Welcome

Conservation Applied Research & Development (CARD) Webinar

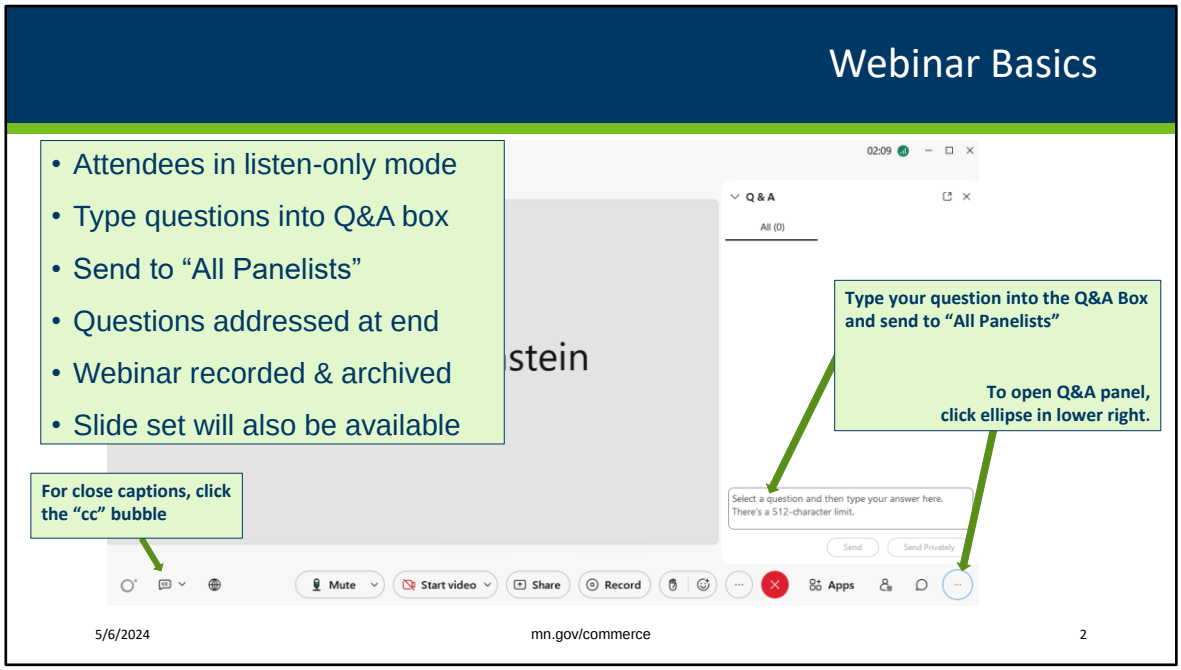
April 25, 2024

Ductless Cold Climate Heat Pumps for Multifamily Applications

Good morning.

Welcome to this Conservation Applied Research and Development (CARD) Webinar today on Ductless Cold Climate Heat Pumps for Multifamily Applications

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 made available on the Department's website
- The slide set from this webinar will be emailed to all registrants within 2 weeks from today's broadcast, as well as also will be made available on the website.
- Finally, if you would like closed captions on this webinar, click the "cc" bubble in the lower left of your screen.

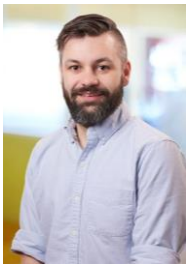
Ductless Cold Climate Heat Pumps for Multifamily Applications



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I am **Catherine Fair**, a 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 lead Conservation Applied Research and Development program management functions, manage CARD research projects, as well as support ECO affordability work.

With me today is **Lindsay Anderson**, a Utility Energy Conservation Research Planner at the Department of Commerce, where she identifies and analyzes gaps within utility energy conservation and optimization programs and coordinates and plans research to fill those gaps. The CARD program is a major tool of that work. Lindsay is the project manager on the research that is the subject of this webinar and will be moderating the Q&A portion of today's presentation.

Our presenter(s) today are Ben Schoenbauer and Lindsay Genty from Center for Energy and Environment.

Ben Schoenbauer is the Assistant Director of Research at CEE where he researches new and innovative technologies and ideas dealing with residential and commercial energy efficiency. This work includes identifying new opportunities, conducting research, identifying pursuing funding opportunities, and disseminating the results. Ben's areas of focus include water heater performance, service water heating, and residential HVAC systems. Ben has been with CEE since 2008. Ben has a master's degree in mechanical engineering from the University of Minnesota and a bachelor's degree in physics from St. John's University.

Lindsay Genty is a Research Analyst and provides data collection and analysis for CEE's various energy efficiency research projects. She is currently focusing on analyzing energy efficiency in retrofit homes and in HVAC systems.
Lindsay is a graduate of the University of Arkansas where she obtained her bachelor's in physics. While in school, she helped gain local support to pass legislation on the Solar Access Act of 2019.
Welcome Ben and Lindsay. We look forward to your presentation.

Minnesota Applied Research & Development Fund

- **Purpose to help Minnesota utilities achieve energy savings goal by:**
  - ***Identifying new technologies or strategies to maximize energy savings;***
  - ***Improving effectiveness of energy conservation programs;***
  - ***Documenting CO_2 reductions from energy conservation programs.***

  Minnesota Statutes §216B.241, Subd. 1e

- **Utility may reach its energy savings goal**
  - **Directly through its Energy Conservation and Optimization (ECO) program**
  - **Indirectly through energy codes, appliance standards, behavior, and other market transformation programs**

State Capitol Image: Courtesy Minnesota Department of Administration

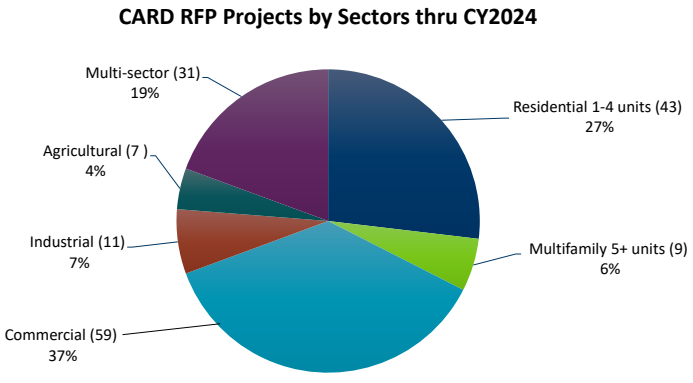
This webinar is one in an ongoing series designed to summarize the results from research projects funded by Minnesota's Applied Research and Development Fund, which was established in the Next Generation Energy Act of 2007. Research areas were expanded with the passage of the Minnesota 2021 Energy Conservation and Optimization Act (known as ECO).

