Welcome

Conservation Applied Research & Development (CARD) Webinar

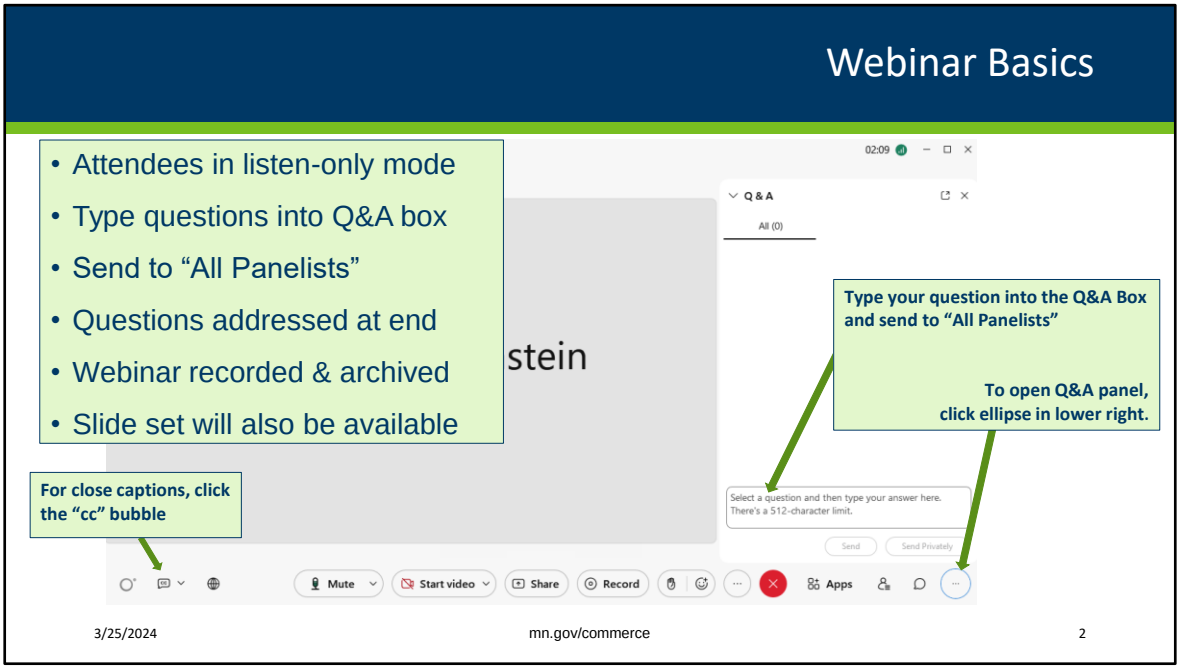
March 21, 2024

Optimizing the New Generation of Grocery Refrigeration Equipment

Good morning.

Welcome to this Conservation Applied Research and Development (CARD) Webinar today reviewing results from Optimizing the New Generation of Grocery Refrigeration Equipment

Thanks so much for joining us today.



I'd like cover a few housekeeping items before we start:

- All attendees will be in listen-only mode.
- We will answer all questions at the end of the presentation, but as questions occur to you, please type them into the Q&A box and send them to "**All Panelists**."
- The Q&A Box can be opened by clicking the ellipse in the lower right of your screen, as indicated on this slide.
- We will do our best to answer all questions within the time allocated, but if we don't get to some, we will answer them after the webinar.
- This webinar is being recorded and will be available on the Department's website in a few weeks.
- The slide set from this webinar will also be available on the website, but if you need it sooner, email me directly.
- Finally, if you would like closed captions on this webinar, click the "cc" bubble in the lower left of your screen.

Optimizing the New Generation of Grocery Refrigeration Equipment



Lindsay Anderson
Utility Energy Conservation Research Planner
MN Department of Commerce
lindsay.anderson@state.mn.us



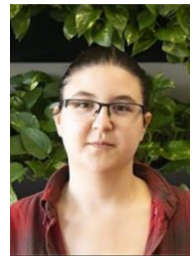
Laura Silver
Principal State Program Administrator
MN Department of Commerce
laura.silver@state.mn.us



Russ Landry
Senior Research Engineer
Center for Energy and Environment
rlandry@mncee.org



Grant Baumgardner
Research Engineer
Center for Energy and Environment
gbaumgardner@mncee.org



Angela Davis
Engineering Consultant
VEIC
apdavis@veic.org

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I am Lindsay Anderson, the Utility Energy Conservation Research Planner at the Minnesota Department of Commerce, Division of Energy Resources within the Energy Conservation and Optimization Business Unit. In that role I identify and analyze gaps within utility energy conservation and optimization programs and coordinate and plan research to fill those gaps. The CARD program is a major tool of that work.

With me today is Laura Silver, Principal State Program Administrator within the Energy Conservation and Optimization business unit at the Department of Commerce, where she reviews utility Energy Conservation and Optimization triennial plans and annual status reports. Laura is the project manager on the research that is the subject of this webinar, and she will be moderating the Q&A portion of today's presentation.

Our presenter(s) today are Russ Landry from CEE, Grant Baumgardner from CEE and Angela Davis from VEIC.

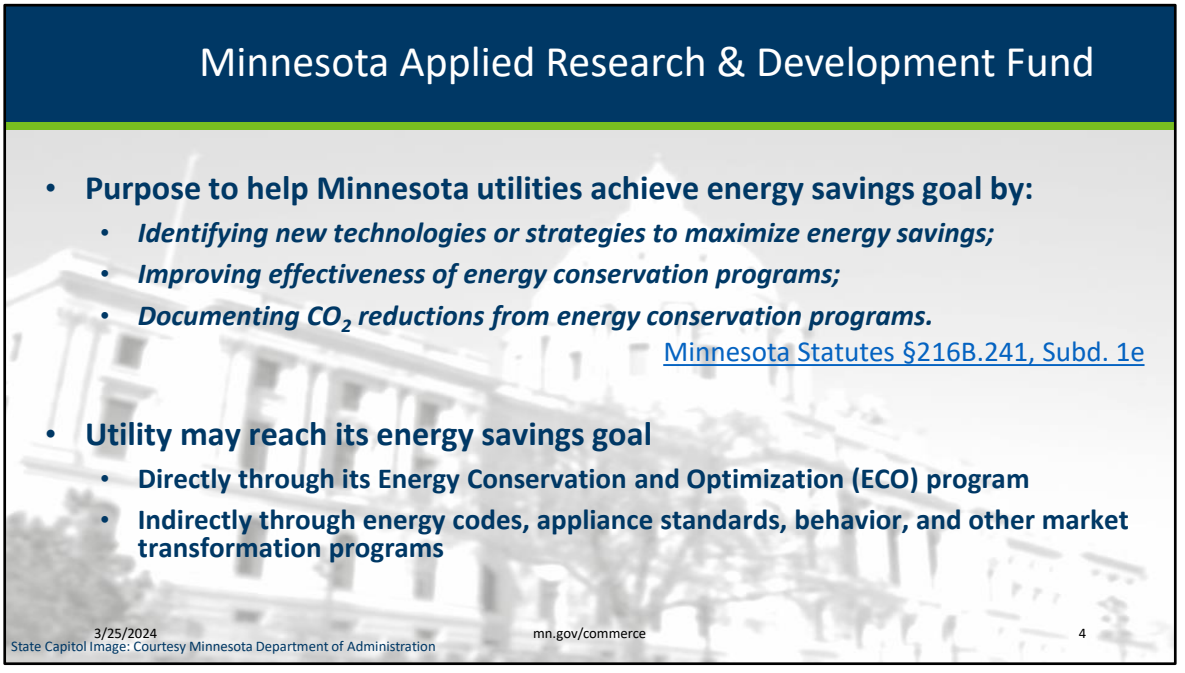
Russ Landry is a Senior Research Engineer at CEE where he has carried out a wide variety of work on energy efficiency in commercial and multifamily

buildings over the last 34 years, including working with multiple Minnesota utilities on commercial refrigeration programs and more than a dozen field research projects.

As a Research Engineer at CEE, **Grant Baumgardner** conducts research on emerging technologies in HVAC and refrigeration systems. Prior to joining CEE in 2022, Grant spent six years developing commercial HVAC and transport refrigeration products.

