Field Assessment of Cold-Climate Air Source Heat Pumps: Cost-Effective & Cold-Climate Ready

- **Slide 1: Welcome to the Conservation Applied Research & Development (CARD) Webinar**
- **Slide 2: Introductions**
  - I'm Mary Sue Lobenstein, R&D Program Administrator at the Minnesota Department of Commerce, Division of Energy Resources.
  - With me today is Mark Garofano, who is the Energy Engineer at the Division of Energy Resources where he performs engineering reviews of custom efficiency projects and leads the department's efforts by maintaining and updating the reference manual that utilities use to calculate the savings and cost-effectiveness of conservation improvement programs. Mark is also the project manager on the research that is the subject of this webinar.
  - Our presenter today is Ben Schoenbauer, who is the Senior Research Engineer for the Center for Energy and Environment (CEE). Ben conducts research on new and innovative technologies and ideas dealing with residential and commercial energy efficiency. His work includes identifying new opportunities, conducting field research, identifying and pursuing funding opportunities, and disseminating the results of research that he's conducted. Ben's areas of focus include water heating performance, service water heating, residential HVAC systems, and beneficial electric.
- **Slide 3: Webinar Basics**
  - Before we start, I'd like to go over a few webinar basics. All attendees will be in listen-only mode. As questions occur to you during the presentation, type them into the Question Box in the Goto Webinar panel and send them to us. We will address all questions at the end of the presentation, but if for some reason we don't get to all questions, we'll answer them later and e-mail all participants a copy of the Q&A from the webinar. This webinar is being recorded and will be available on both CEE and the department's websites at a later date. Finally, the slide deck for this webinar is available as the handout of your GoTo Webinar panel and you can download it at any time during the presentation.
- **Slide 4: Minnesota Applied Research & Development Fund**
  - This webinar is one of an ongoing series designed to summarize the results of research funded by Minnesota's applied research and development fund. The applied research and development fund was established in the next generation energy access 2007. The purpose is to help Minnesota utilities achieve their 1.5% energy savings goal by identifying new technologies and strategies to maximize energy savings; improve effectiveness of energy conservation programs; and documenting CO2 reductions from energy conservation programs. A utility may reach its annual energy savings goal either directly through its Conservation Improvement Program or indirectly through energy codes, appliance standards, behavior, and other transformation programs.
- **Slide 5: CARD RFP Spending by Sector thru mid-FY2017**
  - About 2.6 million of respondents set aside annually to the CARD research which rewards research grants in a competitive requests for proposals process. Since the legislation was enacted, the CARD program has had 8 funding cycles with 22 RFPs posted, received nearly 380 proposals, and funded 92 projects, representing over 21 million in research dollars. And as you can see from the pie chart here, projects funded today have been all build inspectors. The subject of today's

webinar is the residential sector and reports on a project that will assess on the efficiency, standing potential, cost-effectiveness, and comfort of new heat-pump technology designed for operations in cold climates. So I'm going to turn it over to Ben now, who is now going to tell us about the results of his great research project.

- **Slide 6: Field Assessment of Cold-Climate Air-Source Heat Pumps**
    - Hi everyone. Thanks for attending today. So I'm going to talk a little bit about the results from our field assessment of cold-climate air-source heat pumps. As alluded to, the final report [for this project] will be out shortly and available on the DR and CEE websites so if you're looking for more follow-up information afterwards, that will be available.
- **Slide 7: Discover + Deploy**
    - So a little bit of background for anyone that isn't familiar with CEE; if you're not familiar and interested, probably the best place to go is to our website, mncee.org, but a little bit of background. We kind of do all things energy and energy-efficiency. We run programs, including the Home Energy Squad and One-Stop Commercial Lighting Programs. We do planning and consulting. We have a loans group that does financing. We do a lot of policy work as well. And the group that I'm apart of is the research group and we do research into lots of different areas. We've done a number of different CARD projects over the last handful of years and we'll dive deeper into one of those—Cold Climate Air Source Heat Pump today.
- **Slide 8: Agenda**
    - This is a little overview of what we're going to talk about today. We're going to start talking about the background of the technology and recent advancements that have been made; go into the opportunity if you're interested in this technology, why it's a good technology to study is a part of the CARD program and start to get into the results, looking into the things that are important, the installation and operation of the system as well as the results and the performance, and some of the conclusions as well.
- **Slide 9: Cold Climate Air-Source Heat Pump?**
    - For people who aren't familiar, here's just a little background on how these systems work. So an air-source heat pump is a space conditioning device that does both heating and cooling in residential homes—at least, we're focusing on residential homes for this project. And it uses forced air to do that, so it works a lot like your typical cooling system or air conditioner. In the summer it does provide cooling, it simply transfers heat from inside the house through a refrigerated system to the exterior.
    - What differentiates air-source heat pumps from traditional a/c systems is that this system can then be run in reverse to provide heating in the winter and so that is what the top side of this figure illustrates here. You're moving heat from the outdoor air into the house and this is capable even at very cold temperatures and that's really the advancement in technology has been made in the last couple of years is generating heat at cooler and cooler outside temperatures. So some of these systems are capable of moving heat from -13 degree air outside and heating your house even at those cold temperatures.
    - And actually since this project has been underway in the last couple of months, there's been some even further advancement to the technology that's moved the temperatures from well below -13 degrees, down even to the -20 degree range. So these systems have made significant steps forward that really open up the potential to deliver energy savings even in cold climates and heating dominated climates. That was really the technology behind this project and the reason why we started to look here.