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 CY2024



RFP Summary

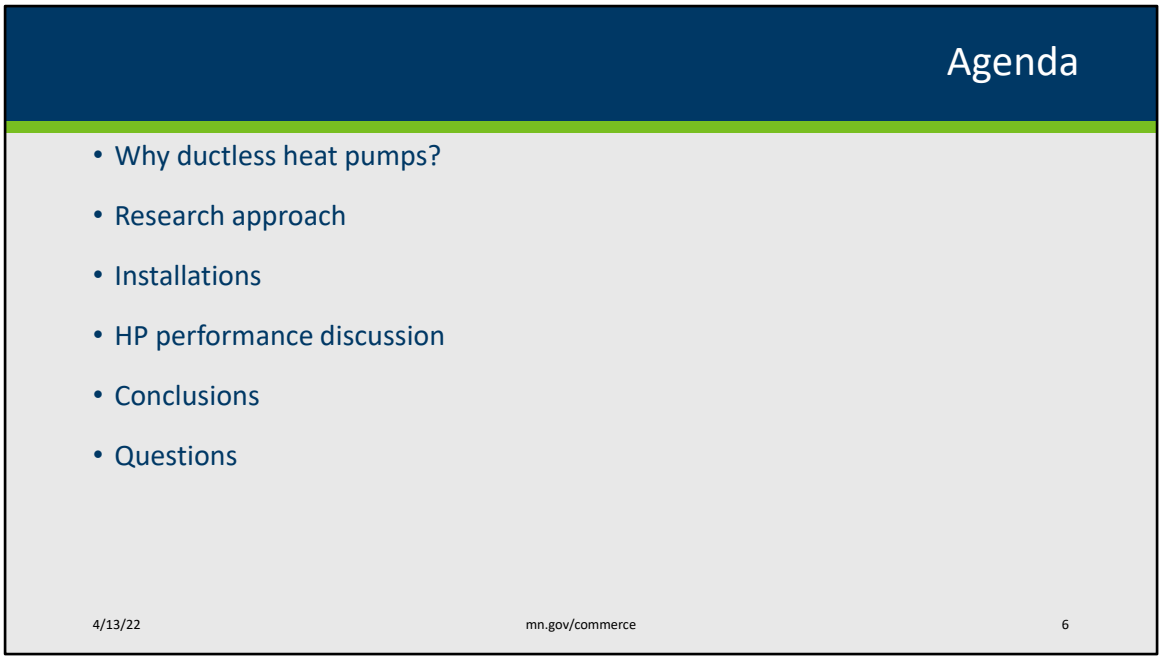
- 13 funding cycles
- 554 proposals
- 160 projects funded
- $36.8 million in research

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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 within in the Multifamily sector and our presenters will share results from a recent CARD project on measurement of the performance, energy savings, and customer acceptance of ductless cold climate air source heat pumps and installation protocols in multifamily buildings to support utility conservation program implementation.

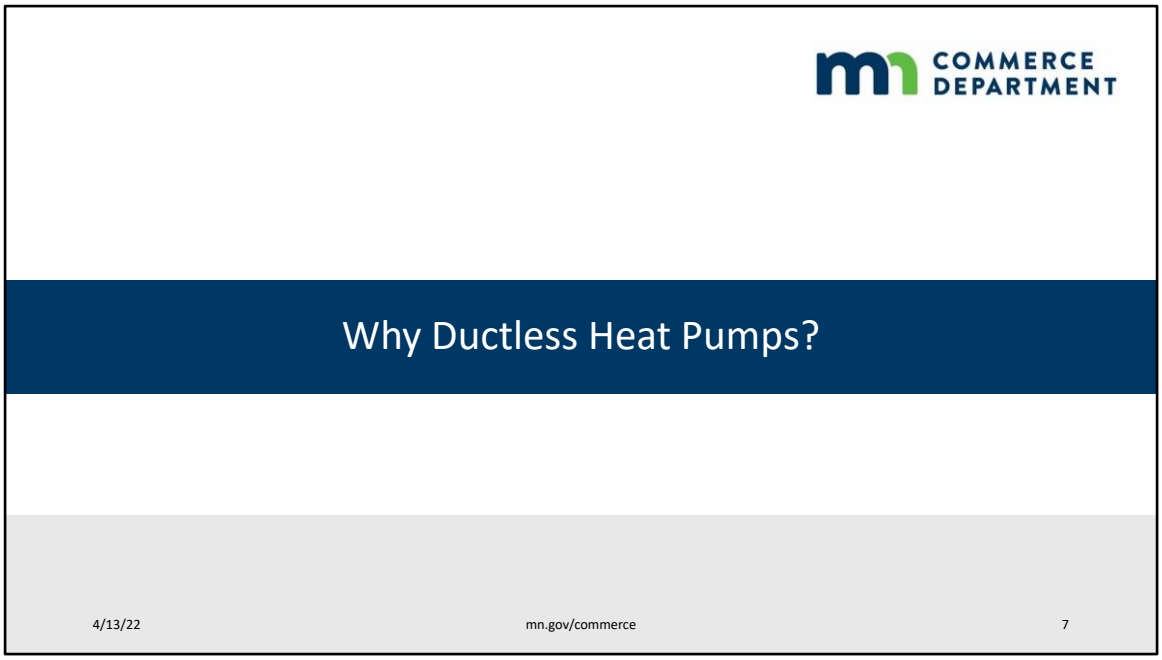
Now, I'll turn it over to Ben for today's presentation.



Thank you, Catherine, and thanks everyone for joining us today. I want to start with a quick overview of the presentation today that will cover the major topics and lessons learned from our research in heat pumps for MN's multifamily buildings.

