as cooling pumps. The stand-alone retail, strip mall, and warehouse reference buildings did not have pumps in their HVAC sytems. Their heating and cooling pumps are assumed to operate whenever their gas heat and electric cooling, repectively, are operating.

Speed or capacity control is required by the 2015 Minnesota energy code by size and application; for VAV fan units greater than or equal to 7.5 Hp without variable pitch fan blades, non-multi-stage hydronic pumping systems with a design output greater than 300,000 Btu/h, heat rejection fans greater than or equal to 7.5 HP.

It is generally accepted that VSDs provide this capacity control for these sizes, and should be considered the baseline for New Construction

Operation below 30% of design speed is not recommended.

References

1. 2008 Database for Energy-Efficiency Resources (DEER), Version 2008.2.05, "Effective/Remaining Useful Life Values", California Public Utilities Commission, December 16, 2008
2. Ohio TRM 8/6/2010 varies by motor/fan size based on equipment costs from Granger 2008 Catalog pp 286-289, average across available voltages and models. Labor costs from RS Means Data 2008 Ohio average cost adjustment applied.
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Revision History

Version	Description	Author	Date
1.0	New EUI measure based on existing C/I measure	GDS Associates	11/21/2016
2.0	Updated calculation approach and default values, requiring custom hours of use	Mark Garofano	11/2018

Compressed Air

Electric Utility Infrastructure - Compressed Air – Compressed Air Leak Detection

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Industrial Process
Applicable To	Electric Utility Infrastructure
Actions	Operation and Maintenance
Required from Customer/Contractor	Number of Leaks Repaired, Leak size (CFM), Air Compressor Type, Air Compressor Control Strategy, and Annual operating hours of compressor The customer must also maintain a 2 or 3 tag leak detection, repair, and monitoring system to receive incentives. Incentives can only be paid after the detected leaks have been repaired, and tested to ensure the repairs were actually performed.
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	1 (Ref. 1)
Unit Participant Incremental Cost	$8 per horsepower (Ref. 2)

Measure Description

This measure shows the energy savings potential associated with reducing compressed air losses through ultrasonic leak detection, and the repair of compressed air leaks. Compressed air leaks can be responsible for as much as 20-30% of the total air compressor output in a facility. This measure is applicable for compressed air systems in utility-owned sites (such as generation facilities) where they are used for blow off, pneumatic tools, and or a variety of other processes.

The incremental cost is associated with base equipment cost and does not include any installation costs.

This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithms

Unit kWh Savings per Year = N_leaks * CFM_leaks * C_aircomp * t * Control_factor

Unit Peak kW Savings = (unit kWh Savings per Year * CF)/t

Where:

N_leaks = Number of leaks repaired

CFM_leaks = CFM loss per leak (review table 1)

C_aircomp = See Table 2. If unknown compressor type, use 0.19 kW/CFM (Ref. 3)

Control_factor = See Table 3. If unknown control type, use 0.3 %kW/%load (Ref. 4)

t = Hours of operation per year. If unknown, use default of 6136 (Ref. 5)

CF = Coincidence Factor (0.845) (Ref. 6)

Example:

An ultrasonic leak detection service is performed at the facility, and identifies 10 small leaks, of 1/64th inch diameter. Assumptions:

- Facility Operates at 100 PSIG
- Facility Operates 3 Shifts (6240 hours per year)
- Single-acting Reciprocating Air Compressor
- Inlet Valve Modulated Compressor Controls

Using the cfm value from Table 1 for a very small leak

Unit KWh Savings per Year = 10*0.41*.23*6,240*.31 = 1,824 kWh/year

Unit Peak KW Savings per Year = (1,824 * 0.845)/6,240 = 0.247 KW

Deemed Input Tables

Table 1. CFM per Leak Size for Compressed Air Leaks (Ref. 7)

Pressure (psig)	Orifice Diameter (inches)					
	1/64	1/32	1/16	1/8	1/4	3/8
70	0.3	1.2	4.8	19.2	76.7	173
80	0.33	1.3	5.4	21.4	85.7	193
90	0.37	1.5	5.9	23.8	94.8	213
100	0.41	1.6	6.5	26	104	234
125	0.49	2	7.9	31.6	126	284

*Leak Loss Recorded in [CFM]

Table 2. kW/CFM efficiencies for several compressor types (Ref. 3)

Type	Efficiency
Single-acting Reciprocating Air Compressor	0.23 kW/CFM
Double-acting Reciprocating Air Compressor	0.155 kW/CFM
Lubricant-injected Rotary Screw Compressor	0.185 kW/CFM
Lubricant-free Rotary Screw Compressor	0.2 kW/CFM
Centrifugal Compressor	0.18 kW/CFM
AVERAGE:	**0.19 kW/CFM**

*Data from Compressed Air Challenge "Fundamentals of Compressed Air Systems" Pg 28-32

Table 3. Efficiency Factors per control type for air compressors (Ref. 4)

Control Type	%kW/%load
Inlet Valve Modulated	0.31
Variable Displacement	0.69
Variable Speed Drive	0.85

*Data extrapolated from Compressed Air Challenge "Fundamentals of Compressed Air Systems" Pg 90-91

Methodology and Assumptions

Assumptions were made based on average data for several different types of air compressors from Fundamentals of Compressed Air. Averages were assumed for compressor type to make calculations simpler.

Notes

Savings are based on a load-unload control style compressor. Load-unload style compressors will have much less savings than their VSD or Variable Displacement counterparts. There are limited studies available on the market saturation of VSD air compressors, and therefore estimates based on the load-unload model are more conservative, and more likely.

References

1. 1 year measure life is based on typical recommendation of annual leak survey.
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8. Industrial Compressed Air – Compressed Air Leak Detection Measure. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs Version 2.0. Effective: January 1, 2017 – December 31, 2019.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Compressed Air - No Loss Drains

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Industrial Process
Applicable To	Electric Utility Infrastructure
Actions	Replace Working, Replace on Fail
Required from Customer/Contractor	CAGI Data Sheet for Air Compressor, Annual Hours of Operation
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	13 (Ref. 5)
Unit Participant Incremental Cost	$450/drain (Ref. 4)

Measure Description

This measure includes replacement of a failed or working open tube, timed, or manual condensate drain in a compressed air system with a qualified electronic, pneumatic, or hybrid "no loss drain" that is designed to automatically adjust with system demand and completely eliminate condensate with zero compressed air loss. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithms

Unit kWh Savings per Year = kW_100_CFM*Hours*Drain_CFM/100

Unit Peak kW Savings = kW_100_CFM*Drain_CFM*CF/100

Where:

kW_100_CFM = Compressor efficiency, kW/100 CFM as listed on Compressed Air and Gas Institute (CAGI) datasheet. 20 kW/100 CFM is default value

Hours = Annual hours of operation. Use actual if known, If unknown, use 6136 hr default value. (Ref. 2)

Drain_CFM = Average CFM of existing drain, 3 CFM (Ref. 3)

CF = Coincidence Factor = 0.80

Example:

Install a no loss drain on a 40hp compressed air system, with a CAGI efficiency of 16 kW/100CFM and running 2,000 hr/yr

Unit kWh Savings per Year = 16 x 3 x 2000 / 10 = 960

Unit kW Savings per Year = 16 x 3 x 0.8 / 100 = 0.39

Notes

The default value of 20 kW/100 cfm is from a market survey of 5 yr old model air compressor systems. Kaeser, Sullair, Ingersoll Rand

The average drain loss (cfm) assumes a timed drain system operating approximately 5% of the time. Average size is 1/4" orifice.

Focus on Energy (WI) and New York Standard Approach uses a CF = 0.80.

Consider updating default hours in future update.

References

1. US Department of Energy. Improving Compressed Air System Performance - A Sourcebook for Industry. November 2003.
2. US DOE, Evaluation of the Compressed Air Challenge® Training Program, Page 19.
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5. Measure Life Study. Energy & Resource Solutions. Prepared for the Massachusetts Joint Utilities; Table 1-1. 2005.
6. Industrial Compressed Air – No-Loss Drains Measure. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs Version 2.0. Effective: January 1, 2017 – December 31, 2019.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Electric Utility Infrastructure - Compressed Air - Variable Speed Drive Air Compressors < 50hp

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Industrial Process
Applicable To	Electric Utility Infrastructure
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	CAGI Data sheet (new), CAGI Data sheet (existing) or nameplate data, Compressed air system operating hours Optional inputs: Annual facility hours where compressed air is required
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	15 (Ref. 1)
Unit Participant Incremental Cost	$428/hp (Replace Working) or $100/hp (Replace on Fail or New Construction)

Measure Description

This measure includes replacement of an inlet modulated, variable displacement, or load/no load controlled air compressor units < 50hp with variable speed drive (VSD) controlled units. Base load units do not qualify. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithms

Unit kWh Savings per Year = hp * SF * C * Hours

Unit Peak kW Savings = hp * SF * C * CF

Where:

hp	=	nominal horsepower of VSD air compressor motor
SF	=	Savings Factor: reference Table 1
Hours	=	annual facility hours where compressed air is required. Use actual if known. If unknown, use default 4024 (Ref. 2)
C	=	conversion constant = 0.746 kW/hp
CF	=	coincidence factor, Default = 0.95

Example:

Replace an inlet modulated 25hp air compressor with a 25 hp VSD air compressor.

Unit kWh Savings per Year = 25 * 18% * 0.746 * 4024 = 13,509 kWh

Unit kW Savings per Year = 25 * 18% * 0.746 * 0.95 = 3.2 kW

Deemed Input Tables

Table 1. Savings factor for VSD replacing existing control strategy (Ref. 3)

	Existing Control		
	Inlet Modulating	Load/No Load	Variable Displacement
% Savings Factor	18%	15%	6%

Notes

$428/hp from surveyed cost from MI and Ohio implemented projects. Full install cost for "replace working"

$100/hp is the incremental cost for replace upon fail or new construction

Focus on Energy (WI) and New York Standard Approach uses a CF = 0.80. The Illinois TRM lists CF = 0.95 and Vectren lists it at 1.0.

Savings factor assumes 75% loaded and the savings factor was interpolated from the part load curves of reference 3 (pages 43-45)

References

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Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Misc

Electric Utility Infrastructure – Conservation Voltage Reduction

Measure Detail	Measure Value
Target Market Segments	Infrastructure
Target End Uses	Distribution
Applicable To	Electric Utility Infrastructure - Retrofit existing distribution equipment or add to new construction design plans
Actions	Retrofit, New Construction
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	See Measure Life section
Unit Participant Incremental Cost	See Measure Cost section

Measure Description

This measure defines a protocol for determining energy savings from installing an automatic Conservation Voltage Regulation (CVR) system, also called Automated Voltage Feedback Control system or Voltage Optimization system.

For the purposes of this TRM, CVR is defined as controlling distribution substation source voltage and/or feeder line voltage(s) so that end-use loads consume less energy. The system uses source voltage regulators or transformer load tap changers (LTCs) to automatically adjust voltages based on remote End-Of-Line (EOL) voltage sensing. All voltages affected by the CVR system, including source voltage, line voltages, and all affected EOL voltages are collectively referred to as the Voltage Control Zone (VCZ).

CVR systems can use existing or concurrently deployed AMI technology to gather EOL voltage measurements by polling meters or monitoring meter voltage alarms. CVR systems can also be implemented with dedicated EOL voltage sensors. For all types of installations, when the EOL voltage rises or falls outside designed setpoints, the CVR system continuously adjusts source voltage to bring EOL voltage back within setpoints. The system should measure and log source voltage, collected EOL voltage(s), delivered real power, and delivered reactive power. The system should also record hourly local temperature either by direct measurement or by accessing the nearest NOAA weather station feed. Fixed voltage reduction and line drop compensation (source voltage adjusted based on feeder load level) projects are not eligible to use this measure.

The savings calculation for this measure is divided into two methods: estimated savings and measured savings. Studies show there is some variance in savings achieved by CVR projects and predictive tools are not yet highly accurate. Therefore, the estimated savings methodology intentionally results in a conservative savings value. Measured savings are more accurate and likely to be greater, but require

one year of system performance data to calculate. Users may choose to combine the methods to claim estimated savings immediately upon project completion and the remainder of measured savings the following year. In all cases, project parameters (including CVR system characteristics, cost, and expected measure lifetime) must be justified by accompanying project documentation.

This measure should only be used for calculating savings from installing CVR and not as an engineering design tool. When installing CVR, ensure all appropriate codes and standards are followed. Of particular importance, feeders with CVR installed must still deliver EOL voltage within the range required by ANSI C84.1.

Measure Life

Savings from CVR can persist indefinitely as long as the system is properly maintained and regularly recalibrated. A maximum measure life of 15 years can be used if project supporting documentation includes a plan to ensure persistence of energy savings. (Ref. 1) (Ref. 2) For an example, see Appendix E. Without such a plan the measure life is assumed to be 3 years.