Angela Davis is an Engineering Consultant at VEIC who works on building simulation modeling and creating scripts to predict energy savings.

Welcome Russ, Grant and Angela. We look forward to your presentation.



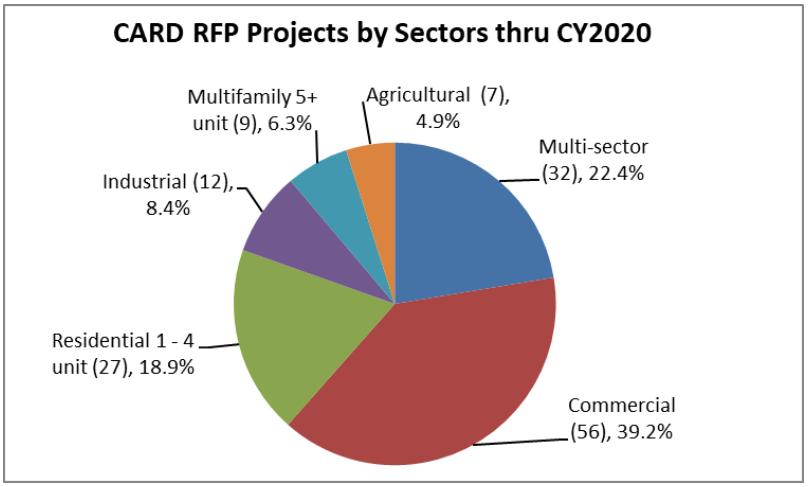
This webinar is one in an ongoing series designed to summarize the results from research projects funded by Minnesota's Applied Research and Development Fund, which was established in the Next Generation Energy Act of 2007.

The purpose of the fund is to help Minnesota utilities achieve their energy savings goal.

$2.6 million is set aside annually for the CARD program, which awards research grants in a competitive Request for Proposal process.

Results from CARD projects provide utilities with data to enhance energy efficiency program designs within their energy conservation and optimization portfolios.

CARD RFP Spending by Sector thru FY2020



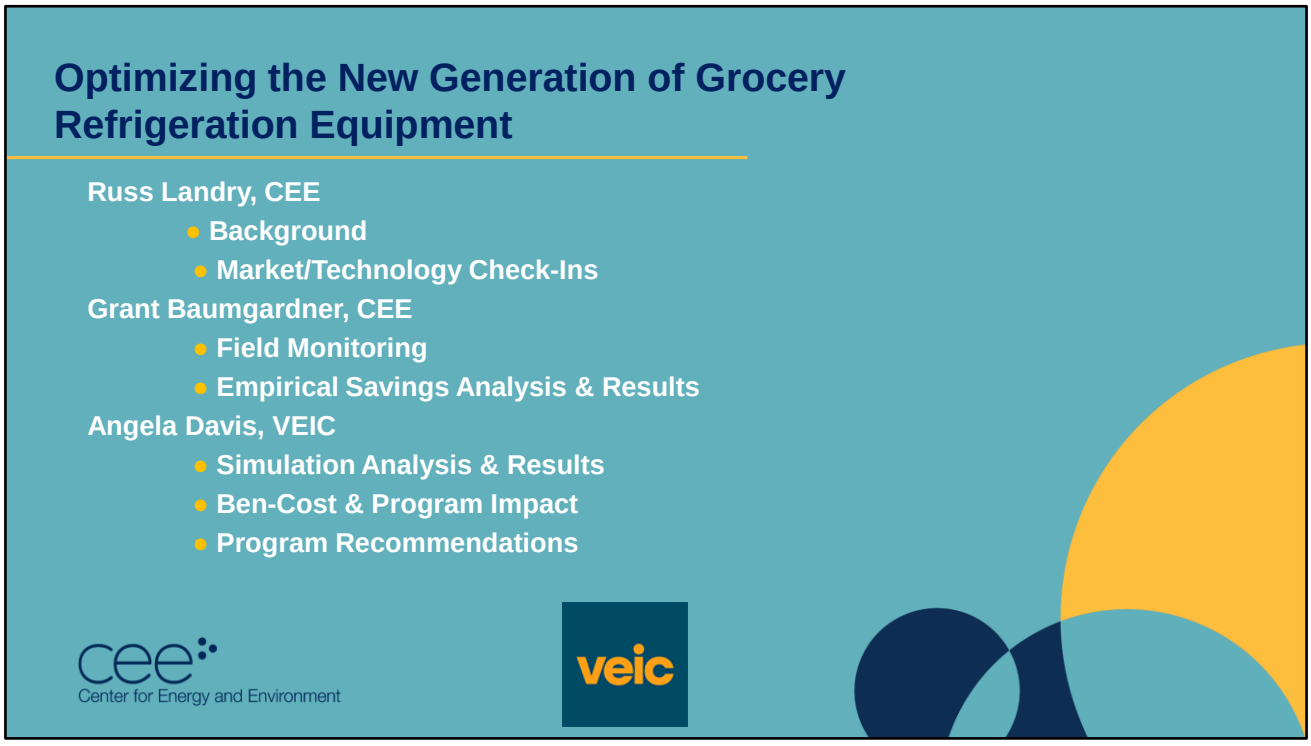
RFP Summary

- 12 Funding Cycles
- 513 proposals
- 143 projects funded
- $31.2 million in research

As you can see by the pie chart, CARD projects funded to date have been in all building sectors, as well as some that cross multiple sectors.

The subject of today's webinar is the commercial building sector and will discuss results from a recent CARD project to evaluate the savings and program potential for design features mitigating increased summertime energy use in the grocery industry by increasing efficiency of transcritical CO2 systems in Minnesota's climate as the industry moves to the use of carbon dioxide (CO2) as a refrigerant.

Now, I'll turn it over to Russ for today's presentation.



Good morning, I'm Russ Landry with CEE, and was the principal investigator and project management for this study. First of all, here's a brief summary of what we'll be presenting today.

I'll start with an overview of the project's background and scope, as well as a discussion of our market and technology check-ins and their key findings. Then Grant will outline the field monitoring and empirical savings analysis that he led. Lastly, Angela Davis from VEIC will discuss the simulation analysis that VEIC led, the program benefit-cost and impact analysis that VEIC led, and the ECO program recommendations that are based on synthesis of all of the findings from this project's efforts.



So, we're moving on to my discussion of the project background and the market and technology check-ins. [advance after a few seconds]

Project Context: Field-Testing CO2 System Options

- CARD-funded market study found significant trend towards new CO2 refrigeration systems in grocery stores
- In MN's cold climate, this tends to lead to higher summertime demand and lower annual energy use
- Many key demand and energy saving design options are new and/or exclusive to CO2 systems so have no CIP program history
- Initial field-testing of measures has focused on much warmer climates

Why? **To provide MN utilities with the information needed to adapt ECO programs to take advantage of opportunities unique to CO2 systems.**

I'll start out by telling why we chose to put the lion's share of this three-year project's efforts towards a local field study of efficient options for CO2 refrigeration systems. First of all, there is a significant trend towards new CO2 refrigeration systems in grocery stores that was highlighted in a CARD-funded commercial and industrial refrigeration market study that was completed in 2021 by CEE and partners of ours. While it is widely recognized that CO2 systems have tended to have lower annual energy use than other refrigeration systems in cold climates, the flip side of that is that basic CO2 system designs also tend to have higher peak demand in hot weather. While there are a number of system design options that can reduce their energy use--and especially their demand in hot weather periods—many of the key demand reducing CO2 system options are new to the US market and most are exclusive to CO2 systems. This means that there are no utility program precedents in Minnesota or elsewhere in the US. Lastly, we felt that it was important to perform local field testing both to increase local acceptance and because initial field trials of CO2 system options in the US have generally been limited to warmer climates where addressing the increased demand in hot weather has a bigger impact on end-user energy costs.

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Now the short version of why we undertook this study was to provide utilities in Minnesota with information to help them adapt ECO programs to take advantage of opportunities unique to CO2 refrigeration systems in grocery stores.

Project Context: What?