We will start with some background on ductless heat pumps and why they are a good fit for the buildings we studied.

We will go through our approach to the research and then discuss the specific installations included in the project and presentation.
We will go through a summary and some highlights from the data collection, analysis, and system performance.
Finally, we will wrap up with some conclusions and hold some time at the end for your questions.



Let's jump in. Why ductless heat pumps?

Ductless Cold Climate Heat Pumps

- Good fit for MN's electrically heated multifamily buildings
  - "Cold climate" terminology is broad
    - Variable speed
    - Designed to maintain capacity at cold temperatures
  - Flexible integration with existing systems and layouts





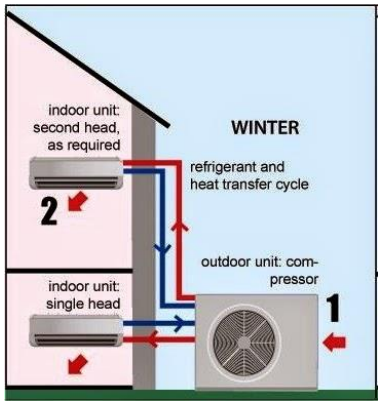
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As a reminder, this project targeted buildings with existing electrical heat. While all our installations were replacing and displacing electric heat sources, many of the lessons learned in this work can be applied to buildings considering fuel switching and decarbonization.

Ductless systems are a good fit for MF in MN for a few reasons. First, cold climate ductless systems are those that are designed to work in cold climates like ours. The term cold climate can be defined in many ways, but for the purposes of this work, we focused on systems that had variable speed and variable capacity, allowing for the heat pump and compressor to ramp up speed and delivered more heating as needed and specifically when temps drop outside.
Ductless systems also offer the most flexibility for retrofit installations. Ductless systems do not require ductwork or direct integration with existing heating systems. Therefore, they can be installed in most MF building regardless of heating system or building layout.

What is a Cold Climate Multi-Head System?

- Similar to ductless systems but uses more than one indoor head
- More cost-effective option to heat multiple zones in one unit or home
- Smaller footprint and less time-consuming installation



Another reason ductless systems are a good fit is the application innovations that have occurred over the past handful of years. Ductless manufacturers have developed several new indoor head components and approaches to increase the usability of these systems.

Manufacturers are offering a wider range of head types than ever before, for those people that do not like the traditional style head.

But a potentially more impactful innovation was the creation of the multi-head system. The image at the right of this screen shows a two to one system with 2 indoor heads and one outdoor unit.
Multi-head systems ability to run more than one head on a single outdoor unit increases the effectiveness of the heat pump across multiple zones or rooms inside the home while limiting the work and material costs associated with adding additional outdoor units.



Now that we've discussed why ductless systems, let's look at how we approached the research.

Research Approach

- Use lessons learned in SF homes and adapt them to MF installations
- Install HPs in four different MN multifamily buildings
- Measure performance
- Review and enhance installation practices and design approaches
- Consider ECO, TRM, and policy implications

Our research approach started with using lessons learned in SF homes and adapt them to MF installations. This included past research by our project team, CARD, and others in similar climates.

Then we installed HPs in four different MN multifamily buildings.

During installation we install a large array of energy sensors which we used to measure performance.

Next, we reviewed and enhanced the installation practices and design approaches, based on our measured data.
Finally we considered the ECO, TRM, and policy implications of the work.

Site Selection

Site	Monitorable	Occupant Participation	Location	Layout	ASHP Approach	Existing Heat	Building Size
MF_01	Yes	Yes	Metro	1 Bedroom	1to1 ductless	ER baseboard	2 stories | 6 units
MF_07	Yes	Yes	Metro	1 & 2 Bedroom	1to1 ductless	ER baseboard	2 stories | 13 units
MF_60	Yes	Yes	Suburban	2 Bedroom	PTHP	PTAC & ER baseboard	6 stories | 71 units
MF_61	Yes	Yes	Suburban	1 & 2 Bedroom	1to1 & 2to1 ductless	ER baseboard	3 stories | 6 units

Here we see a brief overview of the sites selected for installation and the selection criteria for each of them. Each row in this table represents one of the buildings that had HPs installed. Each column represents the different selection criteria.

The ability to install our monitoring equipment and how willing were the occupants to participate I the work were the only yes/no criteria. We know our selection pool was not going to be large enough to give statistical significance, so we targeted a range of responses for the remaining selection criteria. That was intended to give evidence and examples of the process. Collected data will be analyzed, anonymized and used to help understand the site to site variance due to people.



Well that information all as a bit of introduction and background, I'll introduce Lindsay to take over and walk through some of the instrumentation and the HP install at each site.

Measurement and Verification Design



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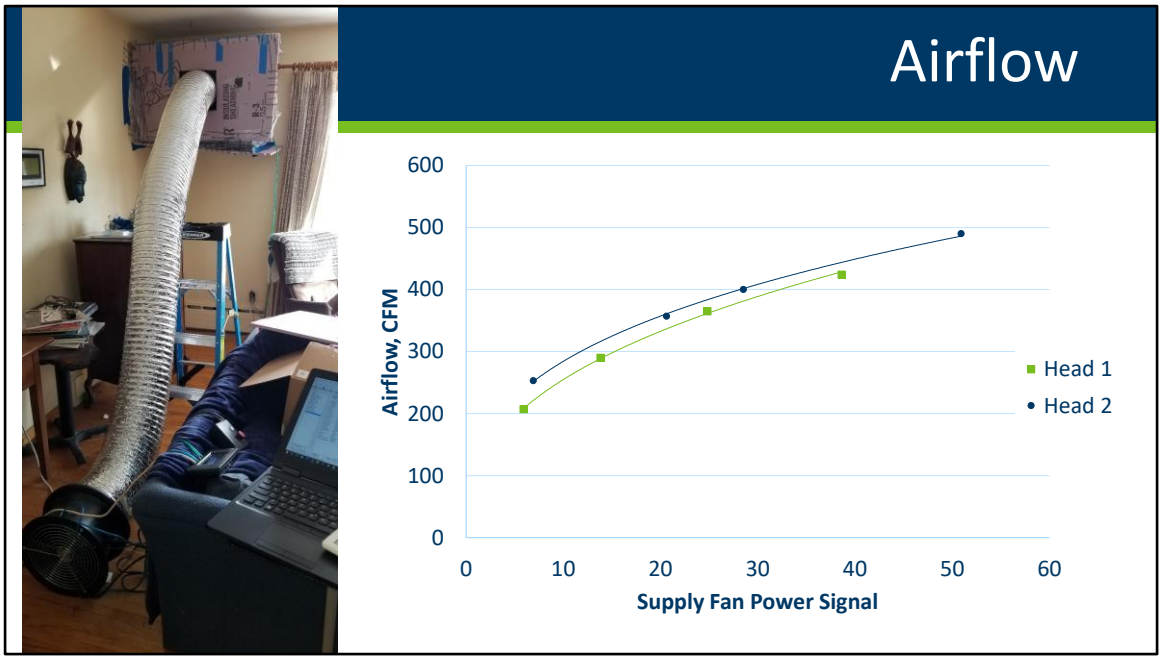
Lindsay G