Measure Cost

Actual project costs should be used. Invoices showing the full materials, software communication infrastructure, and labor costs to design and install an automatic CVR system should be included with project documentation. If measured savings are claimed, labor costs to conduct required system performance measurements and modeling in the first year of operation are also included in the project cost. The cost of AMI deployment does not count toward the cost of implementing CVR unless it is used solely for CVR purposes.

Definition of Baseline Conditions

The baseline condition for this measure is a distribution substation and feeder(s) with no Conservation Voltage Reduction control system installed. Project documentation should include existing baseline voltage setpoint and bandwidth values for the affected substation and feeder(s).

Definition of Post-Install Conditions

The post-install condition for this measure is a distribution substation with an automatic Conservation Voltage Reduction control system installed on at least one feeder. The system must be able to engage and disengage remotely. It must automatically, continuously regulate source and/or line voltages in response to EOL voltage measurements.

For the purpose of calculating savings, the system must measure and record the period averages for the following at least hourly: source voltage on all phases, EOL voltages used for CVR feedback, system kW, system kVAR, and local temperature. For each period, the system must also record whether the CVR system is engaged or disengaged. Each of these data points should include date and time of measurement.

Savings Overview

Savings for this measure can be calculated using two different methods. The first is estimated savings based on historical energy data from the VCZ, a load flow software simulation, and provided inputs based on studies of CVR performance. Estimated savings can be claimed upon project completion. The estimated savings methodology intentionally results in a conservative savings value. This is done to allow flexibility in system design and to account for variability in system performance, while preserving a relatively simple calculation methodology.

The second method is based on measured system performance. Measured savings can be claimed after one year of monitoring system operation. Calculating measured savings requires monitoring the VCZ with CVR engaged and with CVR disengaged to build a statistical analysis of the system's performance.

Measure users may choose to use both methods for the same project. Estimated savings can be claimed immediately upon project completion and additional measured savings can be claimed the following year if measured savings are greater than the estimated savings. Because estimated savings are intentionally conservative, measured savings are likely to be greater than estimated savings.

CVR added to the design of a new distribution substation cannot use the estimated savings methodology; those projects must use the measured savings methodology.

Algorithms

Estimated Annual kWh Savings $= PreEnergy \times CVRF \times EstimatedPercentVR \times AdjustmentFactor$

Measured Annual kWh Savings (Ref. 3) $= \left(\sum_{i}^{8760} OffEnergy_i - OnEnergy_i\right) - (ClaimedEstimatedSavings)$

Required supplemental calculated values

$$MeasuredPercentVR_i = \frac{(PreVoltage - OnVoltage_i)}{PreVoltage}$$

$$CVRF_i = \frac{\left[\frac{(OffEnergy_i - OnEnergy_i)}{OffEnergy_i}\right]}{\left[\frac{(PreVoltage - OnVoltage_i)}{PreVoltage}\right]}$$

Where:

PreEnergy = Total energy delivered to the VCZ over the period of one year prior to the Conservation Voltage Reduction system operating (kWh). This can be measured either directly at the substation source or can be the sum of energy consumption over one year at all EOL applications within the VCZ.

EstimatedPercentVR = Average percentage reduction in the controlled source voltage enabled by CVR over the period of one year. Developed from software load flow simulations.

AdjustmentFactor = 50%. Factor used to ensure estimated savings are conservative.

i = is an index that defines an hour of the year for which each value of time-series variables apply.

$OnEnergy_i$ = Total energy delivered in the VCZ during period i with the Conservation Voltage Reduction system operating (kWh). Developed from a statistical model using measurements of the VCZ with the CVR system engaged.

$OffEnergy_i$ = Total energy delivered in the VCZ during period i with the Conservation Voltage Reduction system disengaged (kWh). Developed from a statistical model using measurements of the VCZ with the CVR system disengaged.

$MeasuredPercentVR_i$ = Average percentage reduction in the controlled source voltage for period i enabled by CVR. Developed from a statistical model using measurements of the VCZ with the CVR system engaged.

PreVoltage = Source Voltage setting prior to installing CVR (Volts).

$OnVoltage_i$ = Average source voltage for period i while CVR is engaged (Volts). Developed from a statistical model using measurements of the VCZ with the CVR system engaged.

$CVRF_i$ = Conservation Voltage Reduction Factor for period i is the ratio of % change in energy delivered for every 1% change in average voltage. For estimated savings, a single, weighted average value of CVRF is used for all periods (Table 1 below). For measured savings, CVRF values and the periods (i) they apply to are determined using linear regression analysis. See Savings Methodology below for determining CVRF values.

ClaimedEstimatedSavings = Identical to Estimated Annual kWh Savings if those savings have already been claimed prior to calculating measured savings. If Estimated savings were not claimed for this project, the value is 0.

Savings Methodology

Method One – Estimated Savings

Before implementation, savings for a proposed CVR project are determined using historical energy consumption data for the VCZ, a load flow software simulation to produce an estimated voltage reduction value, and an estimated CVRF value found in Table 1 below. Project supporting documentation should include justification for all values used to calculate savings.

The value for PreEnergy should come from historical load profile data for the proposed VCZ. SCADA data for the substation is likely the best source for this data. If necessary, it can come from customer billing history as long as a full accounting for all energy consumption in the VCZ can be constructed.

To generate a values for EstimatedPercentVR, industry standard distribution modeling software should be used to build a load flow simulation to represent the VCZ. Most likely the model will already be

defined by engineers to design the CVR system. The simulation should be adjusted such that that the minimum EOL voltage in the VCZ is controlled to be just above the lowest possible level allowed by ANSI C84.1 (116V is often used as an EOL voltage target setpoint). The resulting average percentage reduction in source voltage predicted by the simulation over a period of one year is the value for EstimatedPercentVR. For example, if the simulation predicts an average voltage setting of 119V and the original PreVoltage setting is 121V, the value of EstimatedPercentVR is (121-119)/121 = 1.65%.

The actual EstimatedPercentVR value will depend on feeder length, load type, and other VCZ characteristics, so it must be produced for the specific project. However, for reference, a survey of shows that an average voltage reduction of 2.63% (Ref. 4) was achieved by installed CVR systems.

If approximate Air Conditioning and Electric Space Heat load percentages are known for the VCZ, use Table 1 below to determine an estimated CVRF value. If the end-use applications in the VCZ are unknown, use a CVRF value of 0.60 (Ref. 5). Note that for the Estimated Savings Methodology, a single, average CVRF value is used for all periods.

Table 1. CVRF values for Estimated Savings Methodology (Ref. 6)

% Space Heat of Annual Load	% Air Conditioning of Annual Load				
	<20%	20%-40%	40%-60%	60%-80%	>80%
<20%	0.800	0.825	0.850	0.875	0.900
20%-40%	0.675	0.700	0.725	0.750	0.775
40%-60%	0.550	0.575	0.600	0.625	0.650
60%-80%	0.425	0.450	0.475	0.500	0.525
>80%	0.300	0.325	0.350	0.375	0.400

Method Two – Measured Savings

After implementation, energy savings for an CVR project are determined by directly collecting data on the VCZ with CVR installed. Data is collected both with the CVR system operating and with the CVR system disengaged. From the collected data, linear regression analysis is used to construct a model of the VCZ operation for each period (i) of a full year. The model is developed for both an operating CVR system and for a disengaged system. Comparing the two models over a full year results in the final measured savings for the CVR system.

Over the first year of operating the CVR system, there should be twelve separate weeks (one per month) where the system alternates 24-hours engaged followed by 24-hours disengaged (it is assumed that the CVR system is engaged for the other 40 weeks of the year). The purpose is to generate data to characterize the VCZ under all conditions experienced over the year. Of special importance, the goal is to generate enough data to compare periods where all operating conditions are nearly identical except whether CVR is engaged or disengaged.

A multivariable linear regression should be run to define a model that describes VCZ conditions both with and without CVR engaged. One model should be run with $OnVoltage_i$ and $OnEnergy_i$ as the dependent variables using data from periods when the CVR system is engaged. A second model should

be run with $OffEnergy_i$ as the dependent variable using data from periods when the system is disengaged. Both models should use the same set of explanatory variables. The user can choose explanatory variables to best fit the specific CVR system, but will typically include local temperature, time of day, season, weekday/weekend, etc. At least two explanatory variables should be used to ensure the model captures system variability over the course of a year.

Both models should produce a full year of modeled values for the dependent variables. That is, for all periods i, the user has modeled values of $OnVoltage_i$, $OnEnergy_i$, and $OffEnergy_i$. Using these modeled values as inputs to the time series savings algorithm defined above, annual energy savings can be calculated.

Because the models produce values for $OnEnergy_i$ and $OffEnergy_i$ directly, $MeasuredPercentVR_i$ and $CVRF_i$ are not needed to calculate energy savings. However, these values must be calculated according to the algorithms above for all periods i and submitted with the supporting project documentation.

Example:

Estimated Savings:

A proposed CVR system will be installed on a VCZ that delivers 40,000,000 kWh annually. A load flow simulation predicts that source voltage can be reduced by an average of 2.5% over the course of a year and still deliver ANSI-compliant EOL voltage to customers. The air conditioning and electric heat load percentage in the VCZ is unknown.

Annual Estimated kWh savings for the CVR system are: 40,000,000 x 2.5% x 0.60 x 50% = 300,000kWh

Measured Savings:

As a simplified example of a linear regression model applied to one period, consider a system that collects data including time of day, weekday/weekend, temperature, and season. One measured period is 3PM on a summer weekday, the temperature is 75F and the CVR system is engaged. Source voltage is controlled by the CVR system to be 118V and the measured energy consumed in the VCZ is 10,000kWh.

A second period occurs at 3PM on a summer weekday, the temperature is 75F and the CVR system is disengaged. Source voltage is set at the pre-CVR install level of 121V and measured energy consumed in the VCZ is 10,200kWh.

The values of explanatory variables are identical in the two periods (weekday/weekend, season, time of day, and temperature) and define period i in the statistical models.

For this period i:

kWh savings are $OffEnergy_i$ – $OnEnergy_i$ = 10,200-10,000 = 200kWh.

$MeasuredPercentVR_i$ = (121-118)/121 = 2.48%

$CVRF_i$ = [($OffEnergy_i$-$OnEnergy_i$)/OffEnergyi]/$MeasuredPercentVR_i$
= [(10,200-10,000)/10,200]/2.48% = 0.79

This is an overly simplified example for only one period of the year. An actual multivariable linear regression model will produce statistical correlations between explanatory variables dependent variables over the set of data collected for one year.

For a specific example of modeling savings using Heating and Cooling Degree Days as explanatory variables, see the Regional Technical Forum M+V Protocol #1, Sections 9.1.3.1 – 9.1.3.2 (Ref. 6).

Notes

Potential users of this measure are encouraged to review the references listed below to gain further perspective on CVR functionality and savings potential.(Ref. 4) (Ref. 5) (Ref. 7) (Ref. 8) (Ref. 9) (Ref. 10) In particular, a report produced by the Electric Power Research Institute (EPRI) analyzing CVR tests conducted on substations operated by Sacramento Municipal Utility District (SMUD) outlines examples of actual CVR results, illustrates the range of possible outcomes, and discusses lessons learned from pilot CVR implementation.

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Revision History

Version	Description	Author	Date
1.0	New measure	GDS Associates	12/02/2016

Electric Utility Infrastructure - Efficient Conductors for Transmission and Distribution Lines

Measure Detail	Measure Value
Target Market Segments	Infrastructure
Target End Uses	Transmission, Distribution
Applicable To	Transmission or Distribution Lines owned by the utility
Actions	Replace on Fail, Early Replacement, New Construction
Required from Customer/Contractor	Peak current carried by the conductor (Amperes); Baseline conductor resistance (Ohms/length); Efficient conductor resistance (Ohms/length); Length of the conductor; Loss Factor over the conductor or Load Factor if applicable
Version No.	1.1
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	25 Years. The average expected lifetime of the equipment (per typical utility depreciation schedule) exceeds the CIP planning horizon, thus the measure life is capped at 25 years.
Unit Participant Incremental Cost	See Incremental Cost section

Measure Description

The size and type of conductor used on a transmission or distribution line has a significant effect on the efficiency of the line. Larger conductors and different designs have a lower resistance and thus lower I^2R losses (Ref. 1). Replacing a length of conductor (re-conductoring) with a relatively larger conductor to carry the same load has the effect of reducing the kW loss for that length.

This measure is designed to calculate the energy savings attributable to choosing to install low-loss transmission or distribution line conductors. ROF, NC, and Early Replacement scenarios are all eligible for this measure, but note that each has different baseline assumptions. ROF and NC scenarios are appropriate when a conductor is used which exceeds minimum code for the application. Early Replacement is appropriate in instances where conductors are replaced before the end of their useful lives for the purpose of energy efficiency.