- Initial market/technology check-in to guide field-testing
- Recruited 3 sites and developed high-level testing plans
- Measure installations & field monitoring
- Savings analysis—empirical and simulations
- Evaluated ECO program cost-effectiveness & potential impact
- Repeated market/technology check-in
- Developed ECO program recommendations



Now here's a brief summary of the steps we took to gather information that would help to best inform ECO program developers. We started with an initial market and technology check-in to guide the selection of technologies and sites for field testing. Then we recruited three sites and negotiated testing plans and participant incentives. This was followed by a combination of coordinating measure installations and performing detailed field monitoring. We used the field data as a basis for both empirical energy and demand savings analysis, as well as to tune simulation models that provided engineering-principle based savings estimates. The savings results were then used to evaluate cost-effectiveness and statewide potential impact. Then before finalizing our ECO program recommendations, we repeated the market and technology check-in so that we would have the latest information available.

Market/Technology Check-Ins

- Initial check-in
  - Prioritize measure selection
  - Get leads on possible test sites
- Included literature review
- Repeated check-in at end
  - Get most up-to-date information for program recommendations
  - More focused targeting based on 1st round

Industry Role	# Interviewed
Manufacturers	**10**
Refrigeration Contractors	**3**
End-Users	**5**
Utilities	**5**

Our fist activity was to perform a market and technology check-in to get the most up to date and detailed information both nationally and for Minnesota's market. VEIC led the literature review and outreach to manufacturers, while CEE talked with local refrigeration contractors, end-users and utilities. The initial round of check-in both guided our prioritization of measures for the field study and provided leads on field study sites. This was important because we knew that the very limited number of CO2 refrigeration systems in Minnesota was going to make securing three test sites a critical challenge. Then, near the end of the project we repeated the market and technology check-in with that outreach a little more targeted to focus on the issues most critical to the Minnesota market based on what we had previously learned.

Key Findings of Market/Technology Check-ins

- The growing industry trend towards CO2 systems was confirmed
  - 30+ stores in Minnesota
  - Some contractors reports as the most common choice for new systems
  - Still relatively novel, so any efficiency upgrades should be simple
- Most CO2 efficiency options provide demand savings in hot weather, but little or no savings in cool weather
- The top 5 upgrade options for CO2 systems are exclusive to CO2 systems
- Field testing has primarily been limited to Europe and the southern US

Now I'll provide a high-level summary of the check-in findings before digging into specifics for the highest priority measures. First of all, we confirmed the previous market study's identification of a trend towards CO2 refrigeration systems and found the trend to be accelerating. We found that there are already at least 30 grocery stores in Minnesota with CO2 refrigeration systems and a number of contractors reported that CO2 is the most common choice for new grocery stores. As more regulations are placed against high-GWP refrigerants in the US, there will be a massive push towards low GWP refrigerants. With the global warming impact of "1", CO2 is seen as a future-proof refrigerant. The number of CO2 systems in the US rose from 360 in 2019 to 1850 in 2023 (which represents 2.9% of stores nationally). As this market shift is occurring, it is important for utility ECO programs address the best efficiency upgrade options for these systems.
Even though their use has been increasing rapidly, the local market contacts stressed that contractor technicians and store staff are still getting used to the differences in CO2 systems, so near-term uptake of efficiency measures is expected to be limited to those that are perceived as relatively simple.

When it comes to the specific system-level savings options for CO2 system, we found that most options primarily provide demand savings in hot weather, but little or no savings in cool weather.

We also found that the top 5 system level upgrade options for CO2 systems have not

been customarily used on other refrigeration systems. This is also true for two of the other measures that have gotten recent attention at the national level.

Lastly, we didn't find any new developments concerning other cold-climate testing of CO2 system efficiency options.

The Top 5 CO2 System Upgrade Options for MN

- Adiabatic Gas Coolers
- Flooded Evaporators/FTE
- Mechanical Subcooling

- Liquid Ejectors
- Multi Ejectors

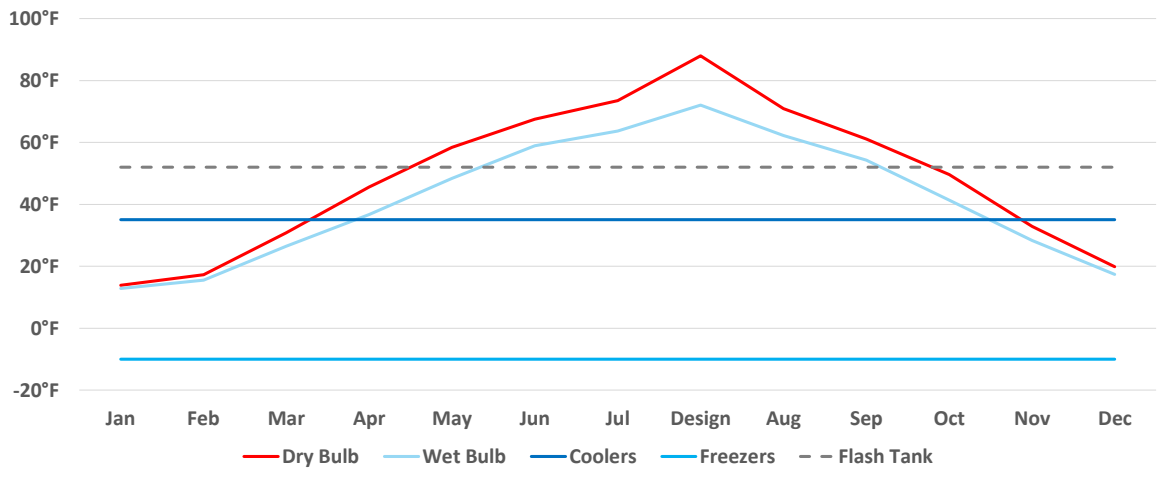
These first three measures were ranked with the highest priority for field testing and were successfully field-tested in this study. Before going into more details about adiabatic gas coolers, flooded evaporators (commonly referred to as FTE), and mechanical subcooling, I'd like to briefly touch on the last two measures listed here that received honorable mention among the other options that are commercially available at this time. ***click for animation***

While these two different forms of ejector technology were receiving a lot of national level buzz in the industry at the time of our first market and technology check-in, they were given a second tier rank for two key local market reasons. First of all, they were perceived by local store representatives and contractors as being much more complex than the first three, which is still an important barrier given that technicians are generally at best still just getting familiar with basic CO2 systems. Another key barrier in the Minnesota market is that the ejector products commercially available at the start of this project were all available from only one rack controls manufacturer and the ejectors could not be effectively controlled by the competitor's rack controller that overwhelmingly dominates the Minnesota market. Contractors and store contacts were very reluctant to consider changing from their familiar standard rack controller in order to achieve compatibility with one system component, especially when combined with the complexity of the measure to begin with. Near the end of our study, a compressor manufacturer had introduced a competing ejector product that initially appears to be much more likely to be compatible with the dominant rack controller in Minnesota.

Despite this, it appeared that the release of this new product had not yet translated into increased local market interest in ejectors.

Now, we'll dive deeper into the top-three priority measures.

Adiabatic Gas Coolers



First of all, adiabatic gas coolers are the most commonly used upgrade option. To understand how adiabatic gas coolers save energy it's helpful to think of a refrigeration system's purpose as taking unwanted heat from a low temperature cooler or freezer where it's not wanted and disposing of that heat to outdoor air. We all know that heat flows from warmer things to colder things, so it's helpful to think of the refrigeration system as moving heat uphill from the refrigerated cases to temperatures well above the outdoor temperature so that the heat will flow from the refrigerant to the outdoor air. The farther the system has to move heat uphill, the more energy the system uses, especially the compressors which are the workhorses and main energy users in refrigeration systems. The flat solid blue lines in the graph represent the temperatures of the coolers and freezers in a grocery store while the red line represents a simplified version of the changes in outdoor air temperature over the course of a year. In the summer, the farther the red line is above the blue lines, the more energy the system uses to move the unwanted heat into the outdoor air. Sorry to complicate this more, but the dashed line on the chart shows a minimum refrigerant temperature level needed for the refrigeration system to work properly so wherever the red outdoor temperature drops below this dashed line, the system must still move heat uphill above the level of the dashed line.

