

Welcome

Conservation Applied Research & Development (CARD) Webinar

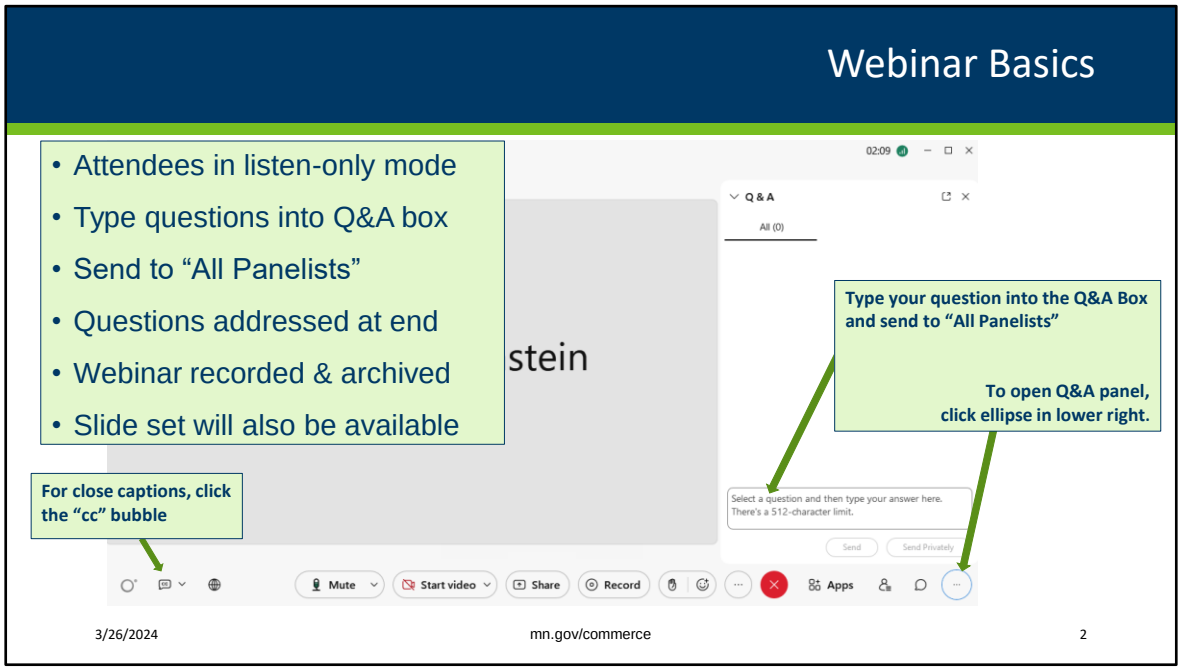
March 19, 2024

Advanced Controls for Residential Heating Ventilation and Air Conditioning (HVAC) Fan

Good morning.

Welcome to this Conservation Applied Research and Development (CARD) Webinar today reviewing results from a field study of Advanced Controls for Residential Heating Ventilation and Air Conditioning (HVAC) Fan

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
- The slide set and script from this webinar will be emailed to all registrants within 2 weeks of the webinar
- Finally, if you would like closed captions on this webinar, click the "cc" bubble in the lower left of your screen.

Advanced Controls for Residential HVAC Fan



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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.

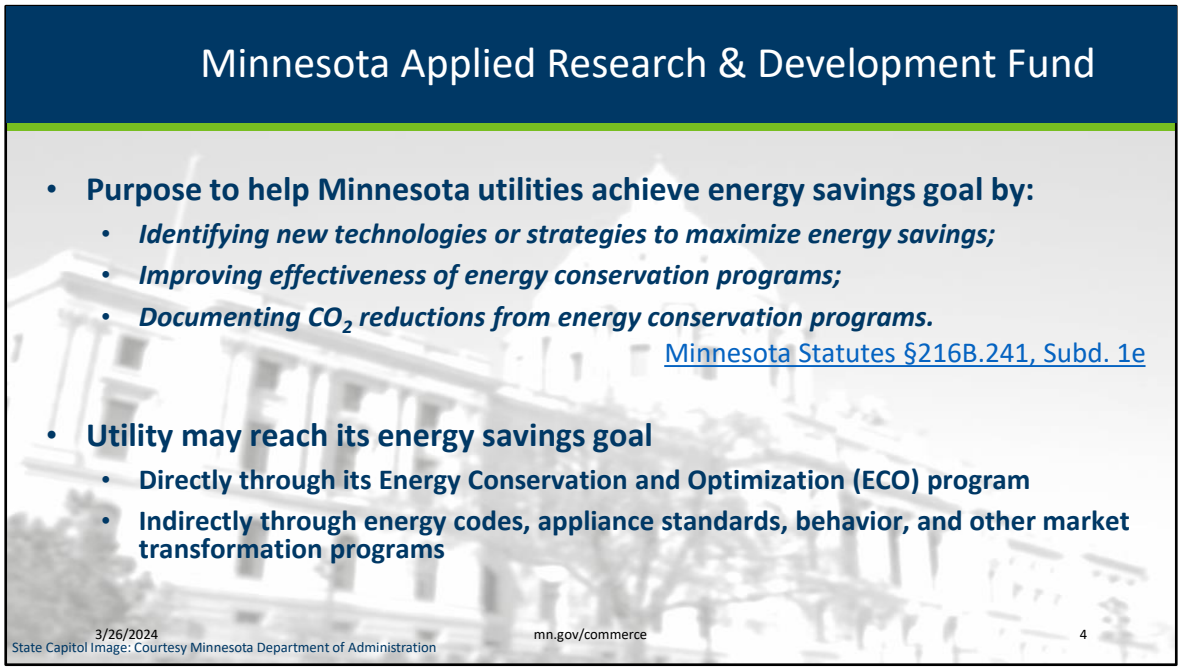
With me today is Lauren Sweeney, a Principal Energy Planner within the Energy Conservation and Optimization business unit at the Department of Commerce, where she specializes in the regulation of electric and gas utility energy efficiency, load management programs, as well as is the staff lead on the Technical Reference Manual. She was the project manager of the research that is the subject of today's webinar, and will be moderating the Q&A portion of today's presentation.

Our presenter(s) today are Grant Baumgardner and Mason Miller from CEE.

Grant Baumgardner is a Research Engineer at CEE, where he 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.

Mason Miller is a Research Analyst at CEE where he deploys data monitoring equipment and provides data analysis for CEE's various energy efficiency research projects.

Welcome Grant and Mason. We look forward to your presentation.



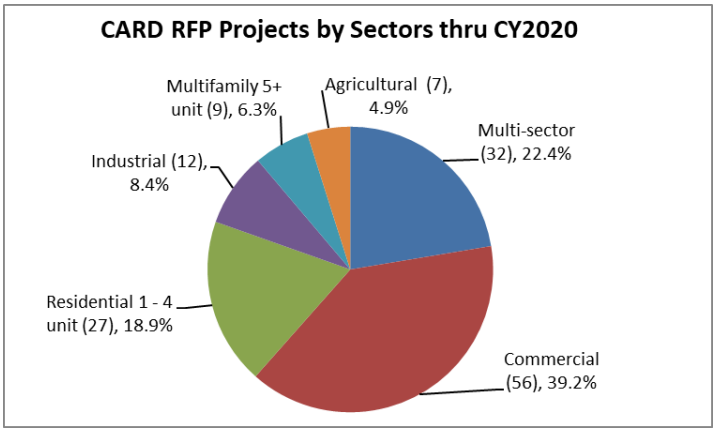
This webinar is one in an ongoing series designed to summarize the results from research projects funded by Minnesota's Applied Research and Development Fund, which was established in the Next Generation Energy Act of 2007.