In order to qualify as eligible to claim greater savings using the “Early Replacement” assumptions, the existing line must sufficiently serve an existing load, the load must not be expanding, and the existing line must have been installed less than 25 years prior to the current project. Also, there must be no changes to any other network components that affect the operating conditions of the conductor (for example, changing the voltage of the line or upgrading to higher-temperature-rated terminals). If any of these conditions are not met, use the New Construction assumptions to calculate savings.

Incremental Cost

For Replace on Fail and New Construction projects:

Actual project costs should be used to determine incremental cost. Conductor costs are volatile and heavily dependent on the price of metals, which could quickly render a deemed value inaccurate. To claim savings, the actual cost for the installed, efficient materials should be submitted with project documentation as well as a quote for the baseline materials. Incremental cost for the project is the actual cost of the proposed project materials subtract the quoted price of the baseline materials.

It is assumed that labor costs for the installation are identical for the efficient and baseline cases. Therefore, incremental cost is driven by the difference in materials cost only.

For Early Replacement projects:

Actual project costs should be used. Invoices showing the full materials and labor costs for the project should be included with project documentation.

Algorithms

Single Phase:

Annual kWh Savings = Length x $(I_peak)^2$ x (R_base – R_ee) x Length x LossFactor x 8,760 / 1,000

Peak kW Savings = Length x $(I_peak)^2$ x (R_base – R_ee) / 1,000

Three Phase:

Annual kWh Savings = 3 x Length x $(I_peak)^2$ x (R_base – R_ee) x Length x LossFactor x 8,760 / 1,000

Peak kW Savings = 3 x Length x $(I_peak)^2$ x (R_base – R_ee) / 1,000

Where:

I_peak	=	Peak current (Amperes). Provided by customer/contractor. Use actual measured load data if possible. If no load data is available, use the design peak load multiplied by a correction factor of 0.8. For projects replacing a distribution line with varying current load, instead of calculating savings for each individual length of conductor, an average can be used: average the current at the beginning of the segment and the current at the end of the segment at peak load.
R_base	=	Base Conductor Resistance (Ohms/length). Provided by customer/contractor. This should come from manufacturer specifications or a recognized industry reference such as the Aluminum Electrical Conductor Handbook (excerpt in Table 2 below). When choosing the resistance value, ensure to use the appropriate temperature rating of the conductor depending on design parameters (terminal ratings, etc).

For Replace on Fail and New Construction, R_base should correspond to a conductor that meets minimum standard requirements for the project according to the National Electric Code.

For Early Replacement, use the actual conductor resistance associated with the existing conductor. See the requirements above to ensure the project qualifies to use the Early Replacement assumptions.

R_ee = Efficient Conductor Resistance (Ohms/length). Provided by customer/contractor. Use single phase or three phase values as appropriate. This should come from manufacturer specifications or a recognized industry reference such as the Aluminum Electrical Conductor Handbook (excerpt in Table 1 below).

Length = Length of the line being installed (ensure to use the same units as the resistance rating of the conductor or convert appropriately). Provided by customer/contractor.

3 = Multiplier for each phase of 3 phase power

8,760 = Hours in a year

1,000 = Conversion from kilowatts to watts

LossFactor = Ratio of average losses to peak instantaneous losses over the conductor, provided by customer/contractor. Note that this is not the same as the Load Factor. Actual Loss Factor should be used if known.

For transmission conductors, the Loss Factor should be known or calculated using the method described in the Notes section. For distribution conductors, if the Loss Factor is unknown and not possible to calculate, use the table below to estimate Loss Factor using the Load Factor of the conductor.

Table 1. Load Factor to Loss Factor Conversion Formulas (Ref. 2)

Load Type Served	Load Factor to Loss Factor Conversion Formula	Approximate Expected LossFactor
Rural-Residential	LossFactor = (0.05*LoadFactor) + (0.95*LoadFactor^2)	0.10
Urban-Residential	LossFactor = (0.07*LoadFactor) + (0.93*LoadFactor^2)	0.16
Commercial	LossFactor = (0.25*LoadFactor) + (0.75*LoadFactor^2)	0.09
Industrial	LossFactor = (0.31*LoadFactor) + (0.69*LoadFactor^2)	0.28
Mixed/Unknown	LossFactor = (0.20*LoadFactor) + (0.80*LoadFactor^2)	0.20

LoadFactor = Measured ratio of average load (Amperes) to peak load of the conductor over a period of one year.

Example

A five-mile length of 3-phase bare 2/0 ACSR conductor (code word Quail) is required by code to replace a failed overhead line, but 3/0 ACSR conductor (code word Pigeon) is installed instead. The peak current is 115 amperes, the segment is rated at 25C, and the Loss Factor is 30%.

From the Aluminum Electrical Conductor Handbook:

R_base = 0.683 Ohms/mile (0.1301Ohms/1000ft x 5.28 = 0.683 Ohms/mile)

R_ee = 0.546 Ohms/mile (0.1034Ohms/1000ft x 5.28 = 0.546 Ohms/mile)

Annual KWh Savings = 3 x $(115)^2$ x (0.683 – 0.546) x 5 x 0.30 x 8,760 / 1,000 = 71,422 kWh

Peak kW Savings = 3 x $(115)^2$ x (0.683 – 0.546) x 5 / 1,000 = 27.18 kW

For this example, an invoice for five miles of 3-phase 3/0 ACSR at a cost of $42,000 and a quote for five miles of 2/0 ACSR for $34,000 is included with the project documentation to demonstrate the project's incremental cost of $8,000.

Table 2. Example Reference for Conductor Resistance Characteristics of Aluminum Conductor, Steel Reinforced (ACSR) (Ref. 3)

			Resistance (Ohms per 1000ft)		
AWG	Strands	kCmil	25C	50C	75C
2	6/1	66.36	0.2591	0.3080	0.3360
1	6/1	83.69	0.2059	0.2474	0.2073
1/0	6/1	105.6	0.1633	0.1972	0.2161
2/0	6/1	133.1	0.1301	0.1616	0.1760
3/0	6/1	167.8	0.1034	0.1208	0.1443
4/0	6/1	211.6	0.0822	0.1066	0.1157
	18/1	266.8	0.0657	0.0723	0.0788
	18/1	336.4	0.0523	0.0574	0.0625
	18/1	477.0	0.0369	0.0405	0.0441
	18/1	556.5	.00318	0.0348	0.0379

This table is meant as an example reference for common conductor types and is by no means exhaustive. If a proposed conductor is not found on this table, a manufacturer specification should be included in project documentation.

Notes

This energy savings measure does not consider loss-of-strength, temperature limitations, substation equipment compatibility, reactive power effects, or any other design parameter outside of energy efficiency.

It may be worth considering updating guidance documents for replacing failed lines to recommend installing lower-loss lines as a matter of protocol. It is unlikely that energy efficiency will be considered on a project-by-project basis when replacing failed lines.

If a Loss Factor is not known directly, it can be calculated using a load profile for the affected line. To do this, integrate the square of the instantaneous load over the profile time period and divide by the length of the time period. If a load profile is available, this method will likely generate greater savings than the conservative load factor to loss factor conversion prescribed in the algorithm above.

A direct cost quote for baseline materials is the preferred documentation to show incremental cost for the project, but a cost quote for a substantially similar project generated within a year of the proposed project is also acceptable.

The Loss Factor variable represents the ratio between average losses and peak losses. It can be calculated by using interval data for the applicable conductor and applying the following equation:

$$LossFactor = \sum_{n=1}^{Int} \left(\frac{Load_n^2}{Peak\ Load^2} \right) / Int$$

Where Int is the number of intervals (preferably over one year), $Load_n$ is the average load (Amperes) in interval n, and Peak Load is the highest value of Load for all n intervals. If neither the Loss Factor itself nor the interval data required to calculate the Loss Factor are available, use the table above to estimate Loss Factor using the Load Factor of the conductor.

Reactance and other inductive properties of conductors are not considered for the purposes of this measure – savings are calculated and reported in real power and energy units.

References

1. Booth & Associates, Inc. Distribution System Loss Management Manual. National Rural Electric Cooperative Association. 1991.
2. Guidelines on The Calculation and Use of Loss Factors, Electric Authority, Te Mana Hiko, February 14, 2013 (conversion formulas derived from the source)
3. Excerpt from Aluminum Association, *Aluminum Electrical Conductor Handbook,* 1989.

Revision History

Version	Description	Author	Date
1.0	New measure	GDS Associates	10/31/2016
1.1	Fixed equations, adding Length variable	Cadmus	1/2019

Electric Utility Infrastructure - Efficient Transformer

Measure Detail	Measure Value
Target Market Segments	Infrastructure
Target End Uses	Transmission
Applicable To	Electric Utility Infrastructure
Actions	Replace on Fail, Early Replacement, New Construction
Required from Customer/Contractor	Peak load served by the transformer (kVA) ; Baseline Transformer rated full-load capacity (kVA); Efficient Transformer rated full-load capacity (kVA) ; Baseline Transformer full-load losses from nameplate or manufacturer specification; Baseline Transformer no-load losses from nameplate or manufacturer specification ; Efficient Transformer full-load losses from nameplate or manufacturer specification; Efficient Transformer no-load losses from nameplate or manufacturer specification ; Loss Factor (or Load Factor)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	25 Years. The average expected lifetime of the equipment (per typical utility depreciation schedule3) exceeds the CIP planning horizon, thus the measure life is capped at 25 years.
Unit Participant Incremental Cost	See Incremental Cost section

Measure Description

Electric transformers of any type are never 100% efficient, but in many cases a higher efficiency option can be installed to minimize losses. Loss characteristics of a transformer consist of both load losses and no-load losses. Load losses vary with the load on the transformer and are also known as winding losses because they occur primarily in the transformer's windings. No-load losses occur because of the electrical currents and magnetic fields necessary to magnetize the transformer core and are present at a constant value whenever the transformer is energized regardless of load conditions[1]. This measure analyzes the energy savings potential of the installation of higher efficiency transformers with lower load and no-load losses.

Replace on Fail, New Construction, and Early Replacement scenarios are all eligible for this measure. ROF and NC scenarios are appropriate when a new transformer is installed which exceeds the minimum efficiency transformer code for the application.

Early Replacement is appropriate in instances where efficient transformers are installed to replace existing equipment before the end of its useful life for the purpose of achieving energy efficiency. The existing equipment must be functional, serving the existing load, and must have been installed less than 25 years prior to the current project. If the load served has changed significantly (+/-10%) since the original installation, use the New Construction assumptions. A new transformer rated at a lower kVA

capacity **can** be installed to replace an existing transformer and achieve energy conservation as long as the same load is still being served.

This measure is designed to calculate energy savings only and should not be substituted for distribution or transmission engineering design.

Algorithms

$$\text{Annual kWh Savings (Ref. 1)} = 8{,}760 \times \left(\left[\left(\frac{Load_{peak}}{FLC_{base}}\right)^2 \times FLL_{base} \times LossFactor + NLL_{base}\right] - \left[\left(\frac{Load_{peak}}{FLC_{ee}}\right)^2 \times FLL_{ee} \times LossFactor + NLL_{ee}\right]\right)$$

$$\text{Peak kW Savings} = \left[\left(\frac{Load_{peak}}{FLC_{base}}\right)^2 \times FLL_{base} + NLL_{base}\right] - \left[\left(\frac{Load_{peak}}{FLC_{ee}}\right)^2 \times FLL_{ee} + NLL_{ee}\right]$$

Where:

8,760	=	Average hours in a year
Load_peak	=	Load during peak period (kVA), provided by customer/contractor
FLC_base	=	Base transformer rated full-load capacity (kVA), provided by customer/contractor
FLC_ee	=	Efficient transformer rated full-load capacity (kVA), provided by customer/contractor
FLL_base	=	Full-load losses of base transformer, winding kW loss at rated load (kW), provided by customer/contractor. From transformer nameplate or manufacturer specification.
FLL_ee	=	Full-load losses of efficient transformer, winding kW loss at rated load (kW), provided by customer/contractor. From transformer nameplate or manufacturer specification.
NLL_base	=	No-load losses of base transformer (kW), provided by customer/contractor. From transformer nameplate or manufacturer specification.
NLL_ee	=	No-load losses of efficient transformer (kW), provided by customer/contractor. From transformer nameplate or manufacturer specification.
LossFactor	=	Loss Factor, ratio of average losses to peak losses on the network segment served by the transformer. Provided by customer/contractor. Note that this is not the same as the Load Factor (instantaneous losses are proportional to load squared). Actual Loss Factor should be used if known or calculated using interval load data if possible (see Notes section for method).

For transmission transformers, the Loss Factor should be known or calculated. For distribution transformers, if the Loss Factor is unknown and not possible to calculate, use the table below to estimate Loss Factor using the Load Factor of the network segment served by the transformer.