With a traditional dry gas cooler the red outdoor temperature line represents the minimum level that the refrigerant temperature must be brought above. Adiabatic gas coolers save energy by precooling the air going into the gas cooler. This precooling is

done by evaporating water into the air as it flows through a wetted media. The blue outdoor wet-bulb line shows a slightly exaggerated estimate of how much the air is cooled down as it enters the gas cooler. This precooled air temperature is then a lower minimum level that the refrigerant temperature must be brought above. The lower temperature means less compressor energy use when outdoor temperature is above the dashed lines representation of minimum temperature required for system operation. You can see that the adiabatic gas cooler benefit is largest in the hottest weather, and can still provide a modest benefit at outdoor temperatures of about 55°F or higher.

So that sums up the technical side of how adiabatic gas coolers save energy.

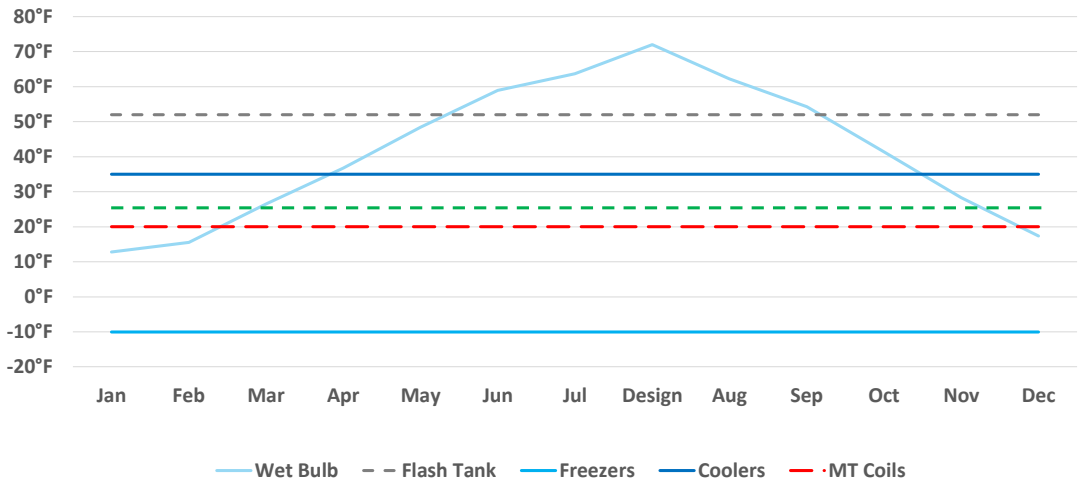
Adiabatic Gas Coolers cont.

- By end of study used in virtually all new large CO2 systems in MN (but not necessarily smaller systems)
- High upgrade cost even at time of new refrigeration system installation
- High demand savings, modest energy savings in cold climates
- Local standard practice was to only operate with water at 75°F and above
- At least one product is now available to convert air-cooled gas coolers



And here are the key market findings. First of all, by the end of the study it appears that virtually all new large CO2 systems being installed in Minnesota grocery stores use adiabatic gas coolers. The possible exception to this is small grocery stores where at least two dozen systems with dry coolers are already in place. There is a high upgrade cost for adiabatic gas coolers, even at the time of installation as part of an entirely new system. While adiabatic gas coolers provide high demand savings and are considered by most local industry contacts as being necessary, they only provide a modest level of annual energy savings in our climate. At the onset of the study, we also found that local standard practice is to only use the water-cooling when outdoor temperatures are 75°F or higher. This led us to make it a high priority to evaluate the potential savings associated with lowering that wet/dry switchover setpoint. One interesting development we heard about near the end of study is that a product was introduced that would convert existing air-cooled gas coolers into adiabatic gas coolers. While this seems to be a promising option for a number of existing stores in Minnesota, the manufacturer's unresponsive to repeated outreach limited the information available to us.

Flooded Evaporators/FTE

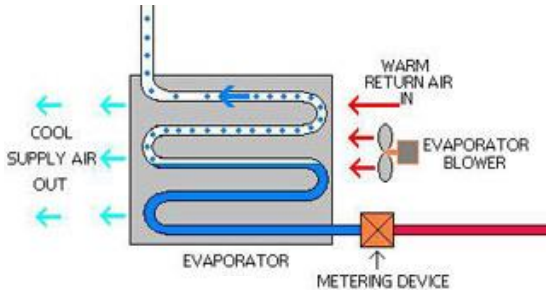


The second high-priority measure is commonly referred to as FTE in the industry, and saves energy by flooding cooling coils with refrigerant and then raising the low-end operating temperature of the refrigeration system. This is a repeat of the previous figure with the refrigerant system low-end operating temperature of the refrigerant cooling the coolers represented by the two lower dashed lines, The red line with longer dashes represents the temperature of the refrigerant inside the cooling coils in a typical CO2 system.

When the evaporators are flooded, the system can remove the same amount of heat form the coolers with a higher refrigerant temperature, represented by the green line with shorter dashes that is above it. This higher year-round refrigerant temperature provides year-round energy savings.

Flooded Evaporators/FTE cont.

- Saves energy by allowing coolers to run at higher refrigerant temperatures
- Moderate demand savings, year-round energy savings
- Only available through one rack manufacturer with modest MN market share
- Local market interest and perception of simplicity
- Much of the savings is very similar to how some of ejector approaches achieve savings



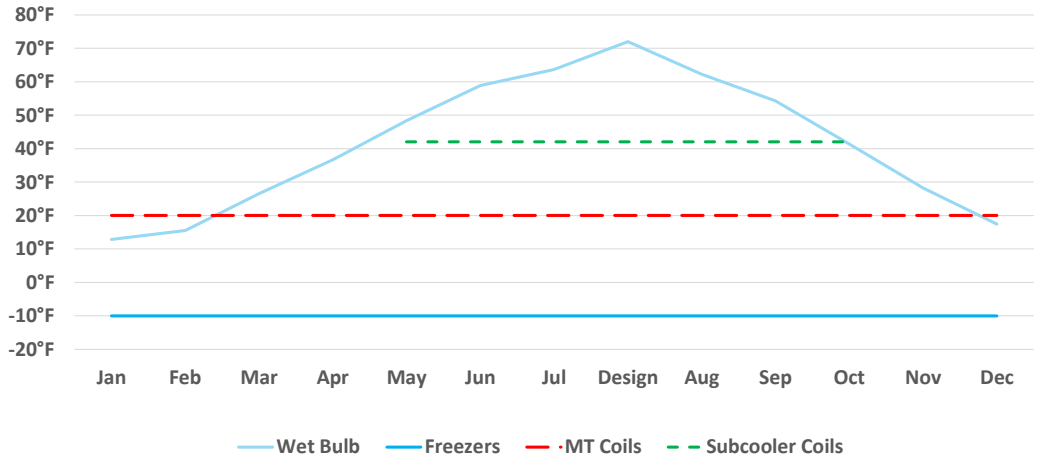
Now I'll try to clarify how the refrigerant temperature can be raised with an FTE system. The diagram on the right shows how a typical cooling coil has primarily liquid refrigerant in a portion of the evaporator coil and primarily gas refrigerant in much of the cooling coil. The portion of the cooling coil with liquid absorbs much more heat from the air blowing over the coil that the portion with vapor. With the FTE technology, most or all of the cooling coil has liquid refrigerant so a lower temperature difference between the air and refrigerant is needed to absorb the same amount of heat.

This technology provides moderate demand savings in hot weather, but provides year-round energy savings that most CO2 system-level upgrade options do not.

While the approach used in FTE systems is patented by one manufacturer that has only a modest market share in Minnesota, that manufacturer has expressed potential to license the approach to other manufacturers. Despite the modest local market share of this manufacturer, multiple local contacts expressed a high level of interest in the FTE approach, and perceived it as being simpler than many other upgrade options.

One last item we considered is that the primary mode of savings is similar to primary savings mode of one of the ejector approaches.

Mechanical Subcooling



The last high-priority measure is mechanical subcooling.
Savings is achieved by using a separate higher temperature coil and compressor to precool the refrigerant on its way back from the gas cooler. The precooled refrigerant is then able to absorb more heat per pound of refrigerant pumped through the refrigeration system compressors.

The line with the small dashes shows an example of a mechanical subcooler's refrigerant temperature compared to the line with the large red dashes representing the refrigerant temperature in the coolers. While the mechanical subcooler does use energy, it has a much lower temperature lift than the main refrigeration system and provides a net energy benefit.

Mechanical Subcooling cont.