- One thing that I will point out at this point is that we really focused on the heating performance of these systems for this project. That's why the innovation occurred here recently. But one thing to keep in mind is that there are cooling savings typically associated with these systems because the technology is so advanced on the heating side with an increased level of performance on the cooling side as well. And so while I won't focus on this and I will mention a few times during the webinar the impact on the cooling side and kind of the savings potential that's available there, but again, we didn't focus on that.

- **Slide 10: Opportunity**
    - So most of you are probably familiar—or, at least most of you from Minnesota are familiar—with the severe shortages in propane that we had a few winters ago and some of the projects that caused for some homeowners in the state. There's a large chunk of our state, maybe 30-40% that is still using delivered fuel as their primary heating source and then there's another significant group of people that are using electricity or some other source because natural gas isn't available and so we wanted to try and look at some opportunities for these people to get off their inefficient delivered fuel systems and heat pumps provide for a pretty interesting option.
    - So that's really the focus here is to look at houses that don't have traditional energy efficient gas heating technologies available to them and focus on looking at solutions to help ease some of those burdens. Obviously we don't expect to regularly go back to those extreme conditions where there were delivered fuel shortages but even under good conditions there still are some pretty seasonal impacts of the cost of delivered fuels in the state.
- **Slide 11: Study Overview**
    - A little overview of the field study we conducted is that we really wanted to focus on, now that these technologies are out, they're new, they claim performance—but, how do they actually work when you actually put them in a really cold climate. Some of these systems have been installed and demonstrated in more moderate climates on the coast, but they haven't really been tested in a climate as cold as it is in Minnesota, especially in the northern part of the state.
    - We really wanted to look at houses that were representative of those homes that didn't have gas available. So you can see from this map, where our installs were for this project. We had 6 sites total that we installed and we had both ducted and ductless systems. I'll get into that description if you're not familiar on the differences as we move through the presentation. But we had some in the metro area, one down a little further south in the state, and then one sort of in the western side, and a couple in the northern part of the state to really try to get a representative performance of the different climates in the state and in cold climates nationally as well. We really wanted to look at how do these systems really work when you put them in real homes that have real loads and sort of make some reason, some results and conclusions on how to incorporate those best into programs moving forward.
- **Slide 12: Instrumentation**
    - I won't go too much into depth here, but an overview of the instrumentation that we installed with these systems give you an idea of how detailed the data was that we were collecting. This is a sketch of a heat pump running in heating mode, so you can see here how it is taking air in from the outside, transferring that heat into the refrigerant, bringing that into the house, and then using the coil, much like the a coil for an air conditioner, and a fan from a furnace, to transfer that heat into the home and heat the house. And you can see that we're measuring power consumption on various components of the system, as well as the delivered air flow into the house, both in terms of air flow and the temperatures of that air. That really lets us characterize this system on a very detailed basis.

- **Slide 13: Installation**
  - As we started to collect data, and install these systems, we saw some very important areas of that install that really help set you up for success as you move into operation. And these are important areas to know, if you were to be developing a program, or things to be thinking about to ensure that you get good success in your system operations.
- **Slide 14: Ducted Whole House Installation**
  - So I mentioned before that we looked at both ducted and ductless systems, and so here we'll start to talk about the differences. A ducted whole house installation air source heat pump looks very much like a traditional a/c system. It's got an outdoor unit, and a line set that comes into the house. The outdoor system is on the left there, with the line sets coming in at the upper right hand corner of that picture on the right, feeds into the duct, just above your furnace, where your coil is located, and then your standard furnace below that. The furnace acts not only as a fan to move the heat from the heat pump, but also as your backup heat. This is basically the ducted whole house installation that feeds right into your likely existing forced air distribution network or duct work and can heat the whole house and anything that is hooked up to that system.
- **Slide 15: Ductless Heat Pump Installation**
  - A ductless system is named such because it doesn't have duct work, so it's very much the same type of system, but it has an outdoor unit and a line coming into the house, but instead of connecting up to your central duct system, it has an indoor unit, typically called a head that is placed inside the home, and transfers heat directly out of that unit, so because it doesn't have a distribution system, it's really limited in effectiveness in areas surrounding that system and we'll get into a bit about the limitations and benefits of that approach.
- **Slide 16: Site Equipment**
  - This is just an overview of the equipment that we installed. You can see that there are 4 ducted systems in green and then the two ductless systems down at the bottom. I'm not really going to get too much into the differences of these different types of systems. There are some small differences, both in performance and operation, but for the most part, the systems operated in a similar extent.
  - Another interesting thing to point out is the size of these systems, so because the ducted systems are designed to meet the whole load of the house, or at least supply heat to the whole house at different points in time, they're much larger than the ductless systems. You can get them up to 3-4 tons, even 5-6 tons, down to 1.5-2 tons, but typically they're in the 2-4 ton range. On the ductless systems, they're much smaller, they typically come in 1, 1.5-2 ton units, so just because of how they're designed and their applications, and there are some different sizes.
- **Slide 17: Manufacturer Specified Performance**
  - And so as I mentioned, the biggest advances in the technology is this cold climate performance. This is some manufactured rated data, right off of the manufacturer's specification, for one piece of equipment. This is for one piece of the equipment that we installed, but in the laboratory test conditions as rated by the manufacturer. So you can see here, we're looking at both the capacities, or the amount of btu used delivered into the home, of the home from the system in the blue as well as the coefficient of performance, which is a measurement of the energy delivered to the energy needed to transfer that around the home in red.
  - So you can see here, we've got three points here versus for each of those specifications at different outdoor air temperatures. And so as it gets colder and colder outside, the system becomes a little less efficient and can't move quite as much heat. Just because it's harder to extract heat out of that 10-0 degree air temperature. Historically this heat pump equipment has only been rated at this 47 degree test point that you see on the right side of your screen.