Table 1. Load Factor to Loss Factor Formulas (Ref. 2)

Load Type Served	Load Factor to Loss Factor Conversion Formula	Approximate Expected LossFactor
Rural-Residential	LossFactor = (0.05*LoadFactor) + (0.95*LoadFactor^2)	0.10
Urban-Residential	LossFactor = (0.07*LoadFactor) + (0.93*LoadFactor^2)	0.16
Commercial	LossFactor = (0.25*LoadFactor) + (0.75*LoadFactor^2)	0.09
Industrial	LossFactor = (0.31*LoadFactor) + (0.69*LoadFactor^2)	0.28
Mixed/Unknown	LossFactor = (0.20*LoadFactor) + (0.80*LoadFactor^2)	0.20

LoadFactor = Measured ratio of average load (Amperes) to peak load of the conductor over a period of one year.

Definition of Baseline Equipment

For Replace on Fail and New Construction projects:

Baseline values used in the savings calculations should reflect characteristics of a standard efficiency transformer that would typically be installed if energy efficiency were not considered. The baseline equipment can be established by one of two methods:

1. If the proposed transformer fits into a category for which federal standards are defined, the standard minimum efficiency transformer should be used as the baseline. Standards are developed by the Department of Energy and published in the Federal Register 10CFR 431 (Ref. 4). For example, although the federal standards increased the minimum required efficiency in 2016, most transformers with a NEMA premium or CEE Tier 2 rating will still achieve energy conservation. Standards are defined for low-voltage dry-type distribution transformers, liquid-immersed distribution transformers, and medium-voltage dry-type distribution transformers.
2. If the proposed transformer does not fit into a category for which standards are defined, characteristics of transformers previously installed on similar projects can be used as the baseline. To be considered a similar project, a standard-efficiency transformer rated at the same kVA capacity as the proposed high-efficiency transformer must have been installed to serve a peak load within 10% of the proposed peak load. The baseline transformer must have been installed within 5 years prior to the proposed project. Documentation demonstrating the transformer characteristics and loading conditions of the baseline project should be available upon request.

For Early Replacement (or Replace Working) projects:

The existing transformer characteristics as found on the nameplate or original design documentation should be used as the baseline values in the savings calculations. The existing equipment must be functional, serving the existing load, and must have been installed less than 25 years prior to the current project. If the load served has changed significantly (+/-10%) since the original installation, use the New Construction assumptions.

Incremental Cost

For Replace on Fail and New Construction projects:

Actual project costs should be used to determine incremental cost. To claim savings, an invoice showing the actual cost for the installed materials should be submitted with project documentation. A justification for the cost of the assumed baseline transformer materials should also be included. Justification can be a quote or an invoice from a previous project that demonstrates what it would have cost to install the

baseline equipment. Incremental cost for the project is the actual cost of the proposed project materials subtract the price of the baseline materials.

It is assumed that labor costs for the installation are identical for the high-efficiency and baseline cases. Therefore, incremental cost is driven by the difference in materials cost only.

For Early Replacement (or Replace Working) projects:

Actual project costs should be used. Invoices showing the full materials and labor costs for the project should be included with project documentation.

Example:

A functional 12,000 kVA transformer with full-load losses of 50 kW and no-load losses of 20 kW is replaced with a more efficient transformer with the same full-load capacity and full-load losses of 45 kW and no-load losses of 18 kW. The peak load is 10,000 kVA and the Loss Factor shown in historical data is 25%.

$$\text{Annual KWh Savings} = 8{,}760\ \text{hrs/yr} \times \left(\left[\left(\frac{10{,}000\ \text{kVA}}{12{,}000\ \text{kVA}}\right)^2 \times 50\text{kW} \times 0.25\ +\ 20\text{kW}\right] - \left[\left(\frac{10{,}000\ \text{kVA}}{12{,}000\ \text{kVA}}\right)^2 \times 45\text{kW} \times 0.25\ +\ 18\text{kW}\right]\right) = 25{,}119\ \text{kWh/yr}$$

$$\text{Peak kW Savings} = \left[\left(\frac{10{,}000\ \text{kVA}}{12{,}000\ \text{kVA}}\right)^2 \times 50\text{kW}\ +\ 20\text{kW}\right] - \left[\left(\frac{10{,}000\ \text{kVA}}{12{,}000\ \text{kVA}}\right)^2 \times 45\text{kW}\ +\ 18\text{kW}\right] = 5.47\ \text{kW}$$

In this example, the full cost of the project can be claimed if the existing transformer is less than 25 years old and the load has not changed more than 10% since the existing transformer was installed.

Methodology and Assumptions

Assume that peak coincidence factor for transformer demand reduction is 1.0. Transmission and distribution demand savings occur at peak load by definition.

Notes

It is anticipated that this measure will be most useful either during the substation design process (for large transmission transformers) or as an incentive to adopt a policy of installing higher efficiency transformers as a matter of practice (for distribution transformers).

If a utility institutes a policy of installing high efficiency transformers as a matter of standard practice, a representative sample of project invoices and transformer characteristics can be used to determine incremental costs and savings for the program.

The Loss Factor variable represents the ratio between average load losses and peak load loss. It can be calculated by using interval data for the applicable network segment and applying the following equation:

$$LossFactor = \sum_{n=1}^{Int} \left(\frac{Load_n^2}{Peak\ Load^2} \right) / Int$$

Where Int is the number of intervals (preferably over one year), $Load_n$ is the average load in interval n, and Peak Load is the highest value of Load for all n intervals.

If neither the Loss Factor itself nor the interval data required to calculate the Loss Factor are available, use the table above to estimate Loss Factor using the Load Factor of the network segment served by the transformer.

References

1. Developed from engineering expertise and several sources including: Booth & Associates, Inc. Distribution System Loss Management Manual. National Rural Electric Cooperative Association. 1991.
2. Guidelines on The Calculation and Use of Loss Factors, Electric Authority, Te Mana Hiko, February 14, 2013 (conversion formulas derived from the source)
3. Claimed lifetimes of transformer equipment easily exceed 25 years. The most commonly-cited reference is REA Bulletin 183-1 from 1977, found at: http://www.rd.usda.gov/files/UPA_Bulletin_183-1.pdf. For one example of MN-specific depreciation schedule, see the 2014 MN PUC Docket E017/D-13-795 at: http://minnesotapuc.legistar.com/gateway.aspx?M=F&ID=6fab26a3-0dff-44c8-ac2d-2b497ef6d005.pdf
4. 10 CFR 431.196 - Energy conservation standards and their effective dates. Summary published by the Legal Information Institute at the Cornell University Law School at: https://www.law.cornell.edu/cfr/text/10/431.196

Revision History

Version	Description	Author	Date
1.0	New measure	GDS Associates	10/31/2016

Electric Utility Infrastructure - Generation Equipment Retrofit

Measure Detail	Measure Value
Target Market Segments	Infrastructure
Target End Uses	Generation
Applicable To	Electric Utility Infrastructure - Retrofit existing generation equipment owned by the utility
Actions	Retrofit
Required from Customer/Contractor	The customer shall include documentation supporting all plant data included in the above calculations to determine the energy savings. Results from initial- and post-performance tests, conducted in compliance with ASME Performance Test codes must be available upon request. Depreciation schedules or manufacturer expected equipment lifetime for all major components of the project must be available upon request to verify measure life.
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	See Measure Life section

Measure Description

This measure applies only to generation plant upgrades of the primary power generation equipment and ancillary systems providing direct support to the primary generation equipment. If improvements are associated with patristic loads, which can be captured through the use of other TRM measures, then the energy efficiency improvements shall be determined using the other TRM measures. Examples of improvements which would be captured using this measure include; combustion turbine upgrades; steam turbine upgrades; enhanced boiler maintenance; coal mill upgrades; reciprocating engine enhancements; boiler feedwater pump upgrades (changing drive to VFD is not included) etc. Examples of improvements which would not be included in this measure include; VFDs; lighting; building HVAC; other parasitic loads.

Any project which improves a generation facility's efficiency by reducing fuel consumption (decreases Btu input) or increases its generation capacity will cause a change in gross plant heat rate. Thus, all generation facility energy efficiency improvements can be measured by capturing the change in the plant's gross heat rate. For example; Generation facility reduces fuel consumption by improving boiler heat transfer; Maintenance cycle for cleaning combustion turbine compressor blades is accelerated by two years; Gross generation output of a generation facility is increased by improving boiler steam production to the steam turbine without increasing fuel consumption; Inlet cooling is added to combustion turbines. This measure outlines a protocol for calculating energy savings from similar type of projects.

The measure is designed to be flexible enough to apply to a wide range of projects, thus input variables are not prescribed directly. Instead, individual project parameters (including generation plant characteristics, cost, and expected measure lifetime) must be justified by the accompanying project documentation.

A project that consists of multiple sub-actions (for example, replacing soot blowers at the same time as modifying a furnace heat transfer surface) is eligible as a single project as long as the overall plant heat rate and capacity are known before and after the project.

At gas generation facilities, a reduction in gas input will be claimed directly as gas savings. All other improvements are converted into equivalent electric savings.

Note: Projects that ONLY reduce parasitic loads should claim savings directly using the appropriate measure (VFD, lighting, etc.). Those measures will calculate savings without reference to the plant's heat rate.

Measure Life

Measure lifetime is equal to the shortest expected individual lifetime of all equipment installed as part of the project. For capital purchases that claim depreciation (for a rate case or tax purposes), the depreciation cycle determines the life of the equipment. For non-capital equipment, the manufacturer's expected lifetime should be used. The maximum measure lifetime is 25 years.

Definition of Baseline Conditions

An initial unit performance test conducted within three years prior to the proposed project shall be used to determine values for Initial Gross Heat Rate (HR_0), and Initial Plant Gross Output (kW_0).

In the special case where a proposed project will improve the plant heat rate for only part of the year (for example, a combustion turbines enhancement intended to improve hot weather performance, such as inlet chilling), the HR_0 and kW_0 shall be determined using the highest average four-hour period temperature during the summer months of June July and August, over the last ten years. For example, if the July highest four-hour 10-year average temperature is 96 °F, the historic HR_0 and kW_0 for that operating temperature will be used.

Generation facility Load Factor (LF) will be based upon an average of historical data collected over the most recent five years.

Unit performance tests should be performed in accordance with ASME Performance Test Codes for the applicable type of generation facility.

Definition of Post-Install Conditions

Once the generation facility improvements are complete, the Post-Heat Rate (HR_1) and Post-Plant Net Output (kW_1) is to be determined by completing a post unit performance test. Operating and ambient conditions used to determine HR_1 and kW_1 are to be adjusted to match the initial unit performance test or ambient conditions used for establishing HR_0 and kW_0.

Unit performance tests should be performed in accordance with ASME Performance Test Codes for the applicable type of generation facility.

Algorithms

Project Resulting in Reduced Natural Gas Consumption

For projects completed at natural gas generation facilities in which the only impact is a reduction in input btu (use Case 4 in the Example Calculations section), the reduced input is directly claimed as gas savings using the following algorithm:

Equation 1: $\Delta\, MMBTU/yr = MNLd \times \left((HR_0 - HR_1)\ \times\ kW_0\right) \times LF \times H$

All Other Projects

For all projects completed at non-gas generation facilities (use cases 1, 2, and 3), and natural gas generation facility projects which do not reduce fuel consumption (use cases 5 and 6); all savings are converted into equivalent electric savings with the following algorithm:

Equation 2: $\Delta\, kWh/yr = MNLd \times \left[\frac{(HR_0 - HR_1)}{HR_1} \times kW_0 \times LF \times H\right]$

Where:

MNLd	=	percentage of load served by the generation facility that is located within Minnesota.
HR_0	=	Initial Heat Rate. Gross heat rate for the plant (BTU fuel consumption divided by gross generator kWh) which comes from a plant performance test completed in the last three years prior to implementation of the project.
HR_1	=	Post Heat Rate. Gross Heat Rate for the plant (BTU fuel consumption divided by gross generator kWh) based upon plant performance test conducted after implementation of the project (ensuring to adjust operating and ambient weather conditions to match the initial plant performance test).
LF	=	Load Factor. Average Load Factor for the plant over the five-year period prior to project implementation (net plant kWh generation divided by plant rated net kW_0 output multiplied by 8,760 hours. Equation 3: $LF = \frac{Average\ Annual\ kWh\ production\ over\ 5\ years}{kW_0 \times 8{,}760\ hours}$
kW_0	=	Initial Plant Capacity. Gross output of the plant (in kW) which comes from a plant performance test completed in the last three years prior to implementation of the project.
kW_1	=	Post Plant Capacity. Gross output capacity of the plant (in kW) which comes from a plant performance test completed after the completion of the project.