When monitoring the heat pumps for this project, the main goal was to compare the overall performance of the heat pumps to the existing system prior the heat pump install particularly during heating seasons. Monitoring equipment was deployed for a baseline period at all sites, then an additional monitoring package was deployed after the heat pump installation (if there wasn't a heat pump already installed which we will talk about in the next few slides).
Here on the screen, you can see examples of what those monitoring packages look like.

On the left side of the screen, you can see our eGauge power meter which is a device that we use to monitor electrical usage directly at the breaker panel. These are installed by an electrician, and each heating circuit, such as electric resistance baseboard and the heat pump, is wired to the device, and we can compile live energy usage of these heating sources in a unit. This was the primary device used to monitor the baseline system, and then on the right of the screen, you can see our Campbell Scientific logger which we deployed after the heat pump installation.

We monitor a number of components of the heat pump to understand how it operates such as the defrost coil, outdoor coil temperatures, and most importantly, the supply and return air. We deploy a thermocouple sensor array that captures the supply air temperature of the indoor head and use that with a few other parameters to calculate the energy output of the system. With the energy input from the eGauge and the output calculated from the Campbell logger sensors, we then can measure COP, which if you are unaware, is the ratio of energy output to the energy input.

These monitoring packages give us high resolution, one-second data. In addition to live data we collected over at least one heating season, we also capture airflow measurements on site during the deployment and at removal.



Lindsay G

This is an example of what our airflow testing looks like. This field measurement often is challenging to make, but it is an important aspect of heat pump performance. CEE (and others at National labs, other research groups, and sensor manufacturers like the Energy Conservatory) have conducted a lot of testing and trials to understand and improve the accuracy of airflow measurements. We are happy with these measurements and think this is an accurate method for measuring.

However…

These measurements can be cumbersome to make especially in smaller multifamily units (as you can see the set up can take up quite a bit of space), and it be time consuming to conduct the test.

The methodology for airflow that we use for mini-splits is what we call our “box method”. So, looking at the image here, inside the box is an indoor head to a mini-split, and the box is taped around the outside edges to create pressure within the box

necessary to calculate the airflow measurement.

There is a margin of error due to some onsite conditions that can't be controlled such as tape not creating a tight enough seal on a wall to create pressure in a box

These are challenges within field measurements, but we are still confident in the accuracy of data we obtained.

The last note about airflow is that we take these measurements onsite because not only is airflow essential to high performance, it can also vary slightly from manufacturer specifications and even from two indoor heads. This plot you see here, is an example of that. This is a two-to-one mini-split with the same sized indoor heads. These two units, of course since they are the same, have the same manufacturer specifications, but when tested, they do vary slightly even compared to each other. The difference isn't large, but it is significant enough to impact our calculations and analysis. So we like to capture this onsite.

Okay – let's talk about the sites.

The Installs: MF_01

- Six unit electrically heated building
- Former SF residence converted to MF
- Smaller units with low heating loads
- One-to-one ductless



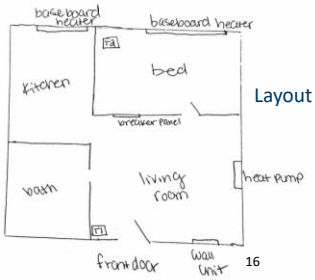
Heat Pump Install





Existing Heating System





Layout

Lindsay G

Our first building, multifamily one, was a six unit electrically heated building in the metro that was a conversion from a single-family home. The units themselves were smaller and had low heating loads, so a one-to-one mini-split was a great application for this building. This building, like most we will see, are heated by electric resistance baseboard heaters. This building already had the heat pumps installed, and the building owner agreed to let us monitor in two of the units.

Then in the corner of the screen you can see an example of how the layout looked in one of the units. The placement of the indoor head is important for comfortability. With the lower heating load and smaller footprint, the single head could heat the main living space, bedroom if the door was left open, and likely parts of the kitchen.

The Installs: MF_07

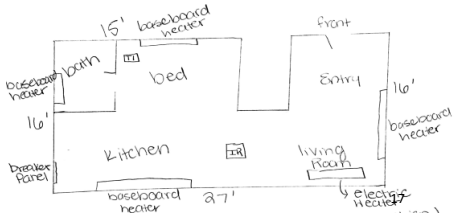
- 13 Unit electrically heated building
- HPs installed in one- and two-bedroom units
- One-to-one ductless heat pumps











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Lindsay G

This next building, multifamily seven, was a 13 unit electrically heated building also in the metro where we monitored 6 of the 13 units. This building was interesting because the building owner encouraged tenants to use IR space heaters in place of their electric resistance baseboard heaters because it was believed they were more efficient. We had mixed feedback on how well the space heaters worked, but most of the tenants questioned the functionality of the existing baseboard heaters and would opt to use the space heaters for reliability reasons.

We monitored two studio units, two one-bedroom units, and then two two-bedroom units. You can see the layout of one of the studios in the bottom of the screen. Most of these units were fairly open floor plans and ideal for mini-split units. As you may know, if the units are particularly compartmentalized (like the building we just saw), the heat pump likely won't heat in areas where partition walls exist, but it does a great job distributing heat in open floor plans.