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

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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.

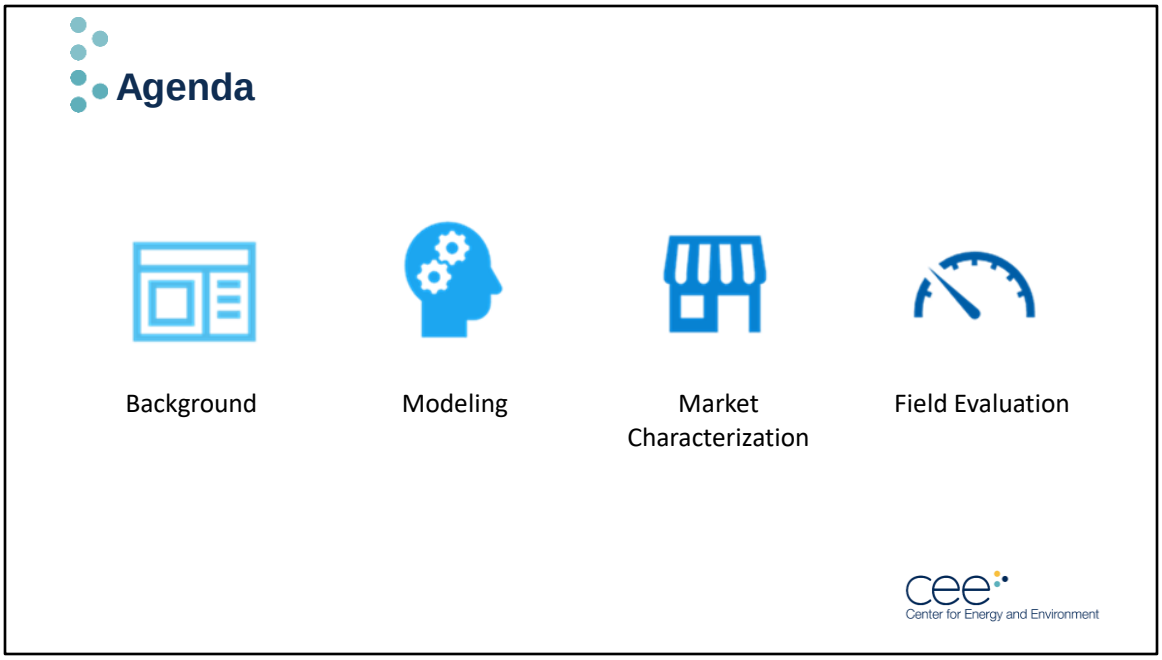
The subject of today's webinar is the residential sector and will discuss results from a recent CARD project To measure the savings potential and characterize the market for a commercially available fan controller to increase the efficiency of residential heating and cooling systems.

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



Thanks Lindsay,

Hi everyone, my name is Grant Baumgardner, and today Mason and I will be presenting our research on Advanced Controls for Residential HVAC Fans.



In today's presentation, we will provide some background information on the residential fan control technology, then go over our process and findings from the major project steps.

Project steps included modeling, market characterization, savings potential, and field evaluation.

The modeling work was intended to independently estimate the savings potential of the device and identify site characteristics that correlated with increased savings.

The market characterization assessed past HVAC research in Minnesota to estimate the statewide savings potential, confirm modeling inputs, and ensure the field sample represented the HVAC systems in the state more broadly.

The largest portion of the project was the field evaluation phase, which consisted of a detailed evaluation of the heating and cooling performance of HVAC systems, with and without the fan controller, in 24 single-family homes and townhouses.

Background

Forced-air HVAC System Review

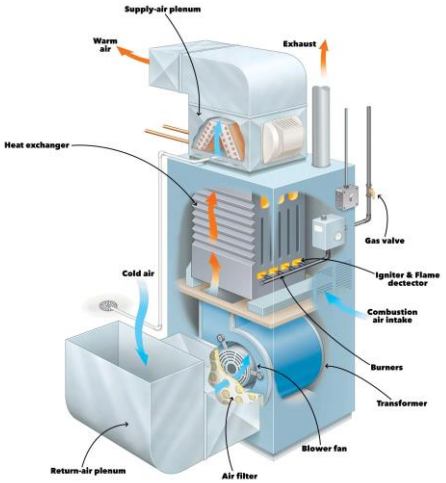


Image: The Family Handyman

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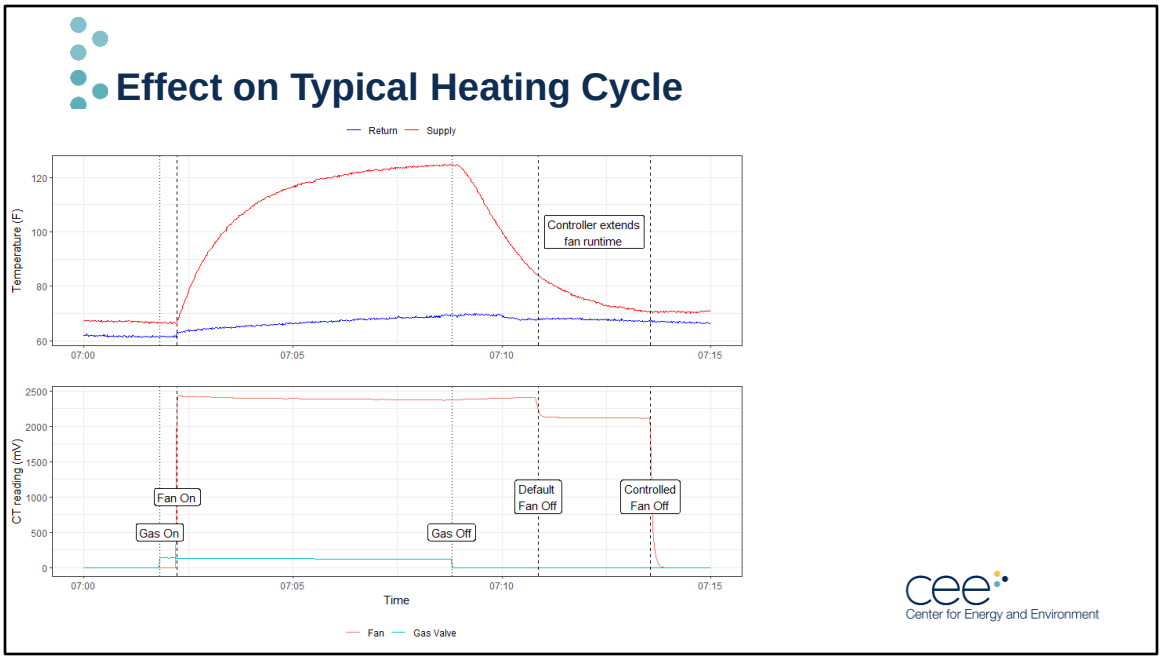
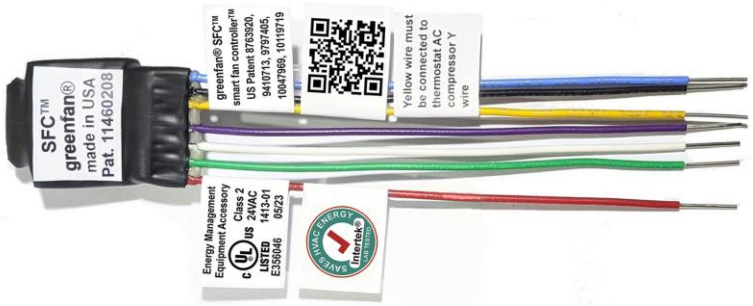
First, a quick refresher on forced-air heating systems. Air from the conditioned space is drawn through the return air plenum and a filter by the blower fan and passed over a heat exchanger. The inside of the heat exchanger tubes is heated by gas combustion. Warm air is distributed by the supply air plenum to the supply registers. The combustion products are exhausted out of the building envelope.