H	=	Average hours per year, operating under the conditions addressed by the Improvement. In most instances this will be 8,760 hours (average annual hours in a year). In the special case where a proposed project will improve the plant heat rate for only part of the year, H shall be set to that number of hours. For example, if a combustion turbine project installs inlet chillers which improve operations above 85°F, then HR shall be set equal to the number of hours the ambient temperature exceeds 85°F.
10^6	=	Conversion factor from btu to MMbtu

Note that if the input BTU is not changing (use cases 2 and 5), the savings formula simplifies to:

Equation 4: $\Delta kWh = MNLd \times [kW_1 - kW_0] \times LF \times H$

Example:

There are six general use cases that can utilize this measure for calculating savings. By applying the algorithms above, the following table demonstrates examples of the possible uses of this measure.

Table 1. Annual Savings by Use Case

	Case	Description	HR_0 (BTU/kWh)	HR_1 (BTU/kWh)	kW_0	kW_1	Annual Electric Savings (MWh)	Annual Gas Savings (MMBTU)
Non-Natural Gas Generation Facility	1	Heat Rate Improvement Only	10,000	9,000	100,000	100,000	70,128	0
	2	Net Generation Improvement Only	10,000	8,696	100,000	115,000	105,164	0
	3	Heat Rate & Generation Improvement	10,000	9,000	100,000	120,000	84,154	0
Natural Gas Generation Facility	4	Heat Rate Improvement Only	10,000	9,000	100,000	100,000	0	701,280
	5	Net Generation Improvement Only	10,000	8,696	100,000	15,000	105,164	0
	6	Heat Rate & Generation Improvement	10,000	9,000	100,000	120,000	84,154	0

For these examples, load factor is assumed to be 80% and all facilities are assumed to be serving 100% Minnesota loads.

Case 1: Non-Natural Gas Generation Facility: Heat rate improvement only, no increase in capacity.

Case 2: Non-Natural Gas Generation Facility: Net generation increase only, with a constant BTU input.

Case 3: Non-Natural Gas Generation Facility: Heat rate and Net Generation improvement.

Case 4: Natural Gas Generation Facility: Heat rate improvement only, no increase in capacity.

Case 5: Natural Gas Generation Facility: Net generation increase only, with a constant BTU input.

Case 6: Natural Gas Generation Facility: Heat rate and Net Generation improvement.

Example Project 1 – Generation Improvement:

Steam turbine high pressure and intermediate pressure turbine is replaced with higher efficiency turbine sections. Gross plant output increases without any change in fuel consumption (Case 2). Operations before and after modifications are as follows:

Table 2. HP/IP Steam Turbine Replacement

Parameter	Variable	Quantity	Unit
Initial Plant Output	kW_0	860,000	kW
Initial Plant Heat Rate	HR_0	9,680	BTU/kWh
Load Factor	LF	85%	
Minn. Load Portion	MNLd	100%	
Post Plant Output	kW_1	877,200	kW
Post Plant Heat Rate	HR_1	9,490	BTU/kWh
Annual Hours	H	8,760	hrs
Electric Savings (EQ2)	ΔkWh	128,159,000	kWh

Revision History

Version	Description	Author	Date
1.0	New measure	GDS Associates	10/31/2016

Electric Utility Infrastructure - Variable Speed Drives (non-HVAC)

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Motors
Applicable To	Motors within Electric Utility Infrastructure
Actions	Retrofit Existing, New Construction
Required from Customer/Contractor	Motor Horsepower, Load Factor (if known), Motor Efficiency (if unknown, Motor size and type are required instead), annual operating hours, existing control type, and approximate duty cycle for the pump or fan application
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	0
Unit Dth Savings per Year	0
Measure Lifetime (years)	10 years (Ref. 1)
Unit Participant Incremental Cost	See Measure Cost section

Measure Description

This measure applies to a Variable Speed Drives (VSDs or VFDs) installed on fan or pump motors at utility-owned facilities. VSDs control the speed of a motor driving a variable load based on differential pressure, flow, temperature, or other control variable. Power drawn by a motor is proportional to the motor's rotational speed cubed, so when the speed can be slowed in response to lower loading conditions, significant power reductions are possible.

Examples of eligible applications include: boiler feedwater pumps, condenser water circulation pumps, cooling tower fans, flue gas fans, induced or forced draft fans, water circulation pumps, or blowdown pumps.

In order to be eligible, the project must meet the following criteria:

- Must be installed on a primary motor (backup or redundant motors are not eligible)
- Must be installed on an AC motor (DC motors are not eligible)
- Must be installed on a motor driving a centrifugal fan or pumping application (material handling and other applications must complete custom calculation)
- Individual motors must not exceed 500HP (>500HP should use custom load profiles)
- Motor must serve a variable load
- Routine replacements do not qualify
- VSDs required by code are not eligible (IECC 2015 or other applicable codes)
- VSDs installed on HVAC equipment should use the dedicated measure
- VSDs installed on air compressors should use the dedicated measure

Measure Cost

Actual costs should be used, if known. For smaller motors (<20HP), default project costs are given in the following table (Ref. 2). VSDs installed on larger motors must use actual costs.

Table 1. Project Cost by Motor Size

HP	Cost
1 -5 HP	$ 1,330
7.5 HP	$ 1,622
10 HP	$ 1,898
15 HP	$ 2,518
20 HP	$ 3,059

Algorithms

$$Annual\ kWh\ Savings = \left(0.746 \times HP \times \frac{LF}{Eff}\right) \times Hous \times ESF$$

Where:

HP = Rated Motor horsepower. Actual value.

LF = Motor load factor at the pump or fan design flow rate. Use actual value if known. If unknown, use default value of 75% (Ref. 3)

Eff = Efficiency of motor. Use actual value if known. If unknown, use default NEMA premium efficiency rating by size and type of motor (found in Table 3 below) (Ref. 4)

Hours = Annual operating hours. Actual run hours must be used for Generation/Utility applications. Justification for run hours assumption must be included in project documentation.

Duty Cycle = Percent of motor runtime at each flow rate. At generation facilities, it is expected that a duty cycle will be known with a reasonable degree of accuracy. See Table 2 below for an example Duty Cycle. Duty Cycle should be in the form of the following table:

Table 2. Duty Cycle Format

Flow Rate (Percent of design flow)	Duty Cycle (Percent of motor runtime at each flow rate)
0% to 10%	
10% to 20%	
20% to 30%	
30% to 40%	
40% to 50%	
50% to 60%	
60% to 70%	

Flow Rate (Percent of design flow)	Duty Cycle (Percent of motor runtime at each flow rate)
70% to 80%	
80% to 90%	
90% to 100%	

$PLR_{Baseline}$ = Part Load Ratio for the baseline control strategy. The ratio of percent of peak power draw that occurs at each flow rate percentage. Consult Table 5 to find $PLR_{Baseline}$ values depending on the existing control strategy.

PLR_{EFF} = Part Load Ratio for the VSD. The ratio of percent of peak power draw that occurs at each flow rate percentage. Consult Table 5 to find $PLR_{Baseline}$ values. They should either be the Pump VSD or Fan VSD values.

ESF = Energy Savings Factor. ESF is the sum-product of DutyCycle and $PLR_{Baseline}$ across all flow rates subtract the sum-product of DutyCycle and PLR_{EFF} across all flow rates. See Table 4 below for example ESF values.

$$ESF = \sum_{0\%}^{100\%} (DutyCycle \times PLR_{Baseline}) - \sum_{0\%}^{100\%} (DutyCycle \times PLR_{EFF})$$

Example:

A 100HP boiler feedwater pump currently using a throttling valve is retrofitted with a VSD. The pump runs for 3,000 hours per year, the motor load factor is 90% and the motor efficiency is 95%. The motor duty cycle is found in Table 2 below.

ESF is calculated using example the duty cycle in Table 2, $PLR_{Baseline}$ (from Table 5 – pump throttling valve values), and PLR_{EFF} (from Table 5 – pump VSD values).

Table 3. Example ESF Calculation (Ref. 5)

Flow Rate (Percent of design flow)	Example Duty Cycle (Percent of motor runtime at each flow rate)	$PLR_{Baseline}$ (Throttling Valve)	PLR_{EFF} (VSD)
0% to 10%	0%	0.80	0.05
10% to 20%	6%	0.81	0.06
20% to 30%	11%	0.82	0.09
30% to 40%	13%	0.83	0.12
40% to 50%	17%	0.85	0.18
50% to 60%	24%	0.87	0.27
60% to 70%	17%	0.90	0.39

Flow Rate (Percent of design flow)	Example Duty Cycle (Percent of motor runtime at each flow rate)	$PLR_{Baseline}$ (Throttling Valve)	PLR_{EFF} (VSD)
70% to 80%	9%	0.93	0.55
80% to 90%	2%	0.96	0.75
90% to 100%	1%	1.0	1.0

ESF = [0*.8+.06*.81+.11*.82+.13*.83+.17*.85+.24*.87+.17*.90+.09*.93+.02*.96+.01*1.0]-
[0*.05+.06*.06+.11*.09+.13*.12+.17*.18+.24*.27+.17*.39+.09*.55+.02*.75+.01*1]

ESF = 0.8659 – 0.2653 = 0.601

Unit kWh Savings per Year = (.746*100*0.90 / 0.95) x 3,000 x 0.601 = 127,425 kWh

Deemed Input Tables

Table 4. Default NEMA Premium Motor Efficiencies (Ref. 4)

Size HP	Open Drip Proof (ODP)			Totally Enclosed Fan-Cooled (TEFC)		
	# of Poles			# of Poles		
	6	4	2	6	4	2
	Speed (RPM)			Speed (RPM)		
	1200	1800 Default	3600	1200	1800	3600
1	0.825	0.855	0.770	0.825	0.855	0.770
1.5	0.865	0.865	0.840	0.875	0.865	0.840
2	0.875	0.865	0.855	0.885	0.865	0.855
3	0.885	0.895	0.855	0.895	0.895	0.865
5	0.895	0.895	0.865	0.895	0.895	0.885
7.5	0.902	0.910	0.885	0.910	0.917	0.895
10	0.917	0.917	0.895	0.910	0.917	0.902
15	0.917	0.930	0.902	0.917	0.924	0.910
20	0.924	0.930	0.910	0.917	0.930	0.910
25	0.930	0.936	0.917	0.930	0.936	0.917
30	0.936	0.941	0.917	0.930	0.936	0.917
40	0.941	0.941	0.924	0.941	0.941	0.924
50	0.941	0.945	0.930	0.941	0.945	0.930
60	0.945	0.950	0.936	0.945	0.950	0.936
75	0.945	0.950	0.936	0.945	0.954	0.936
100	0.950	0.954	0.936	0.950	0.954	0.941
125	0.950	0.954	0.941	0.950	0.954	0.950
150	0.954	0.958	0.941	0.958	0.958	0.950
200	0.954	0.958	0.950	0.958	0.962	0.954
250	0.954	0.958	0.950	0.958	0.962	0.958
300	0.954	0.958	0.954	0.958	0.962	0.958
350	0.954	0.958	0.954	0.958	0.962	0.958

Size HP	Open Drip Proof (ODP)			Totally Enclosed Fan-Cooled (TEFC)		
	# of Poles			# of Poles		
	6	4	2	6	4	2
	Speed (RPM)			Speed (RPM)		
	1200	1800 Default	3600	1200	1800	3600
400	0.958	0.958	0.958	0.958	0.962	0.958
450	0.962	0.962	0.958	0.958	0.962	0.958
500	0.962	0.962	0.958	0.958	0.962	0.958

Table 5. Example Energy Savings Factors (using example Duty Cycle from Table 2)

Baseline Control Type	ESF
Pump – No Control	0.73
Pump - Bypass Valve	0.67
Pump - Throttling Valve	0.60
Fan - No Control or Bypass Damper	0.71
Fan - Discharge Dampers	0.50
Fan - Outlet Damper, Backward Inclined & Airfoil Fans	0.47
Fan - Inlet Damper Box	0.41
Fan - Inlet Guide Vane, Backward Inclined & Airfoil Fans	0.34
Fan - Inlet Vane Dampers	0.24
Fan - Outlet Damper, Forward Curved Fans	0.22
Eddy Current Drives	0.19
Inlet Guide Vane, Forward Curved Fans	0.10

Table 6. Part Load Ratio for Flow rate bins Based on Control Types (Ref. 6)

Control Type	Flow rate (percentage of design flow)									
	0% to 10%	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Pump Baseline values ($PLR_{Baseline}$)										
No Control	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Bypass Valve	0.90	0.90	0.91	0.91	0.93	0.93	0.95	0.96	0.98	1.0
Throttling Valve	0.8	0.81	0.82	0.83	0.85	0.87	0.9	0.93	0.96	1.0
Pump VSD value (PLR_{EFF})										
VSD – pump	0.05	0.06	0.09	0.12	0.18	0.27	0.39	0.55	0.75	1.0
Fan Baseline values ($PLR_{Baseline}$)										
No Control or Bypass Damper	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Discharge Dampers	0.46	0.55	0.63	0.7	0.77	0.83	0.88	0.93	0.97	1.0
Outlet Damper, Backward Inclined & Airfoil Fans	0.53	0.53	0.57	0.64	0.72	0.8	0.89	0.96	1.02	1.05
Inlet Damper Box	0.56	0.6	0.62	0.64	0.66	0.69	0.74	0.81	0.92	1.07