- Uses a higher temperature cooling coil to precool refrigerant
- Significant demand savings, modest annual energy savings
- Potential retrofit—especially for 25+ air-cooled gas cooler systems in place
- Perceived as a simple upgrade
- Savings mechanism is similar to parallel compression



In the field study, this subcooling was carried out by a condensing unit that was packaged with the subcooling heat exchanger located in the same cabinet.

As with most CO2 system-level upgrade options, mechanical subcooling provides significant demand savings, but modest annual energy savings in Minnesota because it typically only operates in warm and hot weather. It is also noteworthy that mechanical subcooling savings is lower when adiabatic gas coolers are used, so we see the primary market for mechanical subcooling as small grocery store systems—especially the existing stores in Minnesota that could be retrofit with mechanical subcooling.

Market contacts generally consider mechanical subcooling to be a simple upgrade. It's also noteworthy that the savings mechanism of mechanical subcooling is very similar to parallel compression, which is another measure with significant national buzz that we categorized as a low-priority measure because of its complexity.



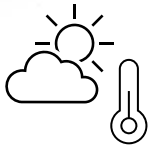
Now, I'll hand it over to Grant to discuss the field monitoring and the empirical savings.

Field Monitoring

- Power monitors
- Weather data
- Control system operation data

Technology	Site ID
Adiabatic Gas Cooler	Site A
Flooded Evaporators/FTE	Site F
Mechanical Subcooling	Site M





Name	Value	Units
U0.2 MT Suction Pressure	438.8	psi
U0.3 MT Discharge Pressure	855.0	psi
P0.3 MT Suction Temp	55.2	°F
Disch. Temp	153.5	°F

First, I want to emphasize the mapping of the technologies to the Site IDs, as I will be referring to these throughout the field monitoring discussion. Each site was given a letter code corresponding to the first letter of the technology we were studying. For example, the site with adiabatic gas cooler was site A, etc.

Refrigeration system energy use was the primary measurement at each site. An eGauge monitoring system was installed to measure the power of each of the three-phase medium-temperature and low-temperature compressors at all three sites. This same eGauge system was also used to measure the gas-cooler power use at Site F and Site M, in addition to the mechanical subcooler

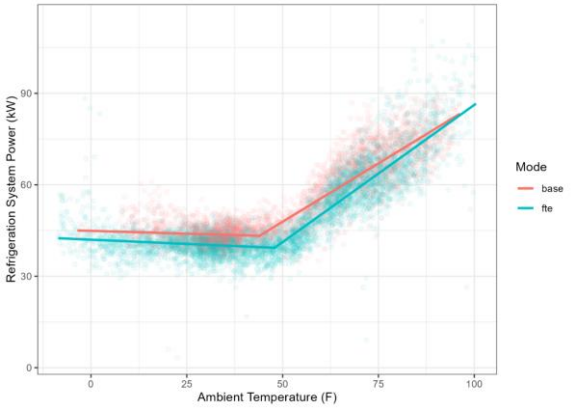
power use at Site M. This system recorded the averages of power measurements for each one-minute interval.

Where possible, additional system operating condition and performance data was also collected from the refrigeration system controllers. Both Site A and Site F use refrigeration controllers that are part of a BAS system to which the store representatives provided project staff with online access. We used this access to collect historical trend data with one-minute interval readings from each of the equipment controllers. Temperature, pressure, and actuator status data was downloaded via the BAS portal approximately weekly.

Weather data from the NOAA NCEI local climatological data table for Minneapolis-St. Paul International Airport was downloaded on a weekly basis and used to supplement outdoor temperature data when it was not available from the control system. Site M only used downloaded weather data for the analysis.

Empirical Analysis Approach

- Linear regression of system power as a function of outdoor temperature
  - Two separate models for each site: Baseline & Measure Active
- Annual energy use calculated by summing hourly predictions
  - Outdoor temperature input from TMY 2020 weather data
- Demand savings calculated by averaging selected hourly predictions
  - Hours used for basis selected based on utility feedback



Linear regressions of system power as a function of temperature were used to estimate the performance of each measure. Note that for the purposes of the empirical analysis, refrigeration system power refers to the combined power demand of all compressors and gas coolers only.

Two piecewise linear regression models predicting hourly average refrigeration system power demand as a function of hourly average outdoor temperature were created for each site. The baseline model was based on system performance with the measure inactive or prior to measure installation, while the measure active model was based on system performance with the measure active or

installed.

The regression models were used to predict hourly power demand at each temperature included in the typical meteorological year (TMY) 2020 weather data. The annual energy consumption was calculated by integrating these power predictions over time for the one-year period covered by the TMY data. For hourly data, this was practically equivalent to summing each of the 8760 predictions. Energy savings were calculated as the difference between the sum of predictions of the baseline and measure active models at each site.

Empirical demand savings were evaluated using the same regression models. Selected hours from the TMY data were used to represent periods of peak grid stress. Each regression model was used to predict power demand at these selected hours. The demand savings associated with each measure was the difference between the average predictions of the baseline and measure active models for each site.

Empirical Analysis Results: Energy Savings

Site: Measure	Baseline Usage (kWh)	Measure Usage (kWh)	Annual Savings (kWh)	Annual Savings (%)	Savings 95% CI (%)
A: Adiabatic Gas Cooler (AGC)	319,031	312,232	6,799	2.1%	[1.8%, 2.4%]
A: Optimizing AGC Control	316,974	312,232	4,742	1.5%	[1.1%, 2.0%]
F: FTE/Flooded Evaporators	449,216	413,822	35,395	7.9%	[7.4%, 8.4%]
M: Mechanical Subcooler	179,072	172,245	6,827	3.8%	[2.5%, 5.1%]

Each measure included in field testing was expected to provide both energy and demand savings. The energy and demand analysis reported for the adiabatic gas cooler are based on regression model predictions using water-cooled operation at outdoor temperatures greater than or equal to 55°F. The optimizing adiabatic gas cooler (AGC) control compares data with an outdoor temperature change-over setpoint of 55°F to the as-found setpoint of 75°F.

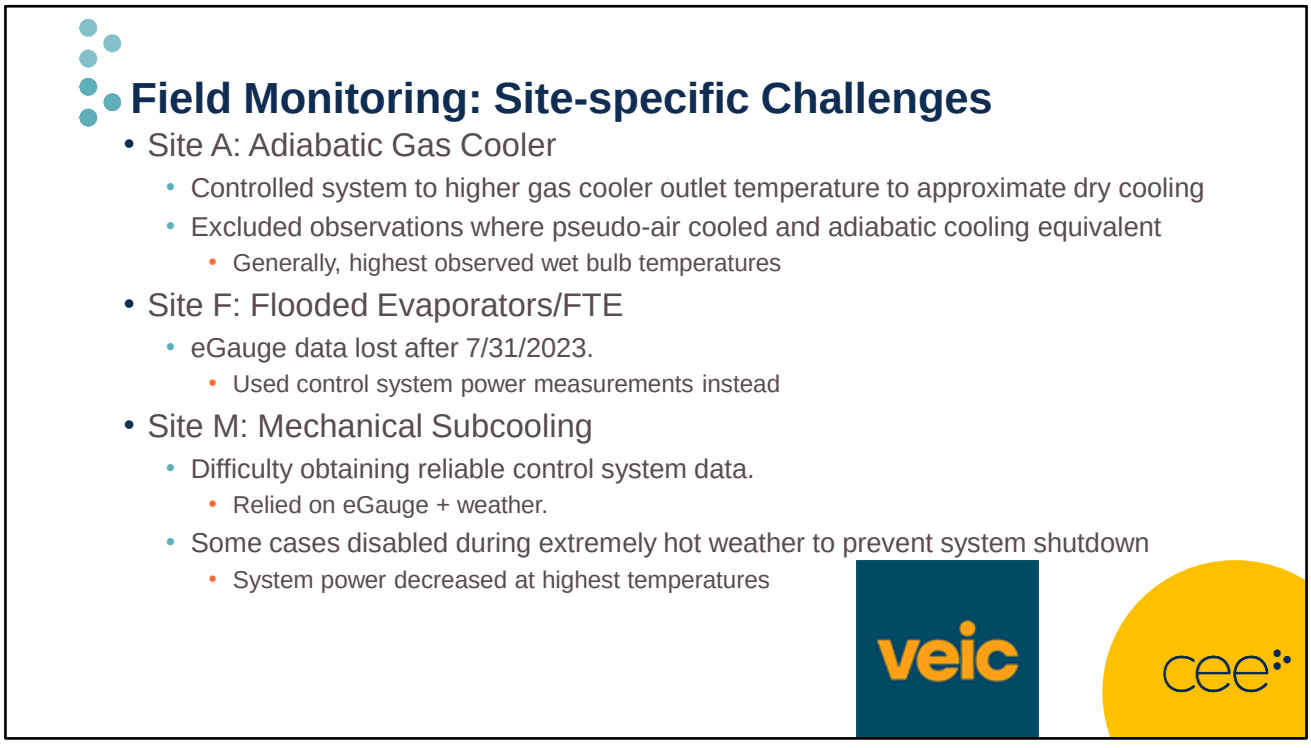
The FTE provides the most energy savings because it improves the efficiency of the refrigeration system in all weather conditions, while the adiabatic gas cooler and mechanical subcooler improve efficiency at high outdoor temperatures.