Here, the effect the device has on a typical heating cycle is shown in the two timeseries plots. The top plot shows the return and supply air temperatures measured before and after the furnace heat exchanger in blue and red, respectively. The bottom plot shows the voltage measured by a current transducer (CT) clamped around the gas valve and fan wires. In a typical cycle, the gas valve turns on to start combustion and allow the heat exchanger to heat up. Within about 30 seconds, the fan turns on to circulate air through the heating system. Once the thermostat call for heat is satisfied, the gas valve closes to stop combustion. The fan continues to run to cool the heat exchanger and continue distributing heat to the home. A small change in fan current was detected at the point where the built-in furnace controls normally de-energized the fan (120 seconds after gas off). The fan controller extended the fan runtime for a few minutes beyond the default fan off point. During this extended operation, heat that is not normally transferred from the heat exchanger via forced convection was pushed into the duct system.

Device Background

- Installed at thermostat terminals in residential air handler
- Claimed savings 334 kWh/year, 21.7 therms/year





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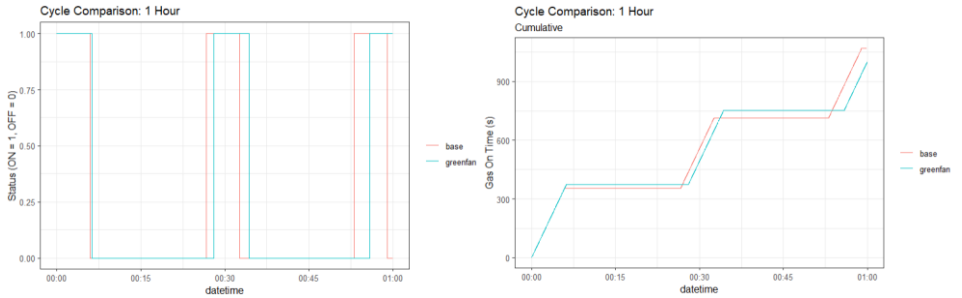
There are a few commercially available controllers that claim to reduce the gas and electricity use of forced-air heating and cooling systems. The device we tested, the Greenfan Smart Fan Controller (SFC) is pictured on the left and shown in one of our field installations in the image at right. Throughout the presentation, I will refer to "Greenfan mode" and "Base Mode", where greenfan mode means the operation of the furnace with the controller active, and base mode means the operation of the furnace in its default configuration.

The manufacturer of the device claims that the device saves 334 kWh/year of electricity and 21.7 therms/year of natural gas depending on the context, according to simulations as well as laboratory and field tests (Greenfan). This device is an approved energy conservation measure in the California technical reference manual for cooling only (California Technical Forum). The unit energy savings value for the measure was based on laboratory testing that evaluated the device's impacts on cooling only.

One of the major goals of this project was to verify the claimed gas savings, since it had not been tested in a cold climate.

Claimed Savings Mechanism

- Longer fan runtime → better distribution
- Better Distribution → Furnace/AC remain off longer between on times
- Over time, furnace/AC operate fewer hours



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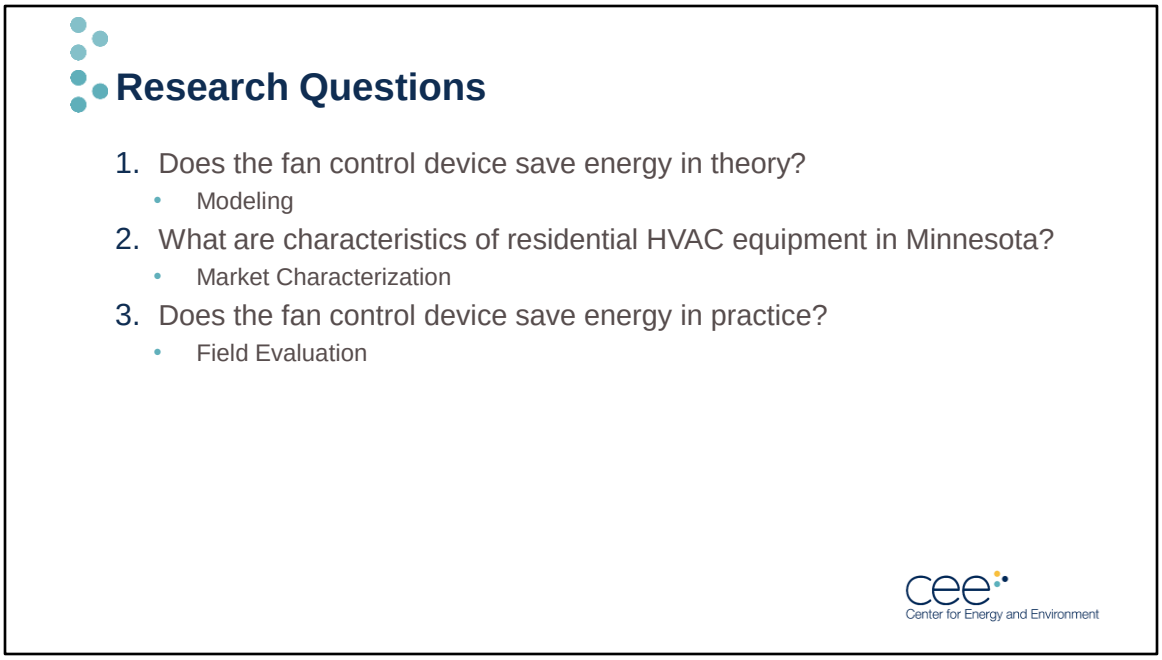
The theory behind the claimed savings is that by improving the distribution of heated or cooled air from the air handler, that the furnace or AC can remain off for longer between cycles. Over time, this slight extension in idle time could lead to fewer operating hours for the HVAC equipment and reduced overall energy use. This effect is shown in the illustrative example plots. In the plot on the left, the cycles are approximately the same length, but the space between the greenfan on cycles is extended. When taken cumulatively, gas is on for less total time over a sufficiently long window of time, as shown in the plot on the right.



As the last bit of background, I will briefly discuss the primary research questions we sought to address in this study. Each of the project steps was designed to answer specific questions.

Through modeling, we assessed whether there was a theoretical basis for energy savings.

Through the market characterization, we sought to understand the characteristics of residential HVAC equipment in MN.

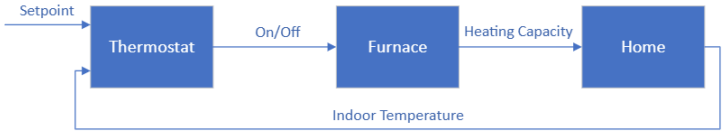
Through field evaluation, we quantitively analyzed whether the HVAC system at each site used less energy with the fan control device active.



Now on to Modeling

Model Development

- Time domain model consisting of thermostat, furnace, and home



Inputs

- Thermostat settings
- Furnace characteristics
- House thermal characteristics
- Weather
- Internal Gains
- **Fan Delay**

Outputs

- Predicted air temperatures
  - Supply
  - Return
- Furnace cycles/day
- Fan on time
- Heat delivered
- **Gas on time**

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A time domain model of a home heating system was developed to understand the energy savings potential of the fan control device. The system model consisted of a state machine feedback controller representing the thermostat, a first order transfer function representing the furnace, and a lumped capacitance model representing the home. The model was designed to accept several configuration parameters, which enabled model tuning to simulate the performance of the heating systems of the various homes in the sample.