- **Slide 18: Cold Climate Specification and Product List**
  - The NEEP has been doing some neat work to create a cold-climate specification, and a link to that database. They've really been working to create these test points at 17 and 5 degrees to get us some more data on how this will perform in the field. If you're interested in finding out equipment that's really designed with this cold climate application in mind, this is a really good resource. They have a database of the equipment that meets their specifications as well as the rated data at these additional test points.
- **Slide 19: System Design: Sizing for Ducted Systems**
  - We're actually seeing that at more of these test points being picked up and some of the rating methods, we're seeing more and more equipment being rated at these cold conditions that are really important if you wanted to design or estimate how the performances are going to be in a cold climate. So with that being said, we use the information provided from those specifications to do some of our sizing information.
  - This is a very similar curve to the last one that I just showed you. This is, again, from specified data, or laboratory measured data that is available from the manufacturer. We have three different pieces of equipment. This is the same model of heat pump, but in three different sizes. So we have a 2 ton size in red, a 3 ton size in yellow, and a 4 ton size in purple. This is really looking at the delivered capacity on the y axis and various outdoor air temperatures on the x axis. The black line on top in this chart is what we expect the heating load to be for the one house. And so this is taken from the design conditions from running a manual j calculation or from looking at your utility bills, you can find out how much energy is needed to keep a specific house warm in the winter. And this should be done as part of any sizing design before installing an HVAC system. And that's sort of what we see in that. Design condition for the metro area takes about 30,000 btus to keep the house warm. And we can assume that somewhere around 60, you don't need any energy to keep your house warm. Somewhere around 60-70 degrees is when people usually turn off their heating systems. What we're looking at here is that if we're plotting the capacity of each given heat pump against this heating curve we can see that the outdoor air temperature at which the heat pump can no longer meet the load of the system.
  - For this specific house and for this specific piece of equipment we went for the 3 ton system that met the load down to around 10 degrees. This let us meet about 80% of the heat in a given heating season with the heat pump but still maintain a reasonable start-up cost. So that's sort of a trade-off that you have to weigh. If you put too small of a system in, you meet less of the load. But if you put too big of a heat pump system in, then you meet the load, but it gets more expensive. The typical rule of thumb that we follow in these installations and other specifications in house sizes is that you're going to have to put in a 1 ton larger heat pump if you design for a system for heating than if you were to design a system for cooling, like the same home with the same size. So you're looking at a 1 ton bigger piece of equipment which is a pretty small incremental cost.
- **Slide 20: Operation**
  - In terms of operation, you're going to have slightly different operations for the different types of equipment, for the ducted system and the ductless systems. As we mentioned in that sizing chart, the ducted systems we targeted in a 10 degree switchover, and that's the point where the heat pump can no longer meet the load of the house so below that temperature the backup system is going to take over.
  - With the ductless systems, it's slightly different. Those systems will just operate at the temperature outside and will contribute some percentage of the heating all the way down to -13 degrees. So you don't really have to set a switchover point for these systems, they will just operate and meet

as much of the load as they can. That kind of feeds into the controls and the interaction with the back-up systems.

  - For the ducted systems it's really automated. For the ducted systems, that type of flex fuel systems with the furnaces as the backup and so the system will measure the outdoor air temperature and know if that set point occurs and will switch over to the backup. It also has some integrated controls if the heat pump—if it's warmer than the temperature, but the heat pump can't keep up for some reason, it also has the backup there to take over and help meet demand if the system can't keep up.
  - The ductless systems are a little less automated, because they're sort of standalone systems and they're separate from the backup which is often electric resistant heat in a home and so you really integrate those systems through setting the set points slightly differently for your thermostats. If you think about it, if you want the heat pump to come on first, you just set your indoor condition temperature on the thermostat slightly higher. So you set your thermostat to 70 degrees and your electric resistance to something like 68 degrees. And so as the heat falls in the home and it's getting cooler and cooler, and it hits 70 degrees, the heat pump system knows to hit the trigger to heat up the home and so you don't hit that 68 degrees and the electric resistance never kicks on. And so the heat pump will be the primary system as you move beyond the capacity of the heat pump, the temperature will drop below that 70 degree point and if it can't keep up, then once the temperature drops to 68 degrees, the electric resistance will kick on and supplement the heating system. It's a slightly different method of operation but achieves much the same success but the heat pump is the primary means of heating and you have a backup heat source available when there isn't enough capacity.

- **Slide 21: Furnace Integration – Keep or Replace?**
  - The furnace integration in particular is a new area for manufacturers so with a traditional heat pump system, before we had the air source heat pump system, there were heat pumps that were available but they couldn't heat beyond 30 degrees outside. In our climate it wasn't really considered a heating option so much in a heating season that went below 30 degrees. So those older pieces of equipment can be installed there because they didn't have that great of an integrated control, it was just if the heat pump was on or not.
  - With these newer systems that have a wider range of modulation and heat at cooler temperatures and have more integration on the control side, it's really important to have a backup furnace system that talks with and has the capabilities needed for the heat pump system. Right now the path to achieve that for manufacturers is to install a new furnace at the same time as the heat pump system and you can imagine that that has a significant impact on the total installed cost. We sort of looked at a few different options for installing this system.
  - First option was to just go for it and install the best furnace they had, brand new, with the new heat pump, and that really gives you the best of both worlds in terms of performance: you get that brand new air handler that works really well, you get the totally integrated controls, all the options that you can do, multi-stage fan, all those sort of things. And it also gives you a condensing furnace for when the furnace does have to run, so you have the 90% furnace.
  - Another option that we considered was to get the really nice multi-stage fan and controls but to limit, to install a cheaper furnace, with a 80% furnace, that's still new, that's got some cost, but just a little bit cheaper and we thought that might be okay, because we're really trying to run down the furnace anyways so if it's only covering 10-20% of the heating load, maybe the impact of using the 80% furnace is really worth it. So that was one option that we considered.
  - Another thing that we're starting to see some movement in the market is some different solutions is a sort of staged installation. So if you install he heat pump then you match it with the existing