Empirical Analysis Results: Demand Savings

Site: Measure	Baseline Demand (kW)	Measure Demand (kW)	Demand Savings (kW)	Demand Savings (%)
A: Adiabatic Gas Cooler (AGC)	65.1	62.1	3.0	4.5%
A: Optimizing AGC Control	62.1, 55.4*	62.1, 55.2*	0, 0.2*	0.0%, 0.4%*
F: FTE/Flooded Evaporators	76.3	74.6	1.7	2.2%
M: Mechanical Subcooler	52.0	49.3	2.8	5.4%

*Demand savings depend on temperatures used in calculation. Control optimization affects performance < 75 °F.

The measure associated with the largest predicted relative demand savings was the mechanical subcooler. This estimate factors in the additional power required for the separate mechanical refrigeration system. The adiabatic gas cooler also shows strong demand savings in Minnesota's climate. While the primary benefit of the FTE system is year-round energy savings because the power demand of the system is reduced relatively evenly at all temperatures, modest demand savings are associated with this measure as well.



Some caveats on the data used in the field analysis:

At site A, the gas coolers were designed to be operated with adiabatic cooling at the highest temperatures. Without wet evaporative media, the gas coolers were undersized to reject heat from the refrigeration system. Therefore, the gas coolers were always operated adiabatically, and to simulate dry cooling, the gas cooler outlet temperature setpoint was configured as an offset with respect to the dry bulb temperature. The gas cooler outlet temperature setpoint was limited to 85 F, so in some cases, the setpoint in pseudo-air cooled mode and in adiabatic cooling modes were equivalent. Generally, this was when the wet bulb temperatures were highest. In these cases, there was no functional difference between operating modes, so we excluded observations meeting this criteria from the analysis.

At Site F, an issue with our power meters resulted in a data loss for the final few months of the project. This interval was intended to capture mild weather performance with the measure active. Fortunately, we were also collecting power meter data from the control system, and this correlated well with the independent measurements we had made up to that point.

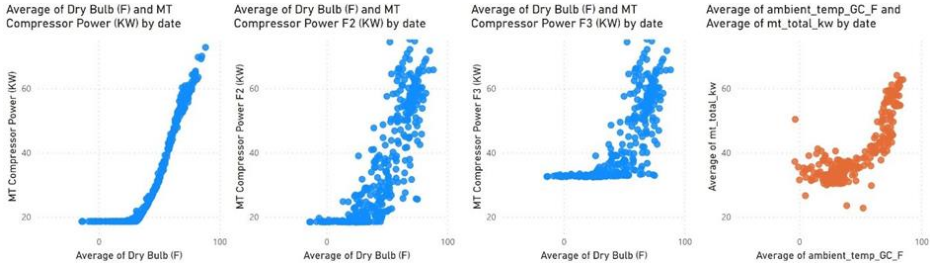
At site M, it was difficult to obtain reliable control system data. The application for accessing data at this site struggled to furnish the data we requested without crashing, and had limited memory, requiring frequent downloads for full coverage. When we

could extract data, we found that the timestamps for simultaneous measurements sometimes differed by hours or more. These challenges caused us to rely only on the power meter and weather data to build our models for this site. In addition, a control strategy that sacrificed refrigeration capacity for some cases to ensure continued operation for most of the cases in the store resulted in a slight decrease in power demand at the highest temperatures

Energy Simulations, Ben-Cost, Impact & Program Recommendations

Angela Davis, VEIC

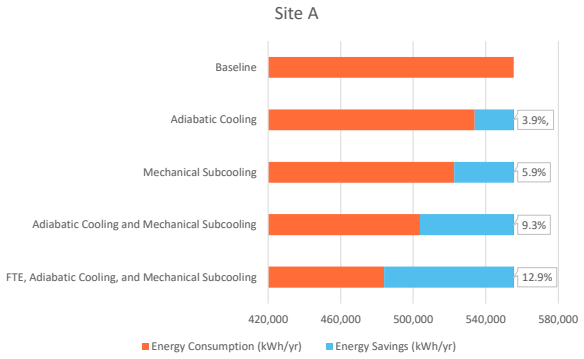
Simulation Methodology

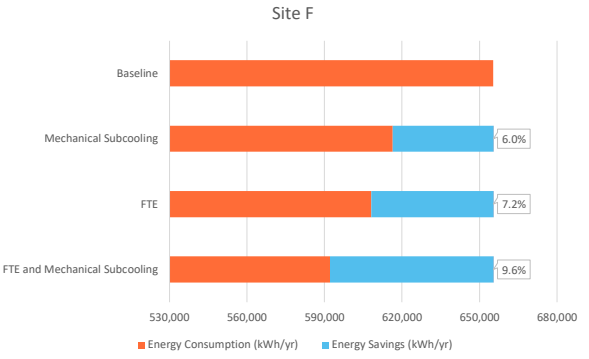


Three sites were modeled using OpenStudio, an opensource collection of tools which leverages EnergyPlus calculations to create energy models. Each site was a grocery store in Minnesota with a transcritical refrigeration system using CO2 as the refrigerant. The blue graphs here show dry bulb temperature vs medium temp compressor power for three versions of the Site F model. The orange graph on the far right shows the metered data. On the furthest left is a mostly prototypical grocery store model with cases, walkins, and compressor curves from refrigeration drawings and manufacturer specs. The next two graphs show a couple iterations of the of the model as adjustments were made to better match reality such as adding air mixing to represent the typical open floorplan of a supermarket sales area and fix an issue with abnormally low humidity in spaces causing too little fluctuation in evaporator loads throughout the day.

Once the results of the model aligned with the metered data we started applying scripts written by VEIC to the baseline models to simulate the changes to the building's energy use. For this project we created scripts to represent adiabatic subcooling, mechanical subcooling, and FTE or full transcritical efficiency.

Simulation Results





There are 5 iterations of the model at site A. Baseline, adiabatic cooling only, mechanical subcooling only, adiabatic with mechanical subcooling, and FTE, adiabatic cooling, and mechanical subcooling. The baseline represents a standard operating transcritical CO2 system with 75F adiabatic cooling. The adiabatic cooling measure shows the savings when the adiabatic cooling setpoint is changed to 55F. Adiabatic and mechanical subcooling combines the 55F adiabatic cooling with a mechanical subcooler. And the last measure combines the FTE system with the 55F adiabatic and the mechanical subcooler. The orange bars represent the energy consumption difference from the baseline. With the total percent savings at the end of the bars. The combination of all the measures yields the highest percent savings at 12.9%. Mechanical subcooling performed better than adiabatic alone (5.9% compared to 3.9% respectively).

The Site F graph shows 4 models which are the baseline, FTE only, mechanical subcooling only, and both FTE and mechanical subcooling. As with Site A, the baseline is a transcritical CO2 system with adiabatic cooling set to operate at outdoor temperatures above 55°F. The FTE system performed better than the mechanical subcooler (7.2% savings vs 6% savings). The combination of them both resulted in 9.6% energy savings, which is significantly lower than the sum of the two individual upgrade measures due to interactive effects.
The overall simulation results expectedly showed that the combination of all of the upgrade measures has the highest potential for energy savings. The pair of measures

with the greatest savings is the combination of an FTE with mechanical subcooling. The combination performed slightly better than an adiabatic gas cooler paired with mechanical subcooling (9.6% vs 9.3%).