The Installs: MF_61

- Six unit electrically heated building
- Two-bedroom units
- Two ground floor units had two-to-one systems
- Upper levels had lower heating loads and used one-to-one systems





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Lindsay G

Multifamily 61 was a building south of the metro. We monitored all six electrically heated units. There were two one-bedroom units, and two two-bedroom units.

For this building, the upper levels had significantly lower heating loads than those on the ground level. Some of the tenants told us that they never needed to turn on their heat because the heat from the floors below was sufficient in keeping the units warm.

So, we installed two-to-one mini-splits on the ground level, and then one-to-one mini-splits on the upper four units. It is not depicted here, but many of these units were long and had hallways where their bedrooms and bathrooms branched off. The indoor heads, for the most part, heated the main living space; however, as mentioned on these upper floors, not as much heat was needed to stay comfortable so this was a very cost effective and practical installation for those units.

The Installs: MF_60

- 71 unit electrically heated condo building
- PTAC to PTHP retrofit installation







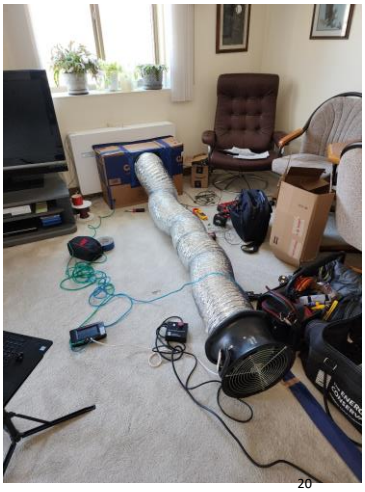
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Lindsay G

Lastly, we have our multifamily 60 unit which was a PTAC site. PTAC units are packaged terminal AC units that you see primarily in hospitality building such as hotels. We wanted to include this site in the project because there has been development on packaged terminal heat pumps which are basically a one-to-one swap with PTACs and could be a ideal solution for multifamily buildings. Especially ones like this which was a high rise 71-unit building, and you wouldn't need to run linesets all on the exterior of the building which can be a pain point for some building owners.

PTHP Install and Testing





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Lindsay G

This is an example of how the installation looked for the PTHP. The entire heat pump itself sits inside the building envelope so there isn't an exterior piece that hangs outside the building.
Here you can see there are holes that get cut in the rigid insulation for the exhaust and such. One downside to this is that if for some reason you need to replace the PTHP, you are limited in which units you can swap out because the holes can't be moved, but these units seem promising for combating many of the barriers we faced during the project when it comes to the aesthetic of heat pumps.

Finally, on the screen, you can just see another version of our airflow testing. The box method needed to be modified to this new type of system, but the process is still the same.

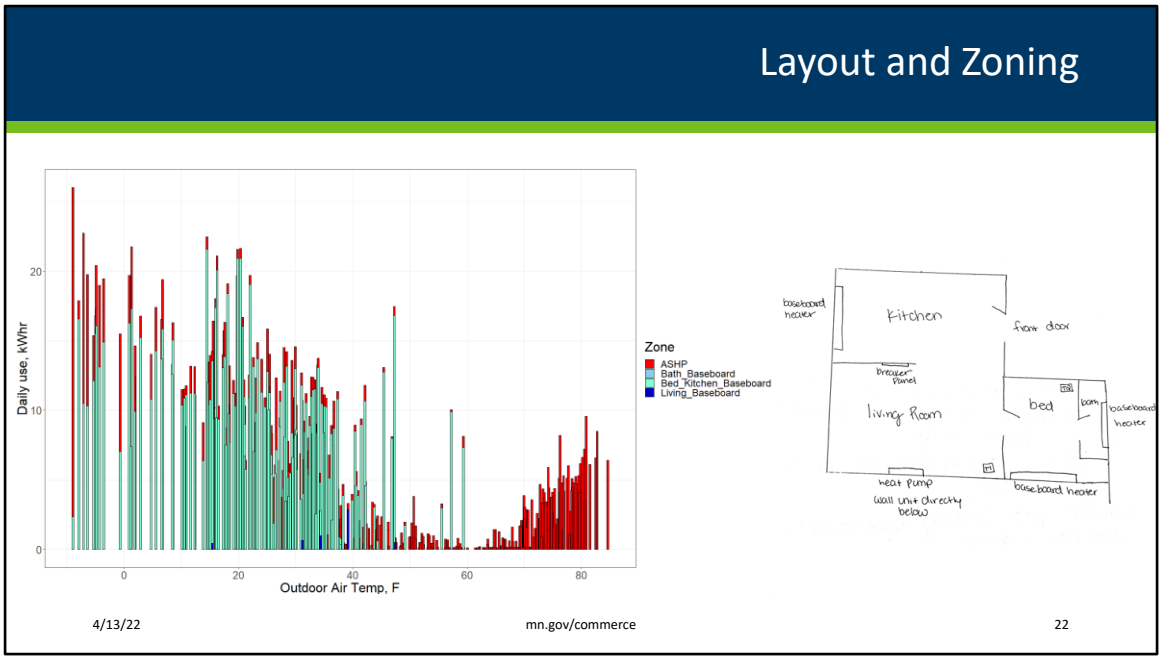
But with that – I will pass it back to Ben to talk about our results.



Thanks Lindsay.

Now let's take a look at how these systems performed

We collected data from __ heat pumps in 4 different buildings. Some of these systems we have data in from multiple years, so it's a lot of data. I've summarized the heat pump performance in this presentation by pulling out some of the interesting and unique findings related to MF installations.