Control Type	Flow rate (percentage of design flow)									
	0% to 10%	10% to 20%	20% to 30%	30% to 40%	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	90% to 100%
Inlet Guide Vane, Backward Inclined & Airfoil Fans	0.53	0.56	0.57	0.59	0.6	0.62	0.67	0.74	0.85	1.0
Inlet Vane Dampers	0.38	0.4	0.42	0.44	0.48	0.53	0.6	0.7	0.83	0.99
Outlet Damper, Forward Curved Fans	0.22	0.26	0.3	0.37	0.45	0.54	0.65	0.77	0.91	1.06
Eddy Current Drives	0.17	0.2	0.25	0.32	0.41	0.51	0.63	0.76	0.9	1.04
Inlet Guide Vane, Forward Curved Fans	0.21	0.22	0.23	0.26	0.31	0.39	0.49	0.63	0.81	1.04
Fan VSD value (PLR_{EFF})										
Fan - VSD	0.09	0.1	0.11	0.15	0.2	0.29	0.41	0.57	0.76	1.01

References

1. 2008 Database for Energy-Efficiency Resources (DEER), Version 2008.2.05, "Effective/Remaining Useful Life Values", California Public Utilities Commission, December 16, 2008. Use value for process VFDs.
2. Ohio TRM 8/6/2010 varies by motor/fan size based on equipment costs from Granger 2008 Catalog pp 286-289, average across available voltages and models. Labor costs from RS Means Data 2008 Ohio average cost adjustment applied.
3. United States Industrial Electric Motor Systems Market Opportunities Assessment, EERE, US DOE, Dec 2002 - Source for motor load factor data
4. Douglass, J. (2005). Induction Motor Efficiency Standards. Washington State University and the Northwest Energy Efficiency Alliance, Extension Energy Program, Olympia, WA. Also listed in the IL Statewide TRM. Retrieved online 12/12/16 at: http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/motor_efficiency_standards.pdf
5. Default Flow Fractions used in the Toshiba VFD Energy Savings Estimator tool.
6. Based on similar table developed for the IL TRM VFD measure. Verified values and added pump control types by entering the average load profiles into the Toshiba VFD Energy Savings Estimator tool.

Revision History

Version	Description	Author	Date
1.0	New measure	GDS Associates	12/12/2016

Electric Utility Infrastructure - Motors

Measure Detail	Measure Value
Target Market Segments	Infrastructure - Generation Facilities; Utility-owned sites
Target End Uses	Fans, Pumps, Motors, HVAC, Process
Applicable To	Motors within Electric Utility Infrastructure
Actions	Replace Working, Replace on Fail, New Construction
Required from Customer/Contractor	New Motor Enclosure Type (ODP/TEFC), RPM, Horsepower, Efficiency; Action Type (Replace on Fail, Replace Working, or New Construction); Building Type and Application (see Table 2)
Version No.	1.0
Unit kWh Savings per Year	See algorithm
Unit Peak kW Savings	See algorithm
Unit Dth Savings per Year	0
Measure Lifetime (years)	6 years (Replace Working), 20 years (Replace on Fail, New Construction) (Ref. 1, 2, 4)
Unit Participant Incremental Cost	Incr. Cost for EPACT to NEMA Premium Efficiency or EPACT to Enhanced NEMA Premium (Replacing Working); Incr. Cost for NEMA Premium Efficiency to Enhanced NEMA Premium (Replace on Fail and New Construction). See Appendix C. (Ref. 6)

Measure Description

This measure includes one-for-one replacement of working or failed/near-failure 1-200 hp motors with motors that meet or exceed NEMA Premium Efficiency levels in industrial and non-industrial applications, as well as installation of motors in new construction.

For replacement of working motors, the new motor efficiency must be at least NEMA Premium Efficiency. For replacement of failed/near-failure motors or new construction, the new motor efficiency must exceed NEMA Premium Efficiency. This measure is adapted from the similar C/I measure with small modifications to apply to utility-owned facilities.

Algorithms

Unit kWh Savings per Year = HP x LF x Conversion x (1/Eff_base – 1/Eff_EE) x Hrs

Unit Peak kW Savings = HP x LF x Conversion x (1/Eff_base – 1/Eff_EE) x CF

Where:

Hrs	=	Annual operating hours. It is strongly recommended to use actual hours if possible. If actual hours are unknown, use deemed annual operating hours by motor HP (see Table 1.). These values were derived assuming industrial applications.
LF	=	Motor load factor, deemed at 75% (Ref. 1, 4)
HP	=	Rated horsepower of new motor

Eff_EE	=	Efficiency of new motor. Eff_EE = NEMA Premium Efficiency or NEMA Premium Efficiency + 1%. See Appendix C.
Eff_base	=	Baseline motor efficiency. Eff_base = EPACT efficency (Replace Working), NEMA Premium Efficiency (Replace on Fail, New Construction). See Appendix C.
Conversion	=	Standard conversion from hp to kW = 0.746 kW/hp
CF	=	Coincidence Factor = 0.78 (Ref. 1, 2)

Deemed Input Tables

Table 1. Deemed annual operating hours by motor horsepower for industrial applications (Ref. 3)

Motor HP	Hrs
5	2,745
7.5	3,391
10	3,391
15	3,391
20	3,391
25	4,067
30	4,067
40	4,067
50	4,067
60	5,329
75	5,329
100	5,329
125	5,200
150	5,200
200	5,200

Table 2. Deemed annual operating hours by building type and application (Ref. 4)

Building Type and Application	Hrs
Office HVAC Pump	2,000
Warehouse HVAC Pump	2,241
Office Ventilation Fan	6,192
Warehouse Ventilation Fan	6,389
Office Other Non-Industrial Application	4,500
Warehouse Other Non-Industrial Application	4,500
Industrial/Manufacturing	See Table 1

Methodology and Assumptions

Measure lives for replacement of failed motors or motors in new construction was 15-20 years in most TRMs prior to the EISA standard for motors taking effect in December 2010. No sources were found for

lifetime of early replacement motors since most states have disallowed rebates for industrial Premium Efficiency motors. However, a review of several TRMs showed that for other measures, the lifetime of early replacements is typically about one-third of the full measure life. Therefore, the lifetime of this measure was set to 6 years (approximately one-third of 15-20 years.)

Notes

According to the EISA standard, general purpose motors (subtype I) manufactured after December 19, 2010, with a power rating of at least 1 horsepower but not greater than 200 horsepower, shall have a nominal full-load efficiency that is not less than as defined in NEMA MG– 1 (2006) Table 12–12 (aka "NEMA Premium®" efficiency levels).

References

1. NYSERDA (New York State Energy Research and Development Authority); NY Energy $mart Programs Deemed Savings Database - Source for coincidence factor, measure life, and motor load factor
2. Franklin Energy Services review, November 2013
3. United States Industrial Electric Motor Systems Market Opportunities Assessment, EERE, US DOE, Dec 2002 - Source for operating hours for industrial motors and source for motor load factor data (Tables 1-18 and 1-19)
4. Efficiency Vermont's Technical Reference User Manual, 2004 - Source for operating hours for commercial motors (p.15) and source for measure life and source for existing motor efficiencies and source for motor load factor default value
5. CEE (Consortium for Energy Efficiency) Premium Efficiency Motors Initiative – source for premium motor efficiencies
6. Xcel Energy Minnesota Electric and Natural Gas Conservation Improvement Program Plan for 2013-2015 (Docket No. E,G002/CIP-12-447) – source for incremental costs.
7. C/I Motors Measure. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs Version 2.0. Effective: January 1, 2017 – December 31, 2019.

Revision History

Version	Description	Author	Date
1.0	New measure based on C/I measure	GDS Associates	11/21/2016

Appendix A - Climate Zones

Weather-dependent measures in the Minnesota TRM reference three different climate zones which are illustrated in the map below. The boundaries follow county lines. The TRM is designed such that weather-dependent measures have county as a required input from customers or contractors. The county can be mapped to the climate zone using Table A-1.

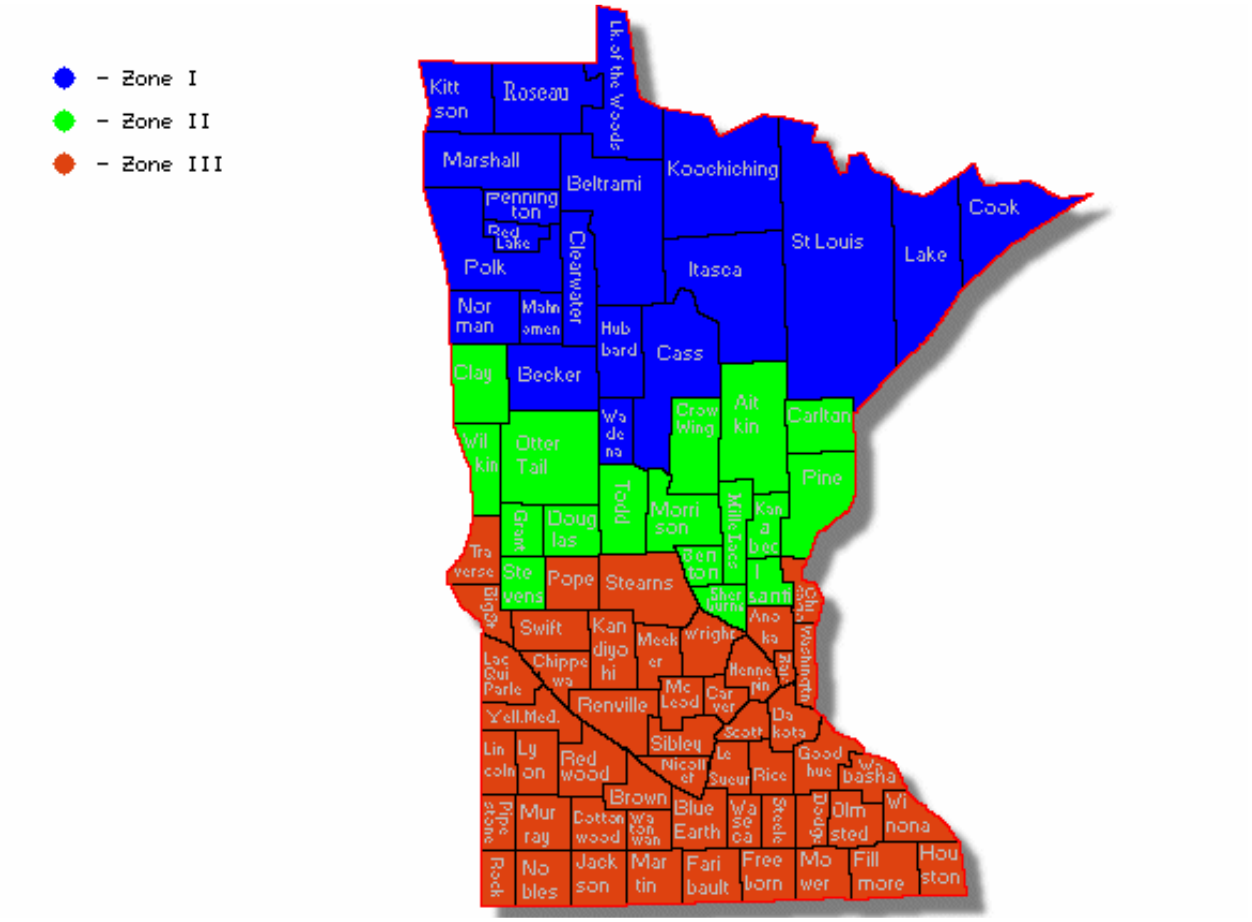

Figure A-1. Minnesota counties by climate zone (1, 2, and 3)

Table A-1. Minnesota counties by climate zone

Zone 1	Zone 2	Zone 3	
Becker,	Aitkin,	Anoka,	Mower,
Beltrami,	Benton,	Big Stone,	Murray,
Cass,	Carlton,	Blue Earth,	Nicollet,
Clearwater,	Clay,	Brown,	Nobles,
Cook,	Crow Wing,	Carver,	Olmsted,
Hubbard,	Douglas,	Chippewa,	Pipestone,
Itasca,	Grant,	Chisago,	Pope,
Kittson,	Isanti,	Cottonwood,	Ramsey,
Koochiching,	Kanabec,	Dakota,	Redwood,
Lake,	Mille Lacs,	Faribault,	Renville,
Lake of the Woods,	Morrison,	Fillmore,	Rice,
Mahnomen,	Otter Tail,	Freeborn,	Rock,
Marshall,	Pine,	Goodhue,	Scott,
Norman,	Sherburne,	Hennepin,	Sibley,
Pennington,	Stevens,	Houston,	Stearns,
Polk,	Todd,	Jackson,	Steele,
Red Lake,	Wilkin	Kandiyohi,	Swift,
Roseau,		Lac qui Parle,	Traverse,
St. Louis,		Le Sueur,	Wabasha,
Wadena		Lincoln,	Waseca,
		Lyon,	Washington,
		McLeod,	Watonwan,
		Martin,	Winona,
		Meeker	Wright,
			Yellow Medicine

Appendix B - C/I Lighting Tables

Appendix B is available as a Microsoft Excel spreadsheet (*.xls) on the Minnesota Department of Commerce, Division of Energy Resources website. From the DER website, (http://mn.gov/commerce/energy/), please navigate to the ESP/TRM page under Conservation Improvement Program->Design Resources.