furnace for backup system lifetime system dies then you can replace it with a newer furnace with all the features and so you have nonoptimal performance while you're working with your existing furnace and when you replace that furnace you unlock the full potential of the heat pump. Another option that we get into in the full report and I'll only briefly mention it here today is the use of eliminating the furnace and the plenum heater as backup. As these heat pumps work at colder and colder temperatures maybe there is a less period of time you're relying on backup at all and you can get away with loose performance so the heat pump can still run always and the plenum can give you extra btus or extra degrees of temperature that you need as opposed to having a full furnace backup. So that's a potential option especially in small tight houses that don't have that big of a heating log.

- **Slide 22: Ductless Heat Pumps**
    - For this project, the first two bullet points were really the ones we considered, for simplicity and to get the best performance out of the systems. But in the future look for those other options.
- **Slide 23: Ductless: Install Location**
    - In terms of the ductless systems here are some pictures of some of those components that I mentioned. The outdoor unit looks a lot like the others, only smaller, since it's only a 1 ton system, you have that indoor system that actually distributes the heat to the house and the thermostat. One thing to consider when you're installing a ductless is how do we get the most out of this system, and so this is just a simple floor plan for one of the houses with the five electric baseboards within those homes highlighted.
    - When you're looking at where you want to install this unit, you can do one of several things. If you installed it in that back bedroom at the top of the screen, you can replace that resistance heater you'd get a really comfortable bedroom out of that heat pump but it would have pretty limited effects to the rest of the house because that room is so closed off. However if you install it in the dining room, on the right side of this slide, you'd have the ability to provide heat to the living room, the dining room, the kitchen, maybe the den, maybe that bathroom, and can really get more bang for your buck for that heat pump. If think about typical floor plans, the more open your house is, the more open the area is that you're installing the system in, the wider heating load you can reach.
    - Another option is to install multiple units in one home, but we really focus on installing one unit in a home to see how it worked as a system. Obviously there was more cost and more load available as you go to more and more systems.
- **Slide 24: Installation Scenarios**
    - Just some things to think about in terms of different scenarios that you might use a cold climate heat pump. If your house has a full-forced air heating system, it's probably easiest to go with a ducted system as it's a life for life replacement, either your furnace or air conditioner, and again, if you do have air conditioning, you have that extra savings potential from the more energy efficient air conditioning as kind of a bonus, and so that's sort of the type of system that you're looking for. One thing that you should consider here is if either the furnace or the air conditioner need replacement in that home, it really helps the cost-effectiveness of these systems to look at upgrading or to look at the incremental cost of comparing to a new furnace or a new air conditioner as to going over to the heat pump, just a thought there.
    - The ductless mini split system is more attractive to houses that have hydronic heat or electric resistance heat that don't have that central ducting system to rely on to transfer the heat so you can use this much more efficient heating source in sort of the main area that needs heating in a home and having this added benefit of cooling that might be much harder to get to those areas in the house if you have hydronic or electric resistance. And the electric resistance scenario is the

one that we really saw in this project. I will note, that most of the installs for these ductless mini split systems that happen where natural gas is available acts as sort of a supplemental heat or cooling to an area that we can't reach in a hydronic house.

- So if you put in a new addition and there's no central duct work, you could stick one of these ductless systems in and it'd be a pretty unique solution. Or if you have a hydronic heating and you have a bedroom that's always really hot and you want to get some cooling in there, you might be able to put a ductless in, and that has some benefits on the heating side as well.

- **Slide 25: Modes of System Operation**
  - Let's get into the performance, in terms of how these systems actually ran once we installed them. When we're in heating mode, there are 3 main modes of operation to think about. Two are really straight forward, first is just when the air source heat pump is running. This is just whenever you're within that 10 degree switchover mode in the home or above the 13 degree if you're ductless. The heat pumps is just going to run whenever there's a demand for heat, it's going to get that COP capacity for that outdoor air temperature. If you're below that set point, that 10 degrees out, and the heat pump can't keep up with that load in the house, we're going to use the backup heating or that LP furnace, and that's pretty straight forward. It's going to run much like a standard furnace. The one that is different is the defrost mode.
  - If you're running this air source heat pump for heating in the middle of the winter you're going to get times when that coil gets cold outside and so the system wants to protect against the buildup of moisture and condensation on that coil and so it does that by actually running the furnace at the same time as it runs the heat pump in reverse basically. You're going to run the refrigerant in reverse to get heat from the furnace and circulates it through the coil to warm up the coil and limit potential frost buildup. The way this is done is purely on a temperature measurement outside, so whenever the conditions are present near the coil for there can be frost buildup, essentially whenever we're below 35 degrees right by that coil, the system will run in reverse, heat up the coil and then start the countdown until the temperature drops in there again and let the defrost run. This is a pretty conservative method of operation so we don't see any frost buildup when the system runs like this. We do some work and we get into more details in the report, looking at various ways this conservative operation might be changed to run only when defrost is actually needed, not just running anytime conditions are present but that's sort of a future improvement type constraint. I'm not going to focus too much on it here but the information is available in the report.
- **Slide 26: ASHP and Furnace Cycle Efficiency, Site 2**
  - Here's some installed performance for various heating cycles in one of the sites. Each of those modes is a different color on this chart. The orange-ish color is the heat pump only mode, the purple color is the furnace-only mode, and the blue color is all the times the defrost kicks on during a cycle. We're looking at the coefficient of performance, the efficiency of the cycle, versus the various outdoor air temperatures. So when you're looking at the cold, very cold temperature performance, when it's 0 degrees outside, especially anytime it's below 10 degrees, you'll see all those purple events somewhere around 80% efficient and that's the furnace-only running in backup each cycle it's running about its rate, its efficiency and those are pretty consistent. When you get above 10, the heat pump events in orange, that range from about 1.75 all the way up to 4 in terms of COP, that really lines up with the manufacturer's specifications so that heat pump is definitely doing what it does. It's running at very efficient, at least twice as much if not three times as much heat to the home as it takes to move that heat from outside inside.
  - There's a lot of noise in the blue, and that's because that's a heating cycle where the defrost is kicked on, there are some times when it's only the defrost running. There is really only 0%