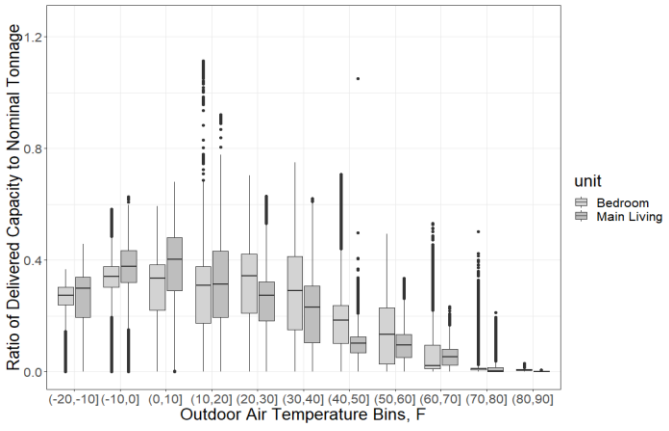
The first think I'd like to discuss in the layout and zoning implications. We discussed previously that the flexibility of these systems and the increased availability of the multi head systems makes HPS a good fit for MF. However, it is really important to think about where the indoor components of the heat pump is installed especially with ductless units where you don't have a distribution system. These systems rely of direct airflow from the head or heads into and around the space to provide heat and cool. Installers should consider which spaces sort of are closed off from the main load. For example, installing a heat pump in the living space it's probably not going to provide a lot of heat into a back room that has a closed door.

Let's take MF1 Unit 3 as an example. On the right-hand side is a sketch of the layout of this unit. It is a main central living space with a pretty open living room and kitchen area and then the bedroom was isolated from that space with a door. This system had three zones that were independently controlled in each of those main rooms. We choose to install the heat pump in the living room because that was had the largest access the largest square footage and the most potential for displacing that baseboard heat. You can see in the chart how these different zones ran. The chart shows energy consumption per day on the y axis and the daily average OAT on the x axis. The red system is the heat pump, and the dark blue is the living room electric resistance baseboards, which was mostly offset by the heat pump and barely ran. The aqua color represents the zone which controlled the kitchen and bedroom. This layout was limiting as the heat pump had little access to provide heat to the bedroom but had more access to the in the kitchen. Recall that this is energy used, so with the HPs high efficiency it is providing two to three times the heat that the electric resistance auxiliary system is delivering for the same consumption. This heat pump issized to be pretty close to the full capacity of the unit but due to the layout of the unit, especially at moderate

temperatures it cannot deliver as much heat as needed into that bedroom and kitchen. And then the backup heat is needed. The layout of the unit really does limit the potential of the heat pump.

Capacity is limited more by space than specification

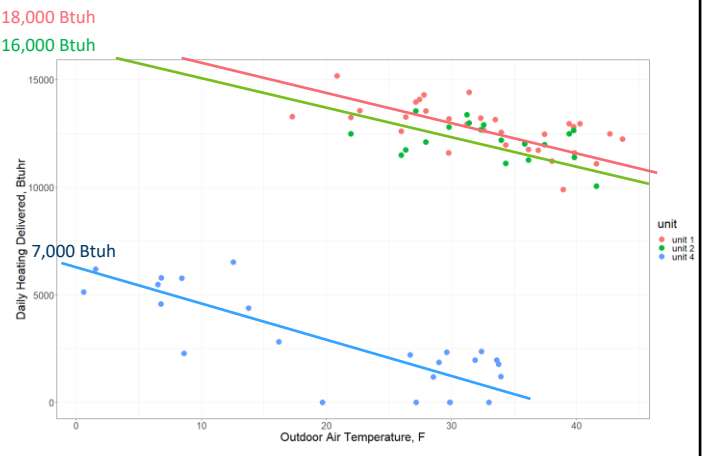
- Ductless systems are capable of delivering heat over a wide range of OATs
- In warmer temperatures systems are limited by load and zone
- In colder parts of the year systems are limited by OAT
- Many systems are layout constrained even in idle operational conditions (~15F) and do not deliver rated capacity



Continuing the thought on capacity. For many MF installations the HP is limited by space as much of more than by the heat pump capacity. The plot shows the delivered capacity of a 2 to 1 system that has a head in the living room and a head in a bedroom. The data in the charts shows the ratio of actual delivered capacity to the nominal tonnage of the system. On the X axis is the outdoor air temperature bin so over on the left hand side it's really cold outside on the right hand side were in the warm winter or shoulder temperatures. What we can see is that this system is just often well below it's nominal tonnage. That can both be from the layout and just because it's cold out and the heat pump can't deliver its full capacity but in this case it you can see that you know the heat pump system is while capable of delivering higher capacity. There are some measured operation that is very closed to the measured tonnage. Especially in moderate temperatures.

Heating Load Impact

- MF_61 three-story buildings, with similar units, but loads vary dramatically by floor
- Heat pumps have similar performance across all floors
- But low loads in some units pose cost-effectiveness concerns



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Let's jump to building 61. This is the three-story building with the same unit design on three floors. The plots shows some of the load variation by the location of the unit within the building. The figure shows the daily heat delivered to the space on the y axis. This includes from the heat pump and backup heating system. The x-axis shows the outdoor air temperature of each day. We saw that the middle floor units do not require much heat. This is no surprise to those of you who have lived in upper floor MF buildings where you need to open windows in the middle of winter. Units in the middle and upper parts of a building, likely have little external wall area and are impacted by heat raising within a building. In MF 61 the middle and upper floors required far less heat that group floor units. The two ground floor units used a lot more heating energy than the middle unit (#4) despite the same layouts. There was a big difference in the total heat needed to keep the unit comfortable at 0F, 7000 btuh in the middle unit and more than 15,000 btuh on the first floor. The outdoor temperature at which the unit stopped heating heat was dramatically different, with the middle unit being able to stop heating around 35/40 degrees.

This is obviously important in the load calculation and heat pump sizing for a unit. But it has impacts in other ways as well. A unit with a smaller load, may be able to meet part of all of the needs of the space at colder temperatures. The energy and cost effectiveness will also be dramatically impacted.