Appendix C - C/I Motor Tables

Table C-1. Efficiencies and Incremental Cost by Motor Size

RPM	Enclosure	Horse-Power	EPACT Efficiency (A)	NEMA Premium Efficiency (B)	Enhanced NEMA Premium Efficiency (C)	Incremental Cost (A to B)	Incremental Cost (B to C)	Incremental Cost (A to C)
1200	ODP	1	80.00%	82.50%	83.50%	$826.86	$311.97	$1,138.83
1200	ODP	1.5	84.00%	86.50%	87.50%	$821.85	$308.62	$1,130.47
1200	ODP	2	85.50%	87.50%	88.50%	$907.18	$365.64	$1,272.82
1200	ODP	3	86.50%	88.50%	89.50%	$953.05	$396.29	$1,349.34
1200	ODP	5	87.50%	89.50%	90.50%	$976.06	$411.67	$1,387.72
1200	ODP	7.5	88.50%	90.20%	91.20%	$1,323.26	$643.67	$1,966.93
1200	ODP	10	90.20%	91.70%	92.70%	$1,475.12	$745.15	$2,220.27
1200	ODP	15	90.20%	91.70%	92.70%	$2,541.29	$976.47	$3,517.75
1200	ODP	20	91.00%	92.40%	93.40%	$2,861.24	$1,190.27	$4,051.52
1200	ODP	25	91.70%	93.00%	94.00%	$3,261.14	$1,457.50	$4,718.64
1200	ODP	30	92.40%	93.60%	94.60%	$3,513.58	$1,626.18	$5,139.75
1200	ODP	40	93.00%	94.10%	95.10%	$4,222.09	$2,099.62	$6,321.70
1200	ODP	50	93.00%	94.10%	95.10%	$4,628.91	$2,371.47	$7,000.39
1200	ODP	60	93.60%	94.50%	95.50%	$5,831.16	$3,174.84	$9,006.00
1200	ODP	75	93.60%	94.50%	95.50%	$6,697.92	$3,754.03	$10,451.95
1200	ODP	100	94.10%	95.00%	96.00%	$8,402.69	$4,412.08	$12,814.77
1200	ODP	125	94.10%	95.00%	96.00%	$10,323.06	$5,695.32	$16,018.38
1200	ODP	150	94.50%	95.40%	96.40%	$10,693.62	$5,942.94	$16,636.56
1200	ODP	200	94.50%	95.40%	96.40%	$12,801.47	$7,351.45	$20,152.92
1200	ODP	250	95.40%	95.40%	96.40%	$15,888.00	$9,413.95	$25,301.95
1200	ODP	300	95.40%	95.40%	96.40%	$20,204.33	$12,298.23	$32,502.56
1200	ODP	350	95.40%	95.40%	96.40%	$29,220.28	$18,322.91	$47,543.19
1200	ODP	400	95.80%	95.80%	96.80%	$32,992.47	$20,843.58	$53,836.05
1200	ODP	450	96.20%	96.20%	97.20%	$56,915.81	$36,829.75	$93,745.56
1200	ODP	500	96.20%	96.20%	97.20%	$59,663.64	$38,665.92	$98,329.55

RPM	Enclosure	Horse-Power	EPACT Efficiency (A)	NEMA Premium Efficiency (B)	Enhanced NEMA Premium Efficiency (C)	Incremental Cost (A to B)	Incremental Cost (B to C)	Incremental Cost (A to C)
1200	TEFC	1	80.00%	82.50%	83.50%	$826.86	$311.97	$1,138.83
1200	TEFC	1.5	85.50%	87.50%	88.50%	$821.85	$308.62	$1,130.47
1200	TEFC	2	86.50%	88.50%	89.50%	$907.18	$365.64	$1,272.82
1200	TEFC	3	87.50%	89.50%	90.50%	$953.05	$396.29	$1,349.34
1200	TEFC	5	87.50%	89.50%	90.50%	$976.06	$411.67	$1,387.72
1200	TEFC	7.5	89.50%	91.00%	92.00%	$1,323.26	$643.67	$1,966.93
1200	TEFC	10	89.50%	91.00%	92.00%	$1,475.12	$745.15	$2,220.27
1200	TEFC	15	90.20%	91.70%	92.70%	$2,541.29	$976.47	$3,517.75
1200	TEFC	20	90.20%	91.70%	92.70%	$2,861.24	$1,190.27	$4,051.52
1200	TEFC	25	91.70%	93.00%	94.00%	$3,261.14	$1,457.50	$4,718.64
1200	TEFC	30	91.70%	93.00%	94.00%	$3,513.58	$1,626.18	$5,139.75
1200	TEFC	40	93.00%	94.10%	95.10%	$4,222.09	$2,099.62	$6,321.70
1200	TEFC	50	93.00%	94.10%	95.10%	$4,628.91	$2,371.47	$7,000.39
1200	TEFC	60	93.60%	94.50%	95.50%	$5,831.16	$3,174.84	$9,006.00
1200	TEFC	75	93.60%	94.50%	95.50%	$6,697.92	$3,754.03	$10,451.95
1200	TEFC	100	94.10%	95.00%	96.00%	$8,402.69	$4,412.08	$12,814.77
1200	TEFC	125	94.10%	95.00%	96.00%	$10,323.06	$5,695.32	$16,018.38
1200	TEFC	150	95.00%	95.80%	96.80%	$10,693.62	$5,942.94	$16,636.56
1200	TEFC	200	95.00%	95.80%	96.80%	$12,801.47	$7,351.45	$20,152.92
1200	TEFC	250	95.00%	95.80%	96.80%	$15,888.00	$9,413.95	$25,301.95
1200	TEFC	300	95.00%	95.80%	96.80%	$20,204.33	$12,298.23	$32,502.56
1200	TEFC	350	95.00%	95.80%	96.80%	$29,220.28	$18,322.91	$47,543.19
1200	TEFC	400	95.00%	95.80%	96.80%	$32,992.47	$20,843.58	$53,836.05
1200	TEFC	450	95.00%	95.80%	96.80%	$56,915.81	$36,829.75	$93,745.56
1200	TEFC	500	95.00%	95.80%	96.80%	$59,663.64	$38,665.92	$98,329.55
1800	ODP	1	82.50%	85.50%	86.50%	$826.86	$311.97	$1,138.83
1800	ODP	1.5	84.00%	86.50%	87.50%	$821.85	$308.62	$1,130.47
1800	ODP	2	84.00%	86.50%	87.50%	$907.18	$365.64	$1,272.82

RPM	Enclosure	Horse-Power	EPACT Efficiency (A)	NEMA Premium Efficiency (B)	Enhanced NEMA Premium Efficiency (C)	Incremental Cost (A to B)	Incremental Cost (B to C)	Incremental Cost (A to C)
1800	ODP	3	86.50%	89.50%	90.50%	$953.05	$396.29	$1,349.34
1800	ODP	5	87.50%	89.50%	90.50%	$976.06	$411.67	$1,387.72
1800	ODP	7.5	88.50%	91.00%	92.00%	$1,323.26	$643.67	$1,966.93
1800	ODP	10	89.50%	91.70%	92.70%	$1,475.12	$745.15	$2,220.27
1800	ODP	15	91.00%	93.00%	94.00%	$2,541.29	$976.47	$3,517.75
1800	ODP	20	91.00%	93.00%	94.00%	$2,861.24	$1,190.27	$4,051.52
1800	ODP	25	91.70%	93.60%	94.60%	$3,261.14	$1,457.50	$4,718.64
1800	ODP	30	92.40%	94.10%	95.10%	$3,513.58	$1,626.18	$5,139.75
1800	ODP	40	93.00%	94.10%	95.10%	$4,222.09	$2,099.62	$6,321.70
1800	ODP	50	93.00%	94.50%	95.50%	$4,628.91	$2,371.47	$7,000.39
1800	ODP	60	93.60%	95.00%	96.00%	$5,831.16	$3,174.84	$9,006.00
1800	ODP	75	94.10%	95.00%	96.00%	$6,697.92	$3,754.03	$10,451.95
1800	ODP	100	94.10%	95.40%	96.40%	$8,402.69	$4,412.08	$12,814.77
1800	ODP	125	94.50%	95.40%	96.40%	$10,323.06	$5,695.32	$16,018.38
1800	ODP	150	95.00%	95.80%	96.80%	$10,693.62	$5,942.94	$16,636.56
1800	ODP	200	95.00%	95.80%	96.80%	$12,801.47	$7,351.45	$20,152.92
1800	ODP	250	95.40%	95.80%	96.80%	$15,888.00	$9,413.95	$25,301.95
1800	ODP	300	95.40%	95.80%	96.80%	$20,204.33	$12,298.23	$32,502.56
1800	ODP	350	95.40%	95.80%	96.80%	$29,220.28	$18,322.91	$47,543.19
1800	ODP	400	95.40%	95.80%	96.80%	$32,992.47	$20,843.58	$53,836.05
1800	ODP	450	95.80%	96.20%	97.20%	$56,915.81	$36,829.75	$93,745.56
1800	ODP	500	95.80%	96.20%	97.20%	$59,663.64	$38,665.92	$98,329.55
1800	TEFC	1	82.50%	85.50%	86.50%	$826.86	$311.97	$1,138.83
1800	TEFC	1.5	84.00%	86.50%	87.50%	$821.85	$308.62	$1,130.47
1800	TEFC	2	84.00%	86.50%	87.50%	$907.18	$365.64	$1,272.82
1800	TEFC	3	87.50%	89.50%	90.50%	$953.05	$396.29	$1,349.34
1800	TEFC	5	87.50%	89.50%	90.50%	$976.06	$411.67	$1,387.72
1800	TEFC	7.5	89.50%	91.70%	92.70%	$1,323.26	$643.67	$1,966.93

RPM	Enclosure	Horse-Power	EPACT Efficiency (A)	NEMA Premium Efficiency (B)	Enhanced NEMA Premium Efficiency (C)	Incremental Cost (A to B)	Incremental Cost (B to C)	Incremental Cost (A to C)
1800	TEFC	10	89.50%	91.70%	92.70%	$1,475.12	$745.15	$2,220.27
1800	TEFC	15	91.00%	92.40%	93.40%	$2,541.29	$976.47	$3,517.75
1800	TEFC	20	91.00%	93.00%	94.00%	$2,861.24	$1,190.27	$4,051.52
1800	TEFC	25	92.40%	93.60%	94.60%	$3,261.14	$1,457.50	$4,718.64
1800	TEFC	30	92.40%	93.60%	94.60%	$3,513.58	$1,626.18	$5,139.75
1800	TEFC	40	93.00%	94.10%	95.10%	$4,222.09	$2,099.62	$6,321.70
1800	TEFC	50	93.00%	94.50%	95.50%	$4,628.91	$2,371.47	$7,000.39
1800	TEFC	60	93.60%	95.00%	96.00%	$5,831.16	$3,174.84	$9,006.00
1800	TEFC	75	94.10%	95.40%	96.40%	$6,697.92	$3,754.03	$10,451.95
1800	TEFC	100	94.50%	95.40%	96.40%	$8,402.69	$4,412.08	$12,814.77
1800	TEFC	125	94.50%	95.40%	96.40%	$10,323.06	$5,695.32	$16,018.38
1800	TEFC	150	95.00%	95.80%	96.80%	$10,693.62	$5,942.94	$16,636.56
1800	TEFC	200	95.00%	96.20%	97.20%	$12,801.47	$7,351.45	$20,152.92
1800	TEFC	250	95.00%	96.20%	97.20%	$15,888.00	$9,413.95	$25,301.95
1800	TEFC	300	95.40%	96.20%	97.20%	$20,204.33	$12,298.23	$32,502.56
1800	TEFC	350	95.40%	96.20%	97.20%	$29,220.28	$18,322.91	$47,543.19
1800	TEFC	400	95.40%	96.20%	97.20%	$32,992.47	$20,843.58	$53,836.05
1800	TEFC	450	95.40%	96.20%	97.20%	$56,915.81	$36,829.75	$93,745.56
1800	TEFC	500	95.80%	96.20%	97.20%	$59,663.64	$38,665.92	$98,329.55
3600	ODP	1	76.30%	77.00%	78.00%	$826.86	$311.97	$1,138.83
3600	ODP	1.5	82.50%	84.00%	85.00%	$821.85	$308.62	$1,130.47
3600	ODP	2	84.00%	85.50%	86.50%	$907.18	$365.64	$1,272.82
3600	ODP	3	84.00%	85.50%	86.50%	$953.05	$396.29	$1,349.34
3600	ODP	5	85.50%	86.50%	87.50%	$976.06	$411.67	$1,387.72
3600	ODP	7.5	87.50%	88.50%	89.50%	$1,323.26	$643.67	$1,966.93
3600	ODP	10	88.50%	89.50%	90.50%	$1,475.12	$745.15	$2,220.27
3600	ODP	15	89.50%	90.20%	91.20%	$2,541.29	$976.47	$3,517.75
3600	ODP	20	90.20%	91.00%	92.00%	$2,861.24	$1,190.27	$4,051.52