efficiency and that's because the system is running almost always all of the heat from the furnace to the heat pump to keep the heat pump from frosting. At other times, it's much more efficient, because the heat pump has been on for a long time and in the last couple of minutes of the event it turns on the defroster and makes it slightly less efficient than the heat pump mode. And that's why you see such a wide range of performance there. But you can see that when you are in defrost mode, you see a significant reduction in efficiency than when the heat pump is on. It is important to understand how that defrost is running when you want to estimate what your savings are going to be.

- One other thing to point out is that these numbers are all installed performance, so they're not the lab rated efficiency that you see with the equipment. So equipment when it's measured and specified, your efficiency, your COP you see on your equipment's decal, represents steady state operation at a given time during a given set of operating conditions which we rarely see when we're out in the field. We see a lot more transience, things ramping up and cooling down, we see a lot of operating at different points so that's one thing to keep in mind here. I said that the efficiency is around 80% for the furnace, for a 90% rated furnace, that's because it takes a while for the furnace to ramp up to its steady state of efficiency and all this plot shows is that sort of instantaneous efficiency of the equipment or the cumulative efficiency of a cycle and how it takes 10-20 minutes to get up to that condensing level of efficiency. And that's important to remember when looking at these numbers which is that these really are the field rated conditions

- **Slide 27: System COP vs OAT**
  - That brings us to this next plot, which has a lot of data on it, which I apologize for, but I wanted to show an overview of the operation of all of these different sites. This is all six sites all on top of each other here, both ducted and ductless sites, so if you look at it, you really see 3 regimes where you've got the heating performance on the left side of the slide, from -20 all the way to 50 degrees outside, we see positive COPs ranging from .8 all the way to 5 in some instances. And as we move over to where it gets hotter and hotter, we see that efficiency start from 0 to negative where the cooling comes on. So in these calculations, we're counting energy removed from the house as cooling as a negative COP. These systems are providing cooling. I don't want to get into that analysis too much right now, but they're providing a lot of efficient cooling out there when it's 75 degrees out and I just wanted to show that.
  - As we zoom in here on the heating performance, we can ignore some of the data points around the 0 in the right hand corner, that's essentially times when it's warm enough out that the heat pump is basically barely on or it's partially in cooling and partially heating and so you get some numbers that are near 0. But if we look at the heating performance down below 0, we see that for the ducted systems those daily system efficiencies are a little bit below one where we're running both the backup furnace as well as the heat pump as we get a little bit warmer out. With the ductless systems in the blue and pink have efficiencies that are greater than 1 and that's because that heat pump is still running all the way until -13 degrees so we're still seeing COPs that are higher than one which is pretty great. That's some really cold temperature performance of those ductless systems.
- **Slide 28: ASHP Performance**
  - This is some similar data, just grouped together to give you a clearer picture. This is the 4 ducted sites, just the heat pump, so we've eliminated the backup performance in these slides and the bins here are sort of what the box plots show, the inner quartile range. Essentially you can think of the color as half of the runtime of each piece of equipment. You can see when it's between 0 and 10 degrees outside, we have COPs that are between 1 and 2, depending on the piece of equipment, and they get a little bit higher and higher as we move along. So once you're out at 40-

50 degrees you can see the average COP is up towards 3 with the caveat that one system at site 4 really gets efficient out there and that has a lot to do with the air flow that's achievable and some of the operating conditions at that site, in particular, that really let it be super-efficient.

- The big takeaway here is that from the point where the heating kicks on from around 50 all the way down to that changeover point at 5 or 10 degrees outside when the heat pump is running on its own it really mashes up with those specifications supplied from the manufacturer. This is really encouraging; these are some really high COP numbers which really indicate the potential for savings. Everything is really straightforward when the heat pump stays on, the conditions, they work great.