Inputs to the thermostat model included a temperature setpoint schedule, a temperature dead band, and the indoor temperature as the feedback signal. The thermostat compared the feedback signal to the setpoint and used a simple hysteresis-based control to determine whether the furnace should turn on or turn off. Upon entry into a new state, the thermostat model logged the simulation time and initial supply air temperature for use in the furnace model. The thermostat was responsible for turning the fan on upon entry into the “on” state but turning the fan “off” was handled by the furnace model so that the fan-off delay could be provided as a configurable parameter.

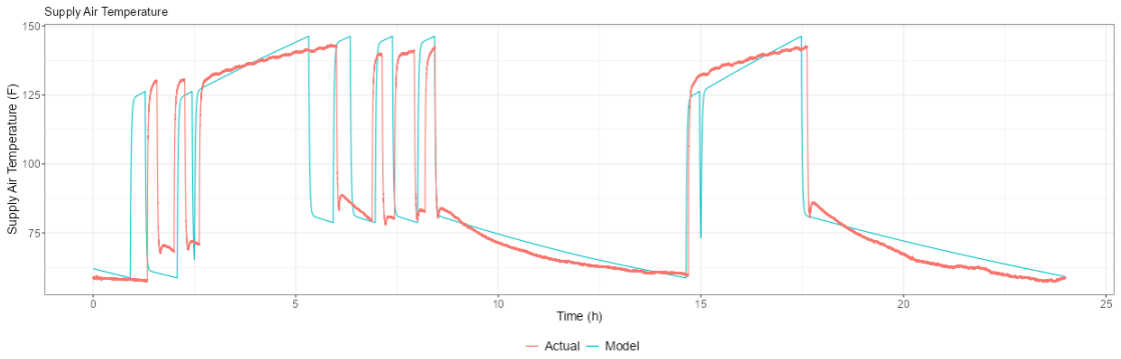
After the thermostat, the system model executed the furnace model. This involved calculating the furnace capacity from the return and supply air temperature difference and fan state. The fan was assumed to be on if the furnace was on, or if the furnace was off and had been off for less time than specified in the fan-off delay configurable parameter. Crucially, the furnace heat capacity was assumed to be exactly zero unless the fan was on.

Energy balance calculations were carried out by determining the heat loss from the house as a function of indoor-outdoor temperature difference and looking up the estimated internal gains from the assumed internal gains schedule. Net heat transfer to the home was modeled as the sum of the furnace input, heat loss, and internal gains.

Model Performance

Model can be tuned to closely match:

- Actual heat delivered/day
- Furnace cycling behavior ★



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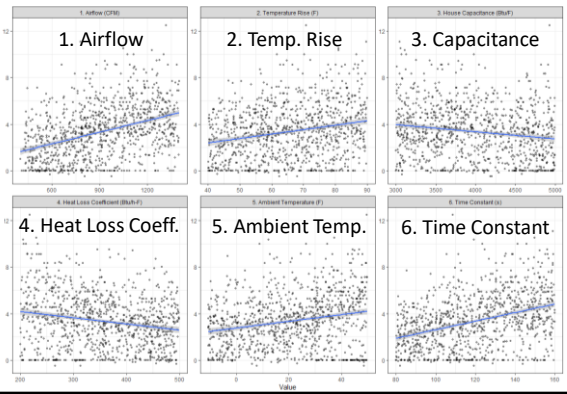
The model was designed to accept time domain inputs such as measured ambient temperature, thermostat schedules, and internal gains schedules to minimize the sources of error between the model and field data. These schedules had a major effect on the modeled furnace cycling behavior, and two of them were estimates. While it was possible to fine-tune these schedules such that the modeled energy delivered by the furnace matched the actual energy delivered by on a given day within 1%, the model was primarily used to isolate the effect of the fan delay parameter on the energy delivered per cycle and per day after tuning the model to plausible scenarios.

Sensitivity Analysis

- Ran 1000 pairs of simulations with identical inputs **except** fan delay time
  - Baseline fan delay = 120 s | Alternative fan delay = 300 s
- All other input parameters sampled from uniform distributions



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Simulation input parameters were generated by repeated random sampling from uniform distributions for the system time constant, house capacitance, house heat loss coefficient, and daily constant ambient temperature. Parameters for temperature gain and airflow were also randomly sampled, but combinations of these parameters were checked to ensure they resulted in a reasonable furnace heating capacity.

The sensitivity to these input parameters was estimated by running pairs of daily heating system simulations with all input parameters fixed except for the fan delay parameter. For the fan delay parameter, 120 seconds was used to represent the baseline system behavior and 300 seconds was used to represent the alternative system behavior under the effect of the fan controller.

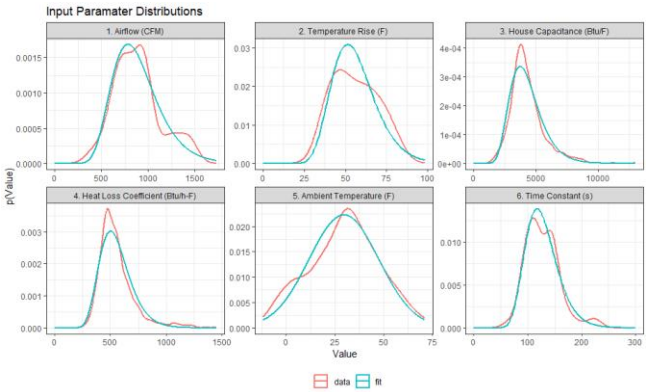
To visualize the sensitivity of the gas savings to each input parameter, the relative savings for each simulation case was plotted against each input parameter. The sensitivity analysis indicated the greatest opportunities for homes with large furnaces relative to the heating load.

The slope of the regression line indicates positive or negative correlation between savings and the parameter. The spread of points about the regression line indicates the uncertainty in the impact of the parameter. This qualitative analysis showed that savings increased with increasing furnace airflow, temperature rise, ambient temperature, and furnace time constant. This matches our intuition, that if more heat is available from the heat exchanger, extending fan runtime should reduce gas on time.

Savings decreased with increasing home heat loss coefficient and capacitance. This also matches our intuition, because larger heat loss means the furnace would tend to be on a larger fraction of the time and cycle less, so the relative impact of the fan off delay is smaller. For larger capacitance, the temperature in the home changes more slowly, so the furnace would tend to cycle less, reducing the impact of the fan off delay.

Opportunity Analysis

- Ran 1000 pairs of simulations with identical inputs **except** fan delay time
  - Baseline fan delay = 120 s | Alternative fan delay = 300 s
- All other input parameters sampled from distributions *representing MN*



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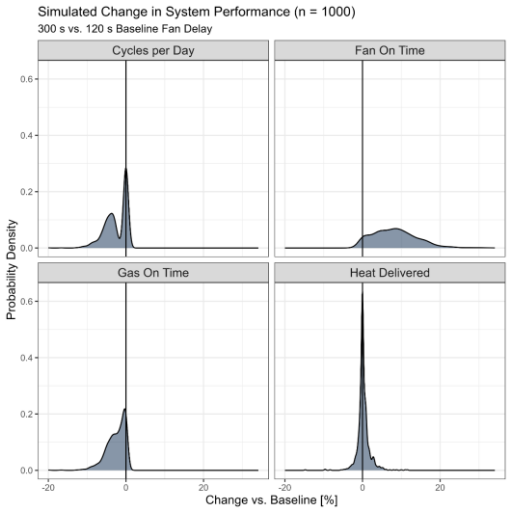
After the first pass analysis using uniform distributions of input parameters, the input parameters were resampled from distributions that represent their prevalence in the field. While the first pass analysis informed estimates of the maximum range of savings, the second sampling approach was used to estimate the most likely distribution of savings in Minnesota homes.