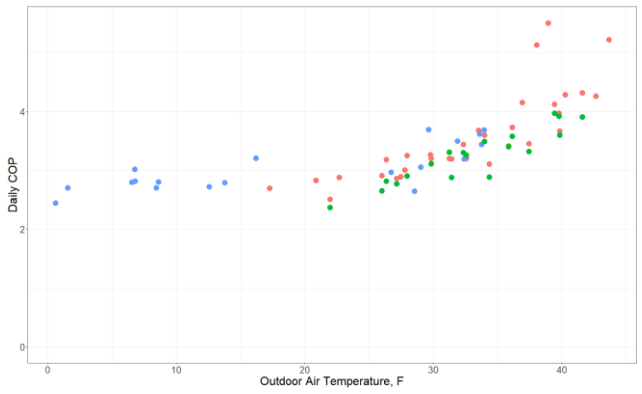
Multi-Head Control

- Multi-head system controls vary by manufacturer (and model?)
- Some systems tend to run indoor heads simultaneously
  - Impact zone control
- Some allow more independent head operation
  - Not VRF
  - Leads to heat loss from inactive heads

We collected data on a few installations of multip head systems in multifamily buildings. These installations represent some of the first measurement and verification of delivered performance to be collected on multihead systems, especially as deployed in MF buildings. The number of installations was limited, but I wanted to touch on some of the unique performance of these systems that we observed from the monitored data and speaking with different manufacturers and installers.

We observed a difference in manufacturer controls of these units. One large distinction is that some systems will run both heads simultaneously while other systems allow for one head to deliver heating or cooling while the fan on the other head remains off.
It is important to remember that these multi-head residential systems are not variable refrigerant flow systems. That means regardless of which zones or heads need heat, the refrigerant will circulate through the full loop and all heads. This can lead to losses of the refrigerant loop. These loses will likely be inside the conditioned space, but are not controlled by the system airflow.
These control choices can impact the zone control and interaction with backup systems. It is useful to understand how the indoor heads will interact and operate when designing a heat pump installation.

Multi-Head Performance

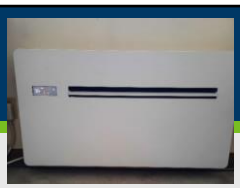


- Total system capacity and COP are consistent with single-head units
- Some interesting head-to-head interactions
  - Defrost
  - Simultaneous vs. independent RT

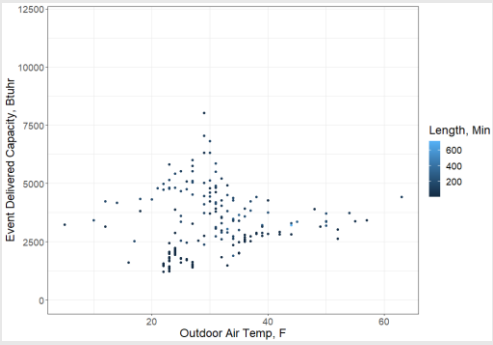
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Overall the system efficiency of the multihead systems (shown here in red and green) are very similar to the single head systems, shown in blue. This plot is the daily heat pump efficiency of heat pumps at building MF_61. We can see the system COPs, shown as daily averages on the y axis, are within the same range when operating as similar out door air temperatures, shown x axis.

So from a high level the multi-head systems are just as capable of delivering high efficiency performance. They have an added advantage that they can deliver heat to multiple zones. But we need to consider some of the system control and performance aspects that are not fully characterized and may impact the user experience with multi-head systems. Things like the runtime of individual heads, refrigerant loop heat loss, and zoning considerations.



Packaged Terminal HP Performance



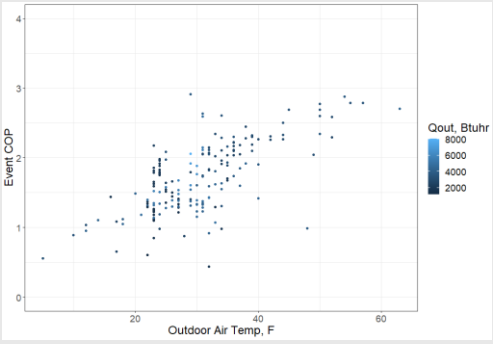
- Delivered Capacity
  - System delivered heat over a wide range of outdoor conditions
  - PTHP was variable speed, but delivered heat capacity was pretty consistent
  - Peak capacity was delivered around 30F where cool temperatures increased the heating load of space, but were not cold enough to limit capacity

I want to move to building MF_60 and talk about the package terminal heat pump. As a reminder the PTHP, shown in the upper left of the slide, replaces those under window style systems common in hotels. We installed this cc PTHP and collect performance data for the system. We were only able to install one PTHP as part of this study, but again this is one of the first ever installations of this type of equipment in a cold climate with performance monitoring data being collected. The figure on this slide shows the heat delivered by the PTHP over the course of the monitored period. This figure shows the delivered heating capacity of the system on the y axis over a range of outdoor air temperatures, shown on the x-axis. This system was rated with a 9,000 btu/hr delivered capacity at 47F. We can see that the delivered capacity peaks around 30Deg F outdoors. This is the condition where there it is cold enough outside for the building and the specific zone this heat pump is installed in to have enough load to cause the heat pump to ramp up, but it's also warmer enough outside to not have a significant impact on the performance of the system. As it gets warmer outside, moving to the right on the chart, the load of the building decrease and the heat pump ramps down and/or reduces it's runtime. As we move to the left, and temperatures decrease, the heat pump's capability to deliver heat is reduced.

This application for heat pumps is newer to the market and the capabilities and specifications of the heat pumps components still trail those used in ducted and ductless systems. As such some of the cold weather performance may be impacted at higher rate than for other heat pumps. At colder temperatures, 5 deg F, this systems rated max capacity was reduced to 4500 btu/hr range and as the chart shows we say some operation at the 3000 to 4000 btu/hr range between 5 and 10 F.



Packaged Terminal HP Performance cont

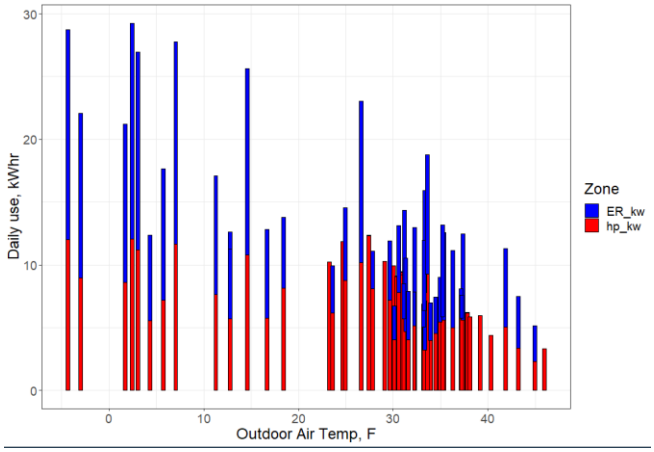


- Coefficient of Performance
  - Annual heating COPs ~2
  - Good performance in warmer shoulder seasons
  - COP dropped off below 15F
  - These heat pumps are cold climate and variable speed, but do not have all the same innovations of currentgeneration ducted/ductless technology

Switching gears to look at the efficiency of these systems. This chart shows the COP of the PTHP over the range of outdoor air temperatures. Each point on this plot is one heating cycle from the PTHP system. The lighter color points represent heating events that delivered a higher heating capacity.