- **Slide 29: Example: Capacity on a 17 degree F day**
  - As I mentioned though, there is this propane runtime that we will stick around for. It really comes in through two ways, the operation of the equipment and the temperatures of that switchover point as well as the defrost. And so I wanted to walk through one day of operation here, to give you a sort of idea, of how that works. So I apologize for the confusing nature of this slide but I wanted to walk through it and highlight a day in the life of a heat pump. This is one site on a day that's about 17 degrees outside on average, so we're fluctuating around 10 degrees from that point, so this is just a time-series plot. One day from midnight to the next day at midnight, for three different variables. The top one is the outdoor unit in green, that's essentially the heat pump energy use so that's in watts, it goes from 0 at the bottom, where it's off, to its max rate of about 3500 watts. You can see that it's off or sort of operating somewhere in the middle with a couple of spikes up to its full capacity. The line in the middle is the fuel consumption or the furnace running in btu/hr, which goes from 0 to its max fire range of about 8000 btu/hr.
  - And the final chart is the outdoor air temperature with the red line on the chart representing the switchover point. So most of the day you can see that it's 20 degrees outside, so it's warmer than its switchover point, and then just before midnight, it switches into a time period where it's right around or below 10 degrees out where the heat pump can't keep up. And so if you look at a few points in the evening here, you can see where the heat pump is on for several hours in a row, where it's about 15 degrees outside and the heat pump is providing more output than is necessary to keep the house warm so it's meeting capacity at that 15 degree set point with no backup from the backup system. And it's actually only running at about 80% of its capacity there so it can actually provide heat for the house at a lower temperature than that which is really encouraging.
  - The other thing that jumps out that we noticed is that there are all these different periods where the propane isn't coming on but it is warm enough outside where the heat pump can meet the load. And that's all those defrost cycles in the house where the outside coil is registering a temperature cold enough where defrost might be present which amounts to 10% of the day in this case. And if you remember back at that mode efficiency slide, you're seeing efficiencies in those time periods anywhere from the heat pump operation all the way down from 0% effective while it's running because it's in defrost and so that's a potential for a pretty big impact on the system.
  - The other thing that we noticed is that out here where it's after we've dropped below the set point of 10 degrees, you can see that the heat pump is turned off and that the furnace comes on and runs the whole time that we're in that mode. And on this day, that's about 8% of the run time. So that's an important factor to know over the course of the year, how much you're doing this LP heating thing because it's below the temperature, and how much you're doing it because it's in defrost. I'll move to the results, but the thing to keep in mind is that on average, about 50% of the LP in this house is being used in defrost mode, and about 50% is going to the below set point mode. And that below set point mode is only about 10% of the total usage in the year. So we're looking at an about 10-15% penalty just from defrost.

- **Slide 30: Cold Temperature Performance of ASHPs**
    - Another thing on the cold temperature performance, this is another box plot to see the median and where most of the run time is against the various outdoor air temperatures. The thing to really look at here is that as you go into colder and colder temperatures, as you go to the right on this chart, the system holds capacity pretty well so the average capacity goes from about 20,000 at 30-25 degrees outside and only drops to about 19,000 btus/hr between 5-10 degrees outside. So we're not using a lot of capacity and a lot of this ramping is not even at full capacity of the system, it's really just the needs of this house.
    - The important takeaway here is that these systems are matching their specifications in terms of how much heat they can actually deliver and they hold pretty well over the range of temperatures we see in these houses. There is a lot of information in this slide to make this point, but the key takeaway is that these systems are really doing the job they claim they can do at 5-10 degrees outside. And this chart is for the ducted system, but I can say the same thing for the ductless system, although I don't have a plot for that on this chart, which is that it really holds its temperatures and its specifications down to those rated conditions.
    - One of the homes that we installed actually happened to be in Wisconsin, in Superior. But previously they had installed the ductless heat pump just before the start of this project so we were able to add our instrumentation and really get some really good information out of it. But that homeowner has now had their ductless system in for two full heating systems and they've used it so little, that they have started to remove several resistance baseboards heat, in Superior, Wisconsin. In northern Minnesota, up by Duluth, that's a pretty encouraging sign. That homeowner does have a fireplace so he can get some supplemental heat in other ways if he has to, but he really doesn't use the backup heat at all in that home, and just relies on the ductless system. We have some evidence on a couple of hours where it got really cold in Superior, where it was down to -20 or so, and the heat pump actually still ran, way below its rated conditions. It's not nearly as efficient as it can be when it's really cold out but it's nice to know that it will actually provide some heat when it gets in those cold conditions.
- **Slide 31: Ducted v. Ductless**
    - So a little comparison between the two system types. Like I mentioned, the rated capacities and the sizes of the ducted systems are much larger so that lets you heat the whole house, have larger airflows, lets you cover a bigger fraction of the load, but they do become slightly restricted at warmer temperatures, whereas the ductless system are really targeted to meet the design load of a specific area or a whole house if it's a smaller or more open floor plan, like an apartment or something. There are really good applications there, and they also go better down to lower temperatures like -13 outside, just to keep in mind.
- **Slide 32: Energy Use Analysis**
    - I want to get into energy use analysis. So a quick summary, we did these really detailed models of the system, that I've shown you some results for and we also got some really good data from characterizing the heating mode in the house, and so we kind of use those two models in typical temperatures to come up with our average performance for a given year.
- **Slide 33: Energy Use vs OAT Models**
    - So this is just a plot of how the system works. The colored points are when the heat pump is running: propane consumption in purple, and energy consumption from the heat pump in orange. And this is compared to the black line which is if you just heated the house with the furnace. So when you get down to those really low temperatures of -10 or so, you can see that the heat pump is turned off and it's all relying on the purple backup system of propane, and it much matches what the house would be like if it was just being heated or kept warm by a furnace. And as you

move into warmer and warmer temperatures, you can see that the heat pump takes over more and more of the load.

  - One thing to remember when you look at this slide is that this is the energy used by the house, so the heat pump has an efficiency, or a COP of 3, compared to the furnace that is less than 1. So any btu consumed in electricity in orange, is essentially 3 times more effective at heating the house, and that's why in times when the heat pump is dominating, like when it's 20 degrees outside or something, it doesn't look like it's using that much more btus than the furnace is.