RPM	Enclosure	Horse-Power	EPACT Efficiency (A)	NEMA Premium Efficiency (B)	Enhanced NEMA Premium Efficiency (C)	Incremental Cost (A to B)	Incremental Cost (B to C)	Incremental Cost (A to C)
3600	ODP	25	91.00%	91.70%	92.70%	$3,261.14	$1,457.50	$4,718.64
3600	ODP	30	91.00%	91.70%	92.70%	$3,513.58	$1,626.18	$5,139.75
3600	ODP	40	91.70%	92.40%	93.40%	$4,222.09	$2,099.62	$6,321.70
3600	ODP	50	92.40%	93.00%	94.00%	$4,628.91	$2,371.47	$7,000.39
3600	ODP	60	93.00%	93.60%	94.60%	$5,831.16	$3,174.84	$9,006.00
3600	ODP	75	93.00%	93.60%	94.60%	$6,697.92	$3,754.03	$10,451.95
3600	ODP	100	93.00%	93.60%	94.60%	$8,402.69	$4,412.08	$12,814.77
3600	ODP	125	93.60%	94.10%	95.10%	$10,323.06	$5,695.32	$16,018.38
3600	ODP	150	93.60%	94.10%	95.10%	$10,693.62	$5,942.94	$16,636.56
3600	ODP	200	94.50%	95.00%	96.00%	$12,801.47	$7,351.45	$20,152.92
3600	ODP	250	94.50%	95.00%	96.00%	$15,888.00	$9,413.95	$25,301.95
3600	ODP	300	95.00%	95.40%	96.40%	$20,204.33	$12,298.23	$32,502.56
3600	ODP	350	95.00%	95.40%	96.40%	$29,220.28	$18,322.91	$47,543.19
3600	ODP	400	95.40%	95.80%	96.80%	$32,992.47	$20,843.58	$53,836.05
3600	ODP	450	95.80%	95.80%	96.80%	$56,915.81	$36,829.75	$93,745.56
3600	ODP	500	95.80%	95.80%	96.80%	$59,663.64	$38,665.92	$98,329.55
3600	TEFC	1	75.50%	77.00%	78.00%	$826.86	$311.97	$1,138.83
3600	TEFC	1.5	82.50%	84.00%	85.00%	$821.85	$308.62	$1,130.47
3600	TEFC	2	84.00%	85.50%	86.50%	$907.18	$365.64	$1,272.82
3600	TEFC	3	85.50%	86.50%	87.50%	$953.05	$396.29	$1,349.34
3600	TEFC	5	87.50%	88.50%	89.50%	$976.06	$411.67	$1,387.72
3600	TEFC	7.5	88.50%	89.50%	90.50%	$1,323.26	$643.67	$1,966.93
3600	TEFC	10	89.50%	90.20%	91.20%	$1,475.12	$745.15	$2,220.27
3600	TEFC	15	90.20%	91.00%	92.00%	$2,541.29	$976.47	$3,517.75
3600	TEFC	20	90.20%	91.00%	92.00%	$2,861.24	$1,190.27	$4,051.52
3600	TEFC	25	91.00%	91.70%	92.70%	$3,261.14	$1,457.50	$4,718.64
3600	TEFC	30	91.00%	91.70%	92.70%	$3,513.58	$1,626.18	$5,139.75
3600	TEFC	40	91.70%	92.40%	93.40%	$4,222.09	$2,099.62	$6,321.70

RPM	Enclosure	Horse-Power	EPACT Efficiency (A)	NEMA Premium Efficiency (B)	Enhanced NEMA Premium Efficiency (C)	Incremental Cost (A to B)	Incremental Cost (B to C)	Incremental Cost (A to C)
3600	TEFC	50	92.40%	93.00%	94.00%	$4,628.91	$2,371.47	$7,000.39
3600	TEFC	60	93.00%	93.60%	94.60%	$5,831.16	$3,174.84	$9,006.00
3600	TEFC	75	93.00%	93.60%	94.60%	$6,697.92	$3,754.03	$10,451.95
3600	TEFC	100	93.60%	94.10%	95.10%	$8,402.69	$4,412.08	$12,814.77
3600	TEFC	125	94.50%	95.00%	96.00%	$10,323.06	$5,695.32	$16,018.38
3600	TEFC	150	94.50%	95.00%	96.00%	$10,693.62	$5,942.94	$16,636.56
3600	TEFC	200	95.00%	95.40%	96.40%	$12,801.47	$7,351.45	$20,152.92
3600	TEFC	250	95.40%	95.80%	96.80%	$15,888.00	$9,413.95	$25,301.95
3600	TEFC	300	95.40%	95.80%	96.80%	$20,204.33	$12,298.23	$32,502.56
3600	TEFC	350	95.40%	95.80%	96.80%	$29,220.28	$18,322.91	$47,543.19
3600	TEFC	400	95.40%	95.80%	96.80%	$32,992.47	$20,843.58	$53,836.05
3600	TEFC	450	95.40%	95.80%	96.80%	$56,915.81	$36,829.75	$93,745.56
3600	TEFC	500	95.40%	95.80%	96.80%	$59,663.64	$38,665.92	$98,329.55

Appendix D - Commercial Building Models

The following table defines the characteristics of the models used for the C/I measures by Franklin Energy Services.

Table D-1. Model Characteristics Used For C/I Measures

Building Type	Building Characteristics			General Occupancy Schedule				HVAC Equipment		
	Total Sq Ft	Number of Floors Above Grade	Secondary Spaces Breakdown (balance is primary space)	Weekday	Saturday	Sunday	Holiday	Air System	Cooling Equipment Type	Heating Equipment Type
Convenience Store	6,000	1	Office: 2%, Dry storage: 15%	7am-10pm	9am-9pm	10am-5pm	10am-5pm	Constant volume packaged rooftop unit	DX	Natural gas heater in RTU
Education - Community College/University	1,000,000	3	classrooms: 43.1%, ind work: 8%, computer rooms: 2.8%, corridor: 3%, dining: 2.4%, dorm: 17%, kitchen: 1.1%, office 22.7%	7am-Midnight (Typical Break Schedules - Summer Occupany 40%)	7am-7pm	10am-Noon	10am-Noon	Variable Air Volume (VAV), [constant volume packaged rooftop unit, kitchen]	Centrifigal Chiller, (DX Kitchen)	Boiler, hot water (Natural gas heater in RTU, kitchen)
Education - Primary	75,000	2	offices: 6%, gym 5%, kitchen 2%, cafeteria 5%, library: 6%	8am-4pm (20% in summer)	closed	closed	closed	Constant volume unit ventilators	Screw air cooled chiller	Boiler, hot water

Building Type	Building Characteristics			General Occupancy Schedule				HVAC Equipment		
	Total Sq Ft	Number of Floors Above Grade	Secondary Spaces Breakdown (balance is primary space)	Weekday	Saturday	Sunday	Holiday	Air System	Cooling Equipment Type	Heating Equipment Type
Education - Secondary	225,000	2	gym: 10%, aux. gym 6%, auditorium 5%, kitchen 1%, cafeteria: 3%, offices 3%, library 4%	8am-4pm (20% in summer)	closed	closed	closed	Constant volume unit ventilators	Screw air cooled chiller	Boiler, hot water
Health/Medical - Clinic	67,500	3	30% exam, 30% corridor/lobby, 20% office, 20% storage/utility	7am-7pm	9am-5pm	closed	closed	Constant volume packaged rooftop unit	DX	Natural gas heater in RTU
Health/Medical - Hospital	200,000	4	56% lobby/corridor, 20% treatment rooms, 9% food service, 11% patient rooms, 3% office	24/7	24/7	24/7	24/7	Constant volume indoor units	Centrifugal water cooled chiller	Natural gas heater in RTU
Lodging	56,000	2	office: 3%, laundry 2.4%, Mtg room 2%, exercise 1%, employee lounge 1%	24/7	24/7	24/7	24/7	Packaged terminal heat pump	Packaged terminal AC	Heat pump, supplemental electric

Building Type	Building Characteristics			General Occupancy Schedule				HVAC Equipment		
	Total Sq Ft	Number of Floors Above Grade	Secondary Spaces Breakdown (balance is primary space)	Weekday	Saturday	Sunday	Holiday	Air System	Cooling Equipment Type	Heating Equipment Type
Manufacturing Facility	120,000	1	10% office space on two floors, 90% manufacturing on single floor	Office: 8am-5pm, mfg: 6am-10pm	Office: closed, mfg: 6am-10pm	closed	closed	Mfg: Make-up air unit; Office: RTU	Mfg.: none; Office: DX	Natural gas heater in MAU & RTU
Office - High-rise	537,600	20		8am-5pm	20% 8am-noon	closed	closed	Variable Air Volume (VAV)	Centrifugal water cooled chiller	Boiler, hot water
Office - Low-rise	7,500	1		8am-5pm	closed	closed	closed	Constant volume packaged rooftop unit	DX	Natural gas heater in RTU
Office - Mid-rise	50,000	5		8am-5pm	20% 8am-noon	closed	closed	Variable Air Volume (VAV)	Centrifugal water cooled chiller	Boiler, hot water
Restaurant	7,500	1	kitchen 27%, dining 73%	7am-8pm	7am-8pm	7am-8pm	closed	Constant volume packaged rooftop unit	DX	Natural gas heater in RTU

Building Type	Building Characteristics			General Occupancy Schedule				HVAC Equipment		
	Total Sq Ft	Number of Floors Above Grade	Secondary Spaces Breakdown (balance is primary space)	Weekday	Saturday	Sunday	Holiday	Air System	Cooling Equipment Type	Heating Equipment Type
Retail - Department Store	45,000	1	back space 17%, point of sale 7%	9am-9pm	9am-9pm	10am-5pm	10am-5pm	Constant volume packaged rooftop unit	DX	Natural gas heater in RTU
Retail - Strip Mall	3,000	1	storage: 15%	9am-9pm	9am-9pm	10am-5pm	10am-5pm	Constant volume packaged rooftop unit	DX	Natural gas heater in RTU
Warehouse	100,000	1	high bay storage: 80%, office 20%	6am-6pm	closed	closed	closed	Constant volume packaged rooftop unit	DX	Natural gas heater in RTU

Appendix E – Conservation Voltage Reduction Examples

From "Simplified Voltage Optimization (VO) Measurement and Verification Protocol" produced by the Regional Technical Forum. Note that Voltage Optimization is another term for Conservation Voltage Reduction.

System improvements typically have a useful life exceeding 35 years. However, control settings are easily altered over time unless they are integrated into utility operating and design standards. For new operating design standards to become entrenched, a three- year monitoring and documentation period is recommended. Standards that become entrenched tend to extend the life of VO perpetually.

This 3-year period includes the following:

1. On a monthly basis, a utility must document that voltage control settings within each the VO voltage control zone are maintained as necessary to be consistent with those determined during the original VO project.
2. On an annual basis, provide total kWh usage on the voltage control zone and provide average voltage at Substation and EOL.
3. A utility must maintain this documentation (or provide it to the appropriate organization) annually for a 3-year period.
4. During this three year period, if the voltage control settings have been off-line, either intentionally or unintentionally for a period of 30 days or longer, the utility must continue to maintain the voltage control setting documentation for a period equal to 30 days or longer beyond the original 3 year documentation period.
5. Verify performance thresholds for each voltage-control-zone and corrective actions taken if any. Thresholds include:
    a. Feeder power factor – Average hourly > 0.98 from *metered* data
    b. Feeder power factor – Maximum hourly > 0.96 from *metered* data
    c. EOL primary voltage must be > [114 Volts + '' the voltage regulation bandwidth + secondary maximum allowed voltage-drop] from *metered* data
    d. Regulator primary voltage must be < [126 Volts - '' the voltage regulation bandwidth + secondary maximum allowed voltage-drop] from *metered* data
    e. Feeder load unbalance must be < 0.15 from system modeling
    f. Feeder Source 3-phase feeder neutral current < 40 Amps from *metered* data
    g. Feeder maximum adjusted primary voltage-drops <3.3% from system modeling
    h. Feeder maximum voltage-drop variance < 2.0 V on a 120V base.