You can see the impact of the slightly lower tier of heat pump with a lower COP, especially at colder temperatures. As we get to outdoor temperatures around 0F the cop is trending towards and below one which is basically the replacement level COP of electric resistance. But in the moderate temperatures in around 30 F range we saw COPs 1.5 and 2 times that of those baseline systems. COPs approach 3 as we reach the balance point of this system. These COPs are slightly lower than the ductless systems, but still significantly better than electric resistance. Additionally we can see the importance of understand the very cold temperature performance and need for integrating with a supplemental heating source.

PTHP Energy Usage

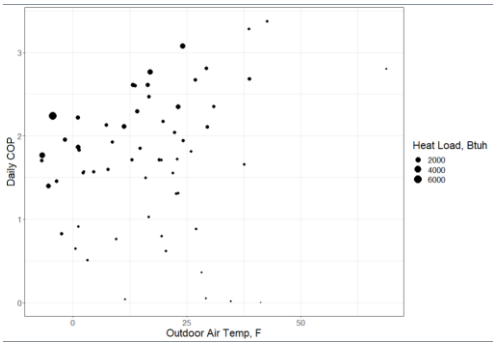


- PTHP accounted for half of the heating energy use
- Adj. for the COP differences the PTHP delivered about 2/3rds of the unit's heat
- PTHP was relatively the same regardless of OAT

This slide highlights the energy use within this full unit. Each bar in the chart represents the energy use to heat the unit. The red bar shows the heat pumps energy use, while the blue bar shows the electric resistance heating. We can just see how much this package terminal heat pump actually offset load in this apartment. The PTHP is using slightly over half the total heating energy at this site, which is a big electric resistance displacement. Remember the PTHP is slightly less than twice as a efficient as the resistance heat, so the PTHP is delivering about 2/3rd of the units heat. We also remember how the PTHP capacity was consistent across the temperature range, we can see that reflected here in energy use. Must days the PTHP is using about 10kWhrs. The resistance backup then fills in the rest with much less use on moderate days and a lot more usage on the coldest days.

Seasonal Performance

Building	Units	Avg heating COP
MF_01	6 – 1to1	2.25
MF_07	4 – 1to1	2.05
MF_61	6 – 1to1 & 2to1	2.12
MF_60	1 – PTHP	1.69



Here we have a summary of the heat season COP at each unit and an example plot of efficiency for one ductless system. We calculate the heating season COP by using the typical meteorological year data to determine the expected outdoor air temperatures in a normal heating season. The measured performance data was then used to calculate the systems delivered heat and efficiency at each of those outdoor temperature conditions. The total load and efficiencies were then calculated for each unit and averaged per building. That number is shown in the chart. This approach allows us to capture the impacts of small number of high load days at the very colder temperatures where COPs are lower which are weighted against the higher number of days of lower load days where COPs are higher.
In general the overall performance of all the systems was very consistent with other measured performance datasets for heat pumps in cold climates. Both from previous CARD work but also conducted elsewhere in the country. Which again highlights that heat pumps are generally very efficient systems. The real value in getting improved performance comes from paying careful attention to the installation, sizing, and design elements we've been discussing.

Technical Reference Manual

- Current TRM is based on capacity and equivalent full load hours
  - Especially difficult to get accurate estimates in MF
    - Sizing
    - Layouts and controls
    - Integration with existing
  - Consider a tiered rebated based on design and installation requirements

The technical reference manual
CEE has been working to support DER and the technical reference manual advisory committee on air source heat pump measures for many years. The most recent versions of the TEM have gone a long way to improve the ASHP calculation. At their core the calculations are still based on the systems rated capacity and an assumed number of operating hours. However, significant advancements have been made to account for installed performance. Calculations are adjusted based on the likely OATs during operation and the amount of load the heat pump is likely to meet. These have greatly increased the accuracy of the calculations.
However, HP applications continue to see innovation seeing heat pumps systems being applied to more and more types of housing and offsetting different types of existing systems. The challenges are especially important with multifamily buildings. Systems cannot always deliver as much heat as that capacity says due to layout and integration constraints. This increased variability and approaches will only make energy performance and savings estimation more difficult. As such, we recommend the TRM consider a tiered rebate approach based more on application and design intent that rated capacity and efficiency ratings. Continuing to incorporate modeling results as feasible is another alternative.

Conclusion

- CC heat pumps perform well with high COPs and good heat delivery
- Design and installation considerations are the biggest barrier to having installed performance meet climate and energy goals and homeowner expectations
- New applications show considerable promise
  - Multi-head systems have clear benefits in specific scenarios
  - PTHPs have significant potential over PTACs

Here are a few of the high-level conclusions. The cold climate heat pumps installed in this work largely delivered on their promise and specified performance. The installation and design considerations are the biggest factor in making sure climate and energy goals are met with these installations. They are also key to ensuring homeowner expectations and comfort are delivered. New applications of heat pumps, such as multi-head systems and PTHPs continue to be developed. These systems also largely meet performance expectations but increase the need for best practices and the need for installation and design requirements to ensure the systems will operate as intended and deliver on their promise.

Questions?

Ductless Cold Climate Heat Pumps for MF



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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.

Lindsay, do you have any questions for Ben or Lindsay?

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Thanks again for your presentation and to Lindsay 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, navigate through the left panel weblinks, and to access Research since 2020 click on 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.

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 on the left side panel shown by the green arrow through the same CARD website where research results are posted.

Your feedback matters. So don't hesitate to contact Lindsay Anderson or myself if you have questions or suggestions for the CARD program or CARD webinars.

That ends this webinar - take care and good bye.