Opportunity Analysis



With longer fan delay,

- Cycles per day same or decreased
- Fan on time increased
- Gas on time same or decreased
- Heat delivered same

Consistent with assumed savings mechanism

Metric	1Q Change (%)	Median Change (%)	3Q Change (%)
C	-4.5	-2.5	0.0
	4.1	8.2	11.9
	-4.0	-2.1	-0.5
H	-0.4	0.0	0.7

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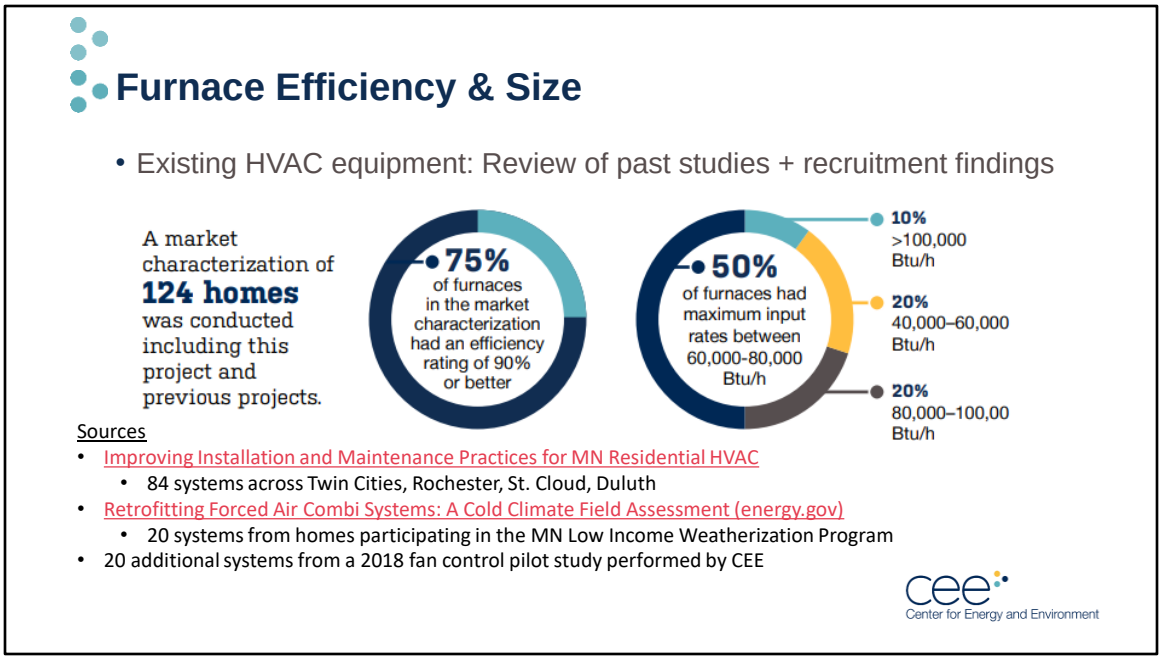
Using the representative distributions of input parameters, the overall results were similar to the results using uniformly distributed input parameters. The median decrease in gas use and cycles per day for the 1000 simulated cases was about 2%, the median increase in fan runtime was 8%, and the median change in capacity delivered was 0%.



Now I will turn it over to Mason to discuss Market Characterization.



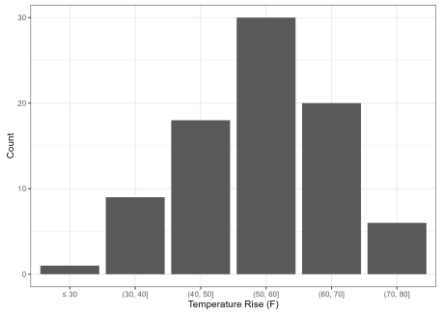
We reviewed past HVAC research characterizing furnaces in Minnesota. Compiling past research with additional outreach conducted as part of this project, we found that most furnaces installed in MN today are 90% efficient or better. The most common first stage input rating is between 60 and 80 thousand BTU/h, with roughly equal numbers slightly smaller or larger, and a handful of very large furnaces.

The largest source of HVAC system data came from the CARD-funded Improving Installation project report. The other main source was the Retrofitting Forced Air Combi Systems report repared for: The National Renewable Energy Laboratory On behalf of the U.S. Department of Energy's Building America Program. Both of these papers are available through the links in the slides. We also supplemented this data with research we did in 2018 as part of a pilot study on the fan control technology.

Fan Off Delay & Temperature Rise

- Fan off delay is typically 120 s
- Past research: 101/104 furnaces had delays of at least 90 seconds
- Longest baseline delay: 180 s

- Temperature rise was between 40 F and 70 F in over 80% of assessed furnaces



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Data from past Minnesota HVAC research indicated a tight range of fan-off delays. Of the 84 furnaces tested in the quality installation project, all but two furnaces had fan-off delays of at least 90 seconds. The longest observed delays were up to 180 seconds. From the 20 sites assessed as part of the pilot study, the longest fan off delay observed was 150 seconds and the shortest was 0 seconds. However, the manual for the furnace with the 0 second fan-off delay indicated that the configurable range for this setting was 90 to 180 seconds, implying that the observed value of zero may have been due to a furnace controls malfunction. The advanced fan controller extends heating fan-off delays
up to 300 seconds, indicating some savings potential on all the systems that were evaluated.
Temperature rise, or the steady state difference between supply and return air temperatures, was between 40 F and 70 F in over 80% of assessed furnaces



Distributor Interview Takeaways

- Confirmed market was dominated by 90%+ efficient furnaces
- Half of interviewees familiar with fan controllers as a retrofit measure
- Saw potential for savings from retrofit fan controllers to some degree
  - Very old equipment should be replaced rather than retrofitted with a fan controller
  - High-end furnaces would likely not benefit from retrofit due to variable speed fans
  - Window of opportunity for savings is only open until the existing equipment is replaced at the end of its useful life with the new and improved equipment on the market
- Concerns with aftermarket fan controllers included comfort complaints

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We interviewed five furnace distributors to learn about the market and their opinion of aftermarket fan controllers. They noted that 90%+ efficient furnaces comprise the majority of the furnaces they sell.

Some of the distributors were familiar with the fan control devices, and those that were familiar saw potential for the device. However, they cautioned that the market and window of opportunity for this device was shrinking as the best applications for the device were “middle-aged” standard efficiency furnaces. Some also were concerned that cooler air distributed at the end of the heating cycle could cause comfort complaints.



Field Evaluation Approach

Now I'll get into the field evaluation approach

Instrumentation

- Each site equipped with two data loggers logging at 1 second intervals
  - Air handler
    - Supply air temperature
    - Return air temperature
    - Gas valve(s) current
    - Supply fan current
  - Electrical panel
    - AC Power
    - Air Handler Power





- On-site airflow measurements correlated to fan current

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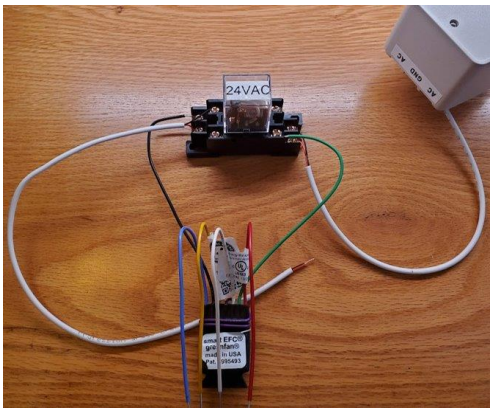
-As shown, our monitoring package included two loggers at each site.
-The left image shows an example of the logger deployed at the air handler and the right image shows the power meter logger deployed at the breaker panel. We monitored supply and return air temperatures along with gas valve and supply fan currents from the air handler. From the electrical panel we monitored AC power and Air handler power.
-Airflow measurements were recorded for a cycle of each available operating mode at the time of the monitoring package installation.