- **Slide 34: Annual Energy Use (by Test Site)**
  - In summary of the energy use of the houses, you can see each of the houses on this chart, and this is looking at the energy consumption in therms/year. On this chart, the blue is propane usage and the red is electric usage. To the left hand side of each site, you can see the baseline assuming you're just using a furnace while the right hand side is the usage of the cold climate heat pump. On sites 6 and 8, the two ductless systems, you can see the baseline is all electric resistance heat. This really gives you an idea of the savings potential in terms of the sites' btus savings percentages here. But you can see we've drastically reduced the propane usage while increasing the electric usage because the heat pump is using more than just the fan and the furnace in this case.
  - I will point out here that there is cooling savings with these systems as well. We're looking at the ducted sides, typically increasing the SEER in cooling from 13 in the baseline case to something like 16.5, up to 20, depending on the heat pump model that is selected, which is a 300-500 kWh per year, around $50/year savings just from the cooling side for these homes, on average across the state, obviously lower if you're in northern Minnesota where there is no cooling, and more in the metro or southern area where there is more cooling.
- **Slide 35: Annual Characteristics and Savings**
  - This is a big picture savings for each site, all 6, both the ducted and ductless. The first two columns are just to give you an idea of the magnitude of the heating load so you can see that the ducted systems are kind of between 20,000-40,000 design conditions which are the typical range we expect to see in Minnesota houses. None of these are giant 5,000 square foot houses, and none of them are tiny 600 square foot houses. They're all a typical 1,500-2,500 square foot homes with a regular level of insulation and those sorts of things. You can see with the ductless, those numbers are more estimated because they don't meet the whole load of the house, but they're much smaller so they're meeting a smaller amount. And so you can see we have some savings numbers both in btus used on site energy reduction between 37-55%, the cost reduction to the homeowner that is the annual heating cost reduction from 30-50%. And the other category that we're looking at here is the propane reduction so you can see over 50% reduced propane usage with all of the ducted sites. And then you have the dollars per year saved at each home so you can see it's a big range, the heating load differs, the amount of propane usage differs at these houses, things like that, so we have a pretty big range of savings of about $500/year on average.
- **Slide 36: Install Costs**
  - In terms of install costs for houses, this is more theoretical number because we only had the 4 to go on for a ducted system so it's not a very good average number to use. We paid about $14,000 to install these systems, including that new furnace and in 3 of the 4, it included a new condensing propane furnace, so that was about half of the cost, maybe about 40% of the cost on most of these cases. We also paid some money for the instrumentation of things so there are maybe some small additional $500 for that.
  - The biggest thing is that most of the contractors that we work with aren't very familiar with these cold temperature systems, but they did have some experience with non-cold climate heat pumps

and lots of more experience with A/C replacement and so there's probably some safety/risk factor built into these numbers that cause it to cost a lot more.
    - If you look at the second bullet point, we maintain some sort of a national database for installed costs and we've got some numbers here that we're showing for just the heat pump for a new condensing furnace, an 80% furnace, and a comparable new SEER A/C cost. And those are sort of better numbers to use, in terms of an average cost that you're expected to pay in a program. The thing that really jumps out here is that the time where this starts to become really attractive from a payback period, where you get a payback of or around $600 a year is when you're looking at already replacing your furnace or your A/C system, you can get that incremental cost down. If you have to replace both the incremental cost, then it's basically nothing, maybe a few hundred dollars, but if you only have to replace one or the other, you can get that incremental cost in the $3,000 area, and you're looking at a much better paybacks so that's something to keep in mind in terms of how much you might stage this.
    - For the ductless system, it's really hard, and I have it here in the presentation, to calculate the paybacks. We can get into that some in the report, but there's a ton of variance here and what fraction of load you may cover and what the actual cost will be depending on how susceptible your house may be to updating the aesthetics because you're putting this system into the conditions base, rather than a mechanical room and so there's a lot more variables.
- **Slide 37: Summary of Results**
    - This is just a summary of the numbers; I mostly went over these already. A couple of new points that I'd like to go over though are that the ducted systems on average met 84% of the homes heating loads so we're only using about 15% of the load on the backup, that includes the defrost runtime. The propane reduction, we had on average about 64% reduction. The great thing is that for all of these houses and what we think is most of the houses in the state that would reduce the propane consumption below 500 gallons which is the typical storage size at a residential house. What that means is that you can avoid filling up your propane tank in the winter when it is much more expensive to do and that's pretty encouraging.
- **Slide 38: Policy Analysis – Minnesota context**
    - Another thing to note is that we have installed system COPs , so total air source heat pumps plus backup of around 1.3 or 1.5 for all of these houses. So this is significant improvement over the 1% you're losing over the electric resistance or the .8-.9% with the furnace. We're starting to run out of time so I'm not going to get too deep into the policy part of this. I've talked a lot about switching from propane to electric; there are a lot of implications from the policy side with the fuel switching. We had A/C Triple E as a partner for this project and they did a report on sort of the precedents in the industry and potential next steps in this arena. There's a really great report about that on our website. There are some precedents in state and around our country that lead to including this in terms of a net btu analysis and there's some really good information there so I'll encourage people to look at that.
- **Slide 39: Conclusions**
    - In conclusion when the heat pump was on, the heat pump worked great, as we would expect really great performance. The big variability in all of this is how much freeze protection and how much integration you're going to get with backup. That can be done very well if you follow the guidelines we put forward here. The systems do work at cold temperatures and if you stage the installs right then it's going to be really attractive.
- **Slide 40: Future Needs**
    - We already touched on most of these things. Upfront costs are a little high at this point if you're not looking at incremental or staged replacements, so looking at ways as the system advances

to get those costs lower as well as improving performance through limiting defrost and getting that operation point lower and lower.