Bridging Empirical to Simulated

Estimate Type	Adiabatic Gas Cooler (AGC)		FTE/Flooded Evaporators		Mechanical Subcooling (MS)	
	Annual Energy Savings (kWh)	Annual Demand Savings (kW)	Annual Energy Savings (kWh)	Annual Demand Savings (kW)	Annual Energy Savings (kWh)	Annual Demand Savings (kW)
Prior Studies or Modeling	-	10%	10.2%	-	-	13.4% (@86°F)
Project Team Engineering Estimate	15.4%	-	15.1%	12.5%	4.5%	11.6%
This Study's Empirical Findings	2.1%	4.5%	7.9%	2.2%	3.8%	5.4%
This Study's Simulation	4.9%	12.3%	9.0%	11.6%	11.4%	14.3%
Simulation When Added After Other Upgrade	4.3% MS		4.5% AGC/MS		7.1% AGC 3.2% AGC/FTE	
Recommended Estimate at This Time	3%	8%	7.9% if AGC (4% if AGC & MS)	5%	3.8% (2.4% if AGC)	10%

The Empirical Results are an actual representation of what was observed on site from metered data. Simulation Results are informed by metered data, but represents optimal operational conditions. This actual vs "perfect world" analysis approach creates slight variations in the savings for the sites. Some of the gaps between the results would align with additional simulation iterations with more data points. But some of the differences are due to site operations, such as compressor control strategies and staging. It was noted for the adiabatic system that the baseline data was not the best representation of air-cooled gas cooler behavior at higher outside air temperatures. The demand savings for the adiabatic and mechanical subcooler sites have also been affected by limited amount of data from the testing modes at high temperature as well as short time intervals of data. But where that issue was encountered, the information provided by the simulation results are used to support the savings claim.

Cost Effectiveness cont.

Customer Focused Economic Analysis

Data Type	Upgrade Measure Description	Cost Per Site	First-Year Savings (kWh)	Demand Savings (kW)	Simple Payback (years)	Annual Energy Cost Savings
Empirical	Adiabatic Condenser	$40,000	6,799	3	76.6	$522
Simulated	Adiabatic Condenser	$40,000	21,540	11	24.2	$1,654
Empirical	Adiabatic Condenser – Temperature Setpoint Optimization	$500	4,742	0	1.4	$364
Empirical	FTE/Flooded Evaporators	$68,075	35,394	1.7	25.0	$2,718
Simulated	FTE/Flooded Evaporators	$68,075	47,197	11.3	18.8	$3,625
Empirical	Mechanical Subcooling	$20,386	6,827	2.8	38.9	$524
Simulated	Mechanical Subcooling	$20,386	18,746	5.2	14.2	$1,440

Cheapest/quickest payback: Adiabatic Temperature Setpoint Adjustment
Highest Savings: FTE

This table shows the empirical and simulated results for the measures with a focus on the metrics that would interest a customer the most. The cheapest and easiest for the customer to implement would be the temperature setpoint adjustments of the adiabatic system. FTE system has the potential for the highest energy savings. The initial investment for the FTE system is substantial though. Outside of setpoint adjustments, the mechanical subcooler is the lowest cost measure to install.

Cost Effectiveness cont 1

BCA Tests

Data type	Measure description	Ratepayer Impact Measure Test	Utility Cost Test	Societal Cost Test	Participant Cost Test	Minnesota Test
Empirical	Adiabatic Condenser	0.6	0.82	0.04	0.05	1.16
Simulated	Adiabatic Condenser	1.26	2.71	0.12	0.11	3.81
Empirical	Adiabatic Condenser - Temperature Setpoint Optimization	1.24	5.76	0.45	0.42	9.27
Empirical	FTE	0.88	1.88	0.72	1.33	2.96
Simulated	FTE	1.17	2.95	1.06	1.65	4.38
Empirical	Mechanical Subcooling	0.59	0.8	0.39	1.36	1.15
Simulated	Mechanical Subcooling	1	2.01	0.99	2.44	2.96

All Measures pass the Minnesota Test

The BCA tests compare various costs of the measure to their associated benefits they will provide. The Ratepayer Impact Measure Test shows the impact of the program on billing rates to the ratepayers. The societal cost test is a test that incorporates broader social and environmental impacts of the measure. The Utility cost test looks at the benefits of a measure from the utility's perspective. The participant cost test looks at the benefits of a measure from a customer's perspective. The Minnesota Test has been recommended as a primary economic analysis test for the state. This test aims to update the cost-effectiveness methodologies for Energy Conservation and Optimization by incorporating elements of the other tests deemed valuable to the state of Minnesota. Tests that are passed are highlighted in green.

The tests were performed using the previously mentioned costs and potential rebates. All measures passed the MN Test and most pass the Utility Cost Test.

Cost Effectiveness cont 2

Utility Focused Economic Analysis

Measure description	First-year savings Retrofit (kWh)	Demand savings Retrofit (kW)	Est. Retrofit Opportunities	Est. New Construction Opportunities	Technical savings potential (first-year, kWh, retrofit)	Technical savings potential (first-year, kWh, new construction)
Empirical - Adiabatic Condenser	6,799	3	3	0.5	20,397	3,549
Simulated - Adiabatic Condenser	21,540	11	3	0.5	64,620	11,244
Empirical - Adiabatic Condenser - Temp Setpoint	4,742	-	7	1.2	33,194	5,776
Empirical - FTE	35,394	2	5	0.5	176,970	18,818
Simulated - FTE	47,197	11	5	0.5	235,985	25,093
Empirical - Mechanical Subcooling	6,827	3	1	0.5	6,827	3,564
Simulated - Mechanical Subcooling	18,746	5	1	0.5	18,746	9,785

- FTE has highest savings potential
- Adiabatic temperature setpoint adjustment has highest opportunity

Here we see the comparison of the measures with a focus on the metrics that pertain to the utility. Based on the market study interviews and installation trends (from previous MN Card reports and US trends), the number of retrofit and new construction opportunities for each measure was estimated. An approximate amount have been found from those installation numbers. The number of opportunities for temperature setback are higher than the other measures because installers consider adiabatic coolers as standard equipment to install along with CO2 refrigeration systems (with the exception of smaller stores). FTE systems have the highest savings potential due to a combined higher energy savings and moderate future growth opportunities.

Cost Effectiveness cont 3

Utility Focused Economic Analysis

Measure description	Estimated Rebate ($)	Simple Payback with Incentive (years)	Total Annual Program Cost to Utility ($)	Generation Cost Savings ($/kWh)	Demand Cost Savings ($/kW)
Empirical - Adiabatic Condenser	15,000	48	62,893	300	346
Simulated - Adiabatic Condenser	15,000	15	62,893	951	1,270
Empirical - Adiabatic Condenser - Temp Setpoint	250	(1)	2,446	209	-
Empirical - FTE	25,000	16	164,633	1,562	196
Simulated - FTE	25,000	12	164,633	2,083	1,305
Empirical - Mechanical Subcooling	15,000	10	27,179	301	323
Simulated - Mechanical Subcooling	15,000	4	27,179	827	600

- FTE measure most expensive to implement, but has highest payoff
- Payback is best with Adiabatic temp setpoint adjustment and Mechanical subcooling

The administrative costs are assumed to be 16% of the total budget (based on historical program operating budgets). Temperature setpoint adjustment has the lowest cost to the utility (due to a smaller estimated rebate). The FTE system has the highest anticipated cost to the utility to implement but also comes with the highest $/kWh generation cost savings. The generation cost savings and the demand cost savings for the utility are based on expected energy savings and scale accordingly. The temperature setpoint adjustment for adiabatic systems has the quickest payback with mechanical subcoolers also having a good payback

Program Impacts

	Adiabatic w/55F Setpoint	Adiabatic Temp Switch	FTE	Mechanical Subcooler
	Good Demand Savings	*Quick Payback*	*Good kWh Savings*	*Economical*
Expected Annual Savings	75.6 kWh/ton	52.8 kWh/ton	433 kWh/ton	136 kWh/ton
Expected % Savings	2.1% of refrigeration energy use	1.5% of refrigeration energy use	7.9% of refrigeration energy use	3.8% of refrigeration energy use
Annual Demand Savings	3 KW	0 KW	1.7 KW	2.8 KW
Estimated Useful Life	15 years	3 years	15 years	15 years
Incremental Cost (Equipment & Labor)	$40,000	$500	$68,075	$20,386
Recommended Incentive	$167/ton capacity	$250	$300/ton capacity	$360/ton
Estimated Total Incentive Per Installation	$15,000	$250	$25,000	$15,000
Simple Payback (with incentive)	48 years	8 months	~16 years	~10 years

NOTE: ANIMATIONS ON SLIDE (ONE CLICK)

This table shows the summation of the measure impacts (from empirical data). The expected annual savings have been reduced to what a kWh per ton savings may be (based on each site's refrigeration capacity). The data again reflects the previous conclusions. ***(CLICK MOUSE FOR ANIMATION)*** The FTE system has the highest savings out of the measures; the adiabatic temperature setpoint optimization has the lowest cost to implement with a quick payback; Adiabatic systems have good demand savings; the mechanical subcooler is cheaper to install than the adiabatic system or the FTE system. Making mechanical subcoolers an economical middle ground between all the measures.