Alternating Mode Testing Approach

- A 24VAC used to alternate between baseline (“base”) and fan control (“greenfan”) mode
- Remote control achieved through a Wi-Fi-enabled smart outlet powering a 24VAC plug-in transformer powering the relay
- Mode changed every two weeks for one year monitoring period



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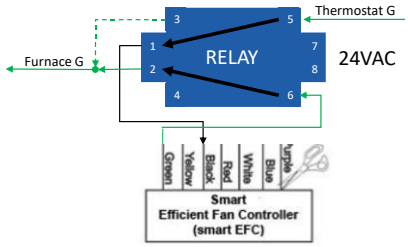
-This photo shows the physical set up of the relay with the fan controller.
-The 24VAC transformer (top right of the photo) was plugged into a wi-fi enabled smart outlet which allowed remote activation or deactivation of power to the transformer.
-In series with the relay, this allowed us to switch between baseline air handler operation and fan controller active operation.
-The mode of the system was typically changed every 2 weeks.

Relay + Controller Detail

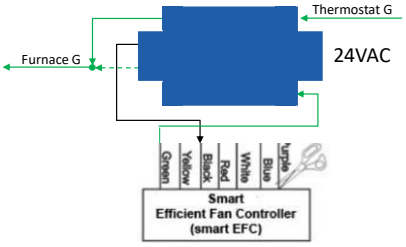
Power is OFF → Controller is active

- Thermostat G is intercepted by controller



Power is ON → Controller is Inactive

- Thermostat G is passed to furnace



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-The default (non-powered) configuration for the relay is activation of the 1 and 2 terminals, which activates the fan controller.
-Provide power, and the relay changes connection to the 3 and 4 terminals, bypassing controller operation.
-These detailed diagrams are nice for showing how the relay switches the fan operation between baseline and fan controller mode based on power status of the smart outlet.



Now I'll turn it back over to Grant to cover the field analysis results

Field Site Summary

n 24	Floor Area (ft^2)	Base fan off delay (s)	Median SAT at gas off (F)	Furnace Efficiency (%)	Stage 1 Rating (Btu/h)	Design Load (Btu/h)	Size/Load Ratio ( )
Min	1086	30	109	80	31500	14069	1.08
Max	4500	150	149	97	120000	53177	3.88
Average	2104	112	126	87	67000	25514	2.46
Median	1700	120	124	80	66000	22110	2.31

- 24 Sites located in and around the Twin Cities

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We tested the fan controller at 24 sites located primarily in the Twin Cities region. The sites all had forced air heating systems but spanned a range of sizes and floorplans. Furnace configuration was consistent, with 16 sites having measured base mode fan off delays of between 100 and 150 seconds. Our study included more 80% efficient furnaces than is representative of the market, but this overrepresentation was acceptable because the savings opportunity was expected to be the largest. The size to load ratio also spanned a wide margin, but most first stage ratings were on average 2.5 times higher than the calculated design heating load.

Field Site Data Coverage

- Site B only operated in fan control mode – no comparison
- Sites E and S were offline for most of heating season
- Site H cooling system malfunctioned while controller was installed
- Most power meters for electric monitoring installed after heating season
- Cooling analysis only includes sites with clear difference in fan performance between modes

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	S	T	U	V	W	X	Y	Z	Total
Gas - Heating		■	■		■	■		■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	20
AHU Electric - Heating		■	■		■			■																	4
Outdoor Unit Electric - Cooling			■	■	■			■	■					■	■		■				■			■	10
AHU Electric - Cooling			■	■	■			■	■					■	■		■				■			■	10

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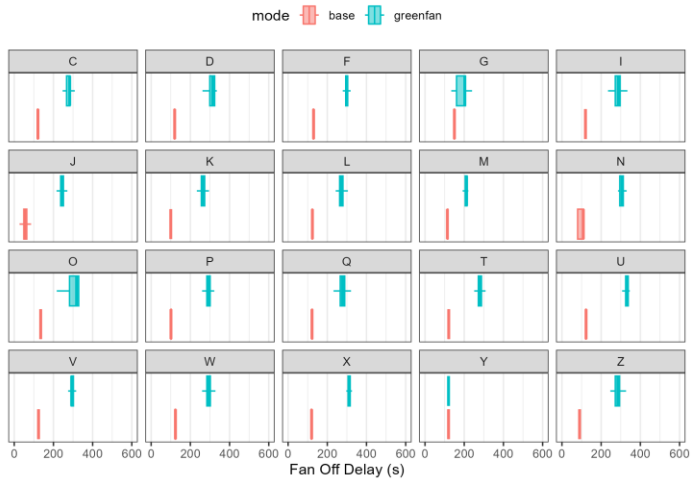
Throughout the results presentation, you will notice that not all 24 sites were included in each analysis. This slide explains which sites were included.

Site B was excluded from all analyses because the HVAC system only operated in greenfan mode. Due to site access issues, the alternating mode relay was never installed, so there was no baseline data.
Sites E and S had communication issues early in the project, so very little data was collected during heating season. However, both of these sites had sufficient data for the cooling analysis.
Site H was excluded from all analyses because the controller caused the air conditioner to short cycle in cooling mode, so we did not leave the controller installed.

We divided the work of installing the air handling monitoring equipment, which we did ourselves, and the work of installing the power meter, which was performed by an electrician, to facilitate scheduling installations and growing the sample size last winter. As a result, power meter installations for electrical monitoring lagged AHU monitoring, and only four sites had sufficient heating season data to assess heating season electricity usage.
The cooling analysis only included sites where we detected a longer fan off delay in greenfan mode relative to base mode. While the fan performance at excluded sites was potentially affected by the greenfan controller, the results from our data processing routines showed either inconsistent differences or no difference in fan off delay between modes.

Verification of Controller Function (Heating Mode)



- Confirmed controller function and data processing: Fan off delay in greenfan mode is longer and more variable
- Sites B, E, H, and S had insufficient data to include in the analysis, due to communications issues, controller compatibility issues, or site contact unresponsiveness
- Site Y turned the fan off before extending runtime in greenfan mode, so delay is not visible here, but was present

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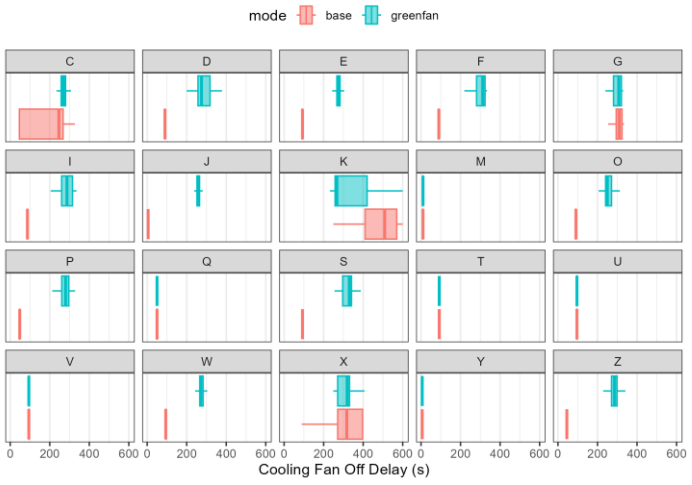
This figure shows boxplots (with outliers hidden) describing the distributions of fan-off delay time observed at each site by mode in heating season. For all sites except Y, the greenfan mode fan-off delay appears longer and more variable than the base mode. This is the expected behavior of the controller. The median of all the median fan-off delays across sites is 120.5 seconds in base mode and 287 seconds in greenfan mode. For base mode, 18 of 20 sites had a median fan-off delay between 100 seconds and 150 seconds (inclusive), while the median values for fan-off delay in greenfan mode ranged from 203 seconds to 334 seconds, except for site Y.

While site Y appears to have a non-functioning greenfan mode, expected operation was confirmed by plotting timeseries fan current signals.
Note that sites B, E, H, and S had insufficient data to include in the analysis, due to communications issues, compatibility issues, or site contact unresponsiveness.

Verification of Controller Function (Cooling Mode)



- Only sites with expected differences in fan off delay between modes after first-pass data processing included in cooling analysis
- Sites included:
  - D, E, F, I, J, O, P, S, W, Z

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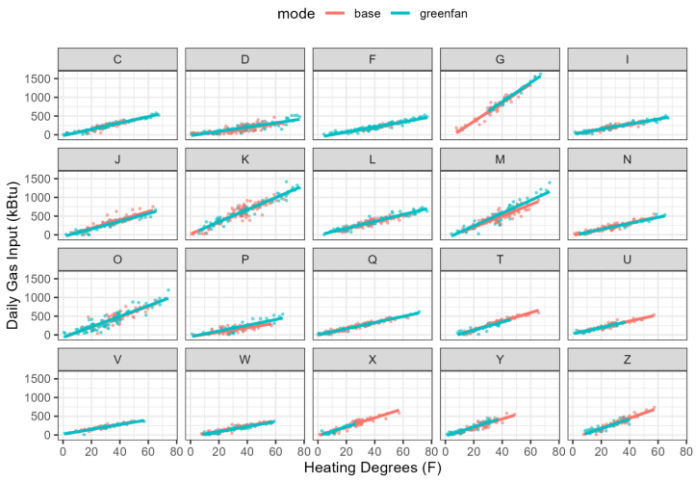
This graphic shows the cooling fan off delay by mode. Because the cooling savings were expected to be smaller than the gas savings, we focused on the sites where the observed performance of the fan controller matched expectations with the first pass data processing routine, and deferred the extensive work of reconciling data processing and labelling issues until we found some evidence for savings associated with greenfan mode. For example, site D showed clear differences in fan off delay associated with greenfan mode, while site C did not. It is possible that the controller was functioning as intended for all these sites, and that our data processing routine contained assumptions that prevented us from detecting the extended fan runtime.

Gas Use vs Outdoor Temperature by Mode



Heating Degrees =
Balance Point Temperature – Daily Average Temperature

Gas use associated with Greenfan mode:

- 14/20 sites: NO statistically significant difference in gas use
- Statistically significant increase in gas use at sites D, M, P
- Statistically Significant decrease at sites J, T, W

Regression equation:

$$E = \hat{\beta}_0 + \hat{\beta}_1 L + \hat{\beta}_2 LM$$

- E: Energy
- L: Load
- M: Mode

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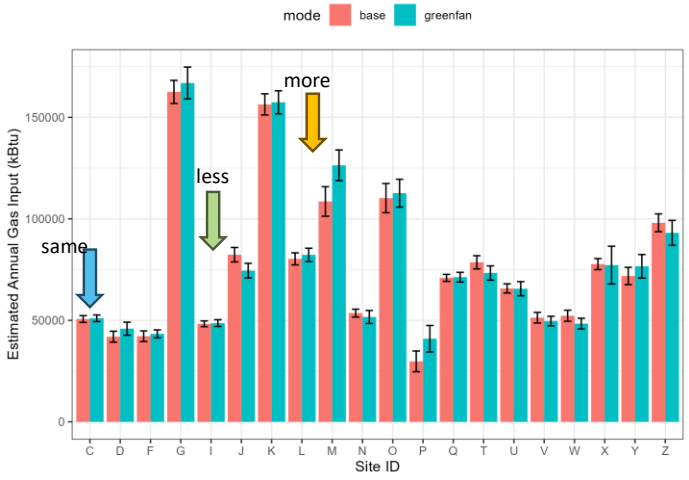
To quantify the impact of the fan controller on gas use, linear regression models of energy use as a function of heating or cooling degrees and control mode were fit to the data.

Heating degrees are defined as the difference between the balance point temperature and the daily average outdoor temperature. The heating balance point temperatures were identified as the daily average temperature on the warmest day that furnace gas use was detected. The cooling balance point was taken as the change point of a piecewise linear regression model fit to the electrical energy required by the air conditioner outdoor unit as a function of temperature.

Each site had a multiple linear regression model fit to the observed daily average data. This plot shows the predictions of the linear regression models overlaid on the observed data.

The independent variables were heating or cooling degrees and control mode. This approach allowed us to directly assess the statistical significance of the control mode variable. In most cases (14/20), we found that there was not enough evidence to say that the control mode predictor was not zero. Graphically, this is indicated by the fact that the slope of the regression lines associated with each mode appear virtually identical.

Estimated Annual Furnace Gas Use by Site



- Error bars represent 95% prediction confidence intervals
- Overlapping confidence intervals = insignificant difference
- 14/20 sites: No statistically significant difference in gas use

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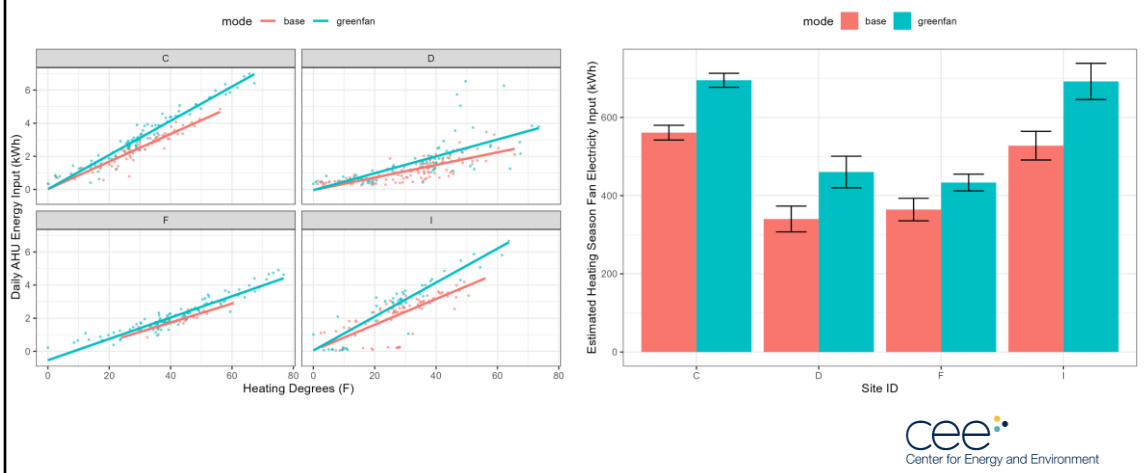
To quantify the magnitude of the impact in meaningful units, typical annual gas use in each mode was calculated using the models and the TMY3 2020 data for the Minneapolis-St. Paul Airport weather station. Even though the prediction confidence intervals are relatively small in most cases, they still overlap between modes, which is another way to see that the effect of the controller was not significant. Note that 1 therm is roughly 100 kBtu. We highlighted a few examples where the estimated annual gas use with greenfan mode was the same as, less than, or more than the estimated gas use in base mode.