Program Recommendations- Near Term

- Implement temperature setpoint optimization on new and existing adiabatic coolers
- Develop rebate program for
  - Mechanical subcoolers as a retrofit opportunity
  - FTE/flooded evaporators for new CO2 systems
  - Adiabatic gas cooler retrofits and/or installations in small refrigeration systems
    - Stores less than 60 tons of refrigeration are less likely to have adiabatic coolers.
- Further research into air-cooled gas cooler to adiabatic gas cooler conversions

The work done for this project was performed to provide information on the savings potential for these measures in hopes that it may support the development of TRM measures. By incorporating these results into a technical resource manual, utilities will have the support to provide incentives for the installation of these measures.

The program recommendations in the near term are:

- Implement temperature setpoint optimization on new and existing adiabatic gas coolers
- Develop rebates for the following - retrofit of mechanical subcooling onto existing systems that use air-cooled gas coolers, FTE/flooded evaporators as part of new CO2 system installations, and adiabatic gas coolers limited to retrofits of existing CO2 refrigeration systems and new system installations in small refrigeration systems
  - Small system meaning stores less than 60 tons of refrigeration which are less likely to have adiabatic coolers
  - Large store CO2 refrigeration systems have been intentionally omitted due to adiabatic gas coolers generally being considered a part of the baseline system design
- The last near-term recommendation is to further research the viability of converting existing air-cooled gas coolers to adiabatic gas coolers

Program Recommendations- Long Term

- Ejectors
  - Controller compatibility
  - Market interest
  - Research savings for currently available options
- Expanders
  - Epta's ZTE system
  - Bitzer products

The long term program development efforts should look at the following:

- Ejectors, especially considering whether the latest product offering addresses the controller compatibility issue, if local market interest increases, and what savings are realized by the various currently available options
- And Expanders, especially watching for the near to mid term release of Epta's XTE system, and possible longer term release of products by Bitzer, then evaluating carefully as more information becomes available

Questions?

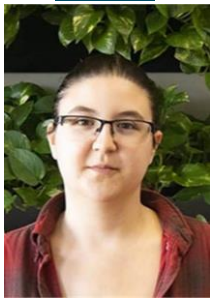
Optimizing the New Generation of Grocery Refrigeration Equipment



Russ Landry
rlandry@mncee.org



Grant Baumgardner
gbaumgardner@mncee.org



Angela Davis
apdavis@veic.org

Send us your questions using the Q&A panel

Thanks for your great presentation!

If you have not already done so, please type any additional questions into the Q&A panel and send them to us.

****

Laura, do you have any questions for Russ, Grant, or Angela?

Thanks again for your presentation and to Laura for facilitating the Q&A. If you have follow-up questions about this CARD project, feel free to contact us.



The slide set will be emailed to all webinar registrants within a week or two of today's webinar.

The recording of this webinar and slide set will be available on the Department's website along with the final report in a couple of months. When available, you can link to either of these from the quick links on our Applied Research and Development webpage as indicated on this slide.

The Department's R&D web page has additional resources and information related to the CARD program and to CARD research projects which you can check out by going to the webaddress in the middle of this slide. The CARD website rebuild is now complete. To access Research before 2020 through the left panel weblinks, and access Research since 2020 through the blue button in the center of the webpage.

Although the CARD website rebuild is now complete, there are ongoing efforts to ensure all the research is posted, so please do not hesitate to contact me if you have any questions or concerns related to accessing CARD research posted here.

Thanks for Participating!

Upcoming CARD Webinars:

- **April 25, 2024: Center for Energy and Environment - Ductless Cold Climate Heat Pumps for Multifamily Applications**

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Lindsay Anderson| Utility Energy Conservation Research Planner
lindsay.anderson@state.mn.us| 651-539-1771

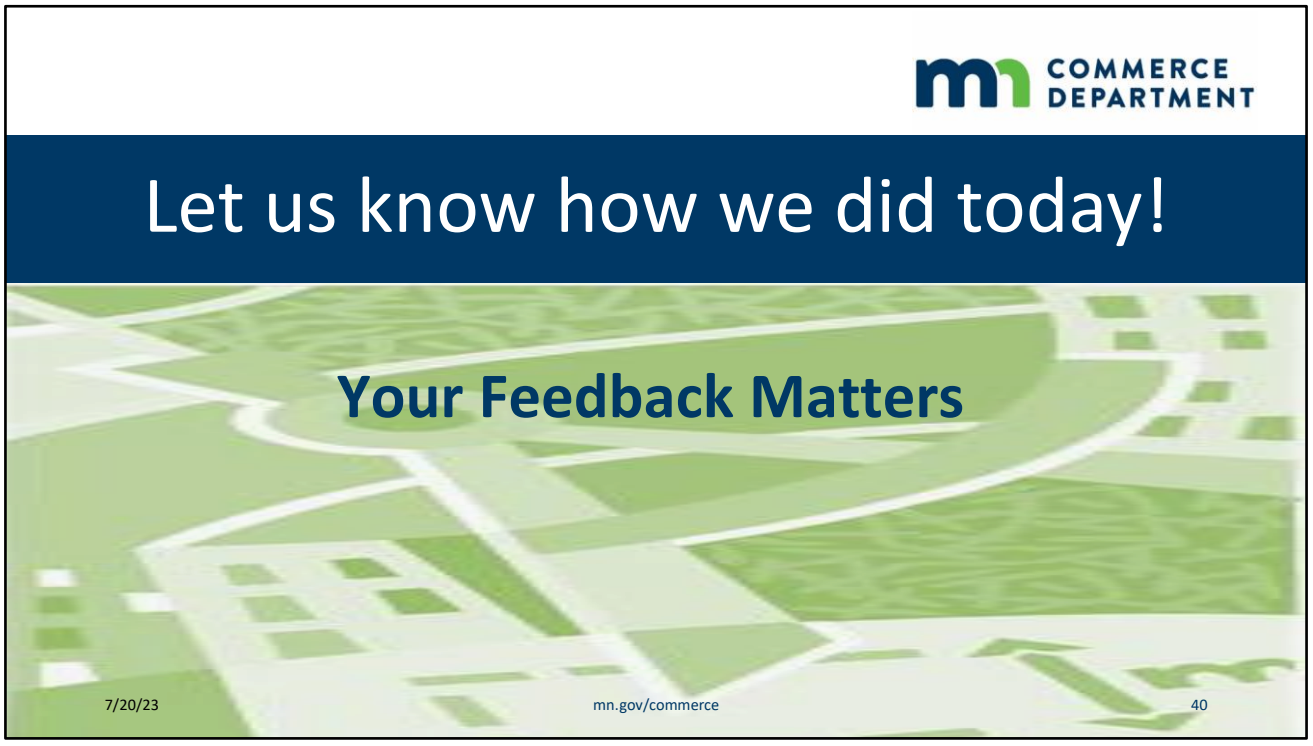
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I want to take a minute to mention an upcoming CARD webinar:

- **April 25, 2024: Center for Energy and Environment - Ductless Cold Climate Heat Pumps for Multifamily Applications**

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In the meantime, contact me if you have questions or suggestions for the CARD program or CARD webinars.



Thanks again for participating today! That ends this webinar - take care and good bye.