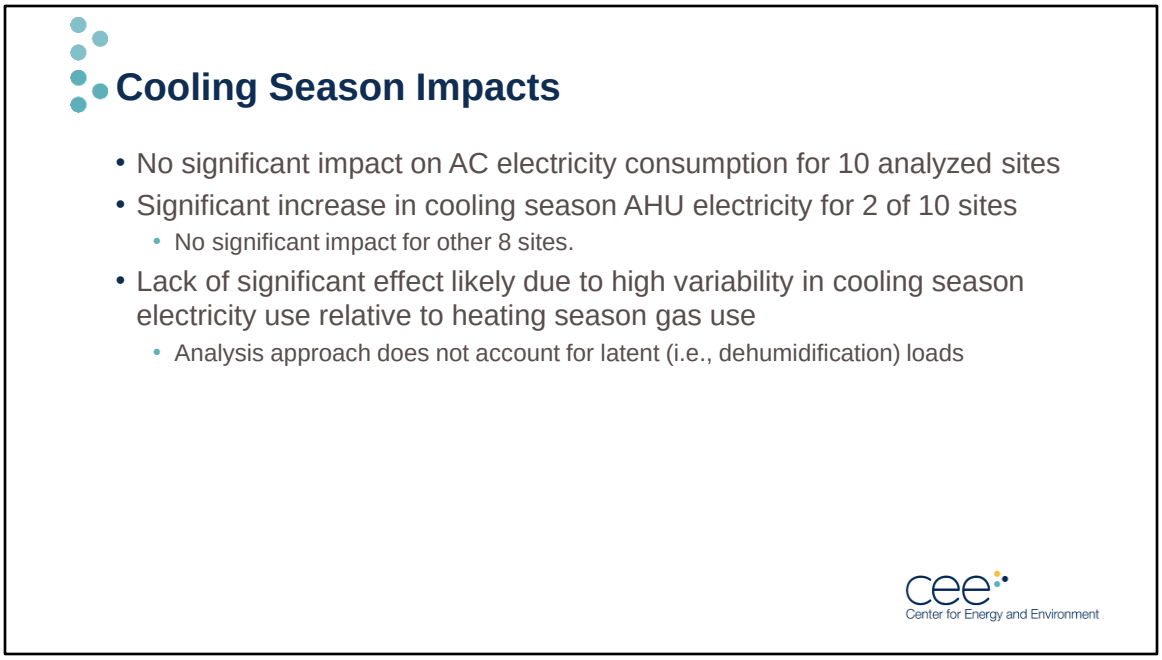
Air Handler Heating Season Energy Use



While we were unable to detect a consistent decrease in gas use associated with greenfan mode, we did see consistent increases in fan electricity use.

Regression equations were fit to the daily total air handler electrical input as a function of the average daily ambient temperature and mode for four sites using the same approach as for the gas use data. This is what the regression plots look like when there is a significant difference between modes.

Using the TMY3 2020 weather data to predict annual furnace electricity consumption for heating by mode produced the results shown in the bar plot. The p-value of the estimate for the mode coefficient was much less than 0.05 in each case, indicating that the mode is associated with a statistically significant difference in electricity use. In each case, this difference was an increase in greenfan mode relative to base mode. On average, the sites used 122 additional kWh for fan operation in heating season, a 27% increase.



As Minnesota is in a heating-dominated climate, most of the market characterization, modeling, and field analysis focused on heating season performance, but the same analysis techniques were also applied to cooling season data.

Extending the fan runtime in cooling mode had no statistically significant impact on air conditioning energy use in this study.

The impact on AC electricity use of extending the fan-off delay was much smaller than that of the sensible cooling load, and apparently much smaller than other unmeasured factors.

Some sites showed statistically insignificant savings, while others showed statistically insignificant increases in energy use. There is no evidence to support that the effect of the fan controller on air conditioning energy use is different from zero.

As in heating season, a small energy penalty due to increased fan runtimes associated with greenfan mode was expected. In practice, the effect of the fan control mode on the fan energy as a function of sensible cooling load was statistically significant for only two of ten sites.

The same unmeasured factors from heating season (solar heat gains, occupancy, and occupant behaviors such as cooking, modifying the thermostat setpoint, and opening doors or windows) apply to cooling season, but cooling season loads are also heavily impacted by the latent load associated with the humidity of the air.

Discussion & Conclusion

Discussion of Results

- For 14 of 20 sites analyzed:
  - no statically significant difference in annual gas use
- For 3 sites with statistically significant increased gas use:
  - return duct leakage in the unconditioned space could cause more cool air to be distributed near the thermostat when the fan runs longer
- For 3 sites with statistically significant decreased gas use:
  - Relative position of thermostat, supply ducts, and return ducts could cause the temperature near the thermostat to remain elevated longer

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Most sites (14 of 20) exhibited no significant difference in gas use associated with greenfan mode. For these sites, the uncertainty associated with the estimate of the interaction term coefficient was large relative to the value of the estimate. In physical terms, this means there are other factors that affect daily gas use that have a far greater impact than the fan-off delay. These factors show up in this analysis as sources of uncertainty. These other factors that affect heating loads either positively or negatively include solar heat gains, occupancy, and occupant behaviors such as cooking, modifying the thermostat setpoint, and opening doors or windows. For the sites that showed increases in gas use, it is possible that return duct leakage allowed cool air from unconditioned basements to be drawn into the duct system and distributed to the area around the thermostat, reducing the time between furnace cycles.

For the sites where the device saved energy, it is possible that the heat exchangers of the efficient furnaces provided highly effective heat transfer to the air stream, and characteristics of the air distribution system caused the temperature at the thermostat to remain elevated between cycles, extending the time between cycles.



Research Questions Revisited

1. Does the fan control device save energy in theory?
   - Saves very small amount of gas if assuming heat not distributed by AHU is lost
     - In Minnesota, heat primarily remains within building envelope
   - Significant increase in fan runtime and energy use
2. What are characteristics of residential HVAC equipment in Minnesota?
   - Furnace characteristics and configuration are relatively uniform
   - High-efficiency (90%+) equipment is dominating new installations
3. Does the fan control device save energy in practice?
   - Insignificant impact on furnace gas and AC electricity
   - Significant increase in fan energy consumption

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Circling back to the research questions we introduced at the beginning of the presentation,

The modeling exercise showed that extending fan runtimes to improve distribution of heating capacity could theoretically lead to long-term savings, assuming that ducts are perfectly sealed and no residual heat from the heat exchanger migrates to the conditioned space unless the fan is running.

We found that there is little significant variation in furnace characteristics and configuration. They are installed with their factory settings and rarely adjusted. Newer equipment is generally highly efficient condensing furnaces, while older equipment is more likely to be 80% standard efficiency furnaces. The theory floated by distributors that the fan control device would make the most sense in newer standard efficiency equipment was not supported by the field evaluation.

In practice, there is insufficient evidence to say that the fan control device we tested reduces gas or electricity use in heating or cooling season in Minnesota.

Questions?

Advanced Controls for Residential HVAC Fan

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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.

Lauren, do you have any questions for Grant or Mason?

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Thanks again for your presentation and to Lauren 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 today! We appreciate your interest in CARD projects.

I want to take a minute to mention two upcoming CARD webinars:

- March 21, 2024: Center for Energy and Environment– Optimizing the New Generation of Grocery Refrigeration Equipment
- April 25, 2024: Center for Energy and Environment - Ductless Cold Climate Heat Pumps for Multifamily Applications

To keep abreast of upcoming CARD webinars as they are scheduled, and other news related to the Minnesota Conservation Improvement Program sign up for CIP updates through our email list. You can use the link on this slide to do that.

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



There will be a short evaluation that launches after this webinar.

Please take a few minutes to fill it out and let us know how we did.

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