- **Future Needs – Metrics and Programs**
  - I do want to plug—stay tuned to CEE for future work. We're doing some work that will be looking at the different metrics that might be used to evaluate heat pumps. So I kind of talked about site energy, efficiency, and cost, but also important then that we touch on some carbon reductions that are a potential here, source energy, and those sorts of things, and how those things might change going forward with the equipment improving and changes to the grid. So that's some upcoming work that CEE will be kind of launching now to stay tuned to if you're interested.
- **Slides 41 & 42: Audience polls**
  - We are going to do a poll because there are a lot of people in the industry here today. We've got about 84 people that have been listening here today from 14 different states. So once you've exited the webinar, we've got a few follow-up questions that will pop-up that you can answer. So we're going to forgo that and go ahead and answer some of your questions, and because there are so many, we're going to stay on for another 10-15 minutes to get through some of those questions. And any that we don't get through, we'll take, per usual, and get them in writing and post them on our website as well as send them out to all those who have registered and are tuned in right now.
- **Slides 43: CEE Website**
  - I just also wanted to mention where on our website you can find more information about air source heat pumps. And also if you're on our website and move over to the "Research" tab, there's a drop-down menu there for webinars and events; that is where we archive all of our webinars, and you'll be able to find the archive of this probably in the next day or two.
  - Turning over to Mark Garafano from the Department of Commerce to lead us through some Q&A.
- **Slides 44: Thank You**
- **Slide 45: Questions?**
  - First question is, does the technical reference manual currently address the heating side of the air source heat pump's SOMETHING?
    - Ben, I can probably answer this one since I manage the technical reference manual. Yes, we currently have this measure in the technical reference manual, but it deals with the typical air source heat pumps that aren't cold climate ones so this study is going to be building on that calculation.
  - The next question is, if you upsize the air source heat pump system, how would that affect the summer operation, particularly in respect to dehumidification control? Will dehumidification performance suffer because of the increased size?
    - So there's actually been quite a bit of work on this issue in general, for A/C oversizing. One of the nice things with these heat pump systems is that the modulation is pretty significant so you have a wide range of difference. On the bigger units when you're increasing the max capacity, you don't have as big of an impact on the minimum capacity and so you're still able to ramp the systems quite a bit and so you can still have long runtimes in cooling. We did do a little bit of analysis looking at that, but it wasn't the primary focus of this report; on that we sort of relied on some other sources, but it doesn't look like it will have a very significant impact on the cooling side, from a 1 ton increase. If you were to increase more and more, to chase that last couple of percent's, then you might start seeing a more significant impact.
  - Are the issues solutions for integrating heat pumps with furnaces the same or different for integrating with boilers?

    - They're different. So the integration with furnaces really comes down to the fact that the furnace and the heat pump use the same fan to distribute the air through the ductwork. And so if you're relying on an existing furnace fan to work with the heat pump, you're sort of limiting the amount of control in stages of fan operation so you're probably only going to have 1 or 2 speeds of fan operation on an existing furnace where there are kind of new air handling units that have lots of or infinite modulations. So that's really the key when you're integrating with an existing furnace. With a boiler system, you probably don't have a fan so you're using hydronic distribution so you're looking at installing a new fan either through ducted or even the mini split system that has its own fan. And so the integration issues aren't there. And then that's sort of just integrating the thermostat so you call for the heat in the way that you want to, as I mentioned, by offsetting them a couple of degrees one way or the other.
  - Did you study the effects on sizing of heat pumps from new inverter driven air source heat pumps?
    - Yes, so I didn't get quite into the technology specifically but as far as I'm aware, all of these cold climate systems rely on the inverter driven technology that really means that it lets you have this variable capacity of the heat pump system and that's really sort of what types of systems we're focusing on here, and that's really what unlocks that cold climate potential of these systems so that's really what was the focus of this work.
  - Looking at the data on slide 26, looking at the heating efficiency versus the temperature, how long is the time variable connected with each data point? Is it a day, an hour, or some other unit?
    - So this slide is really looking at the event-based, so it can be as short as a couple of minutes, if the system really only takes five minutes to meet the set point of the thermostat then that's represented as one point. If the system is really ramping with the thermostat and it's running for 3 hours straight, then that's also going to be represented as one point on the slide. This is really only an event-based analysis, whereas if we're looking at these slides, these are the daily averages. These are really summing up all of the data from the furnace and the heat pump for a given day. So that's why you see a lot more noise in these charts because there's a lot more variances in how these systems are operating over the given day.
  - You said that the crossover points in your study are 10 degrees Fahrenheit for ducted systems and -13 degrees Fahrenheit for ductless systems; do you know what crossover point contractors are designing in practice?
    - Yeah, so that's a big issue, and that's sort of what I got into when I was talking about some of the install costs. Traditional systems are not cold climate systems that don't have this ability to heat up the really cold temperatures, those are being installed with a changeover point out by 30 degrees, there's no real difference in the actual install between those systems and these ductless systems. It's just that their capacities are much greater than the forefront of how we design these systems to meet that point and so we decided based on some background analysis and some other work done in some more moderate climates that we thought we could do 10 degrees. We actually changed it from 5 over the course of the project, we think that you can do some sort of those cold air temperatures but in practice there are not a lot of people doing this yet with these cold climate air source heat pumps. So that might be a part of the outreach that we need to do as part of this project and certainly as part of the outreach that you need to do when you kind of program how to actually get these systems installed right. With the ductless systems they're pretty much standalone so whatever the system is capable of, it will do. And then default to backup when it can't keep up. So then that sort of has been changing as technology advances.

They were -5 a few years ago, and as I mentioned there has been some new equipment now that's -20, so those are nice because they're standalone and you can just install them and they can just cover every inch that they can.

- What is the source or feedback on air source heat pumps, the ductless, and the locality of the heating and cooling as well as the acceptance of how they look and are sold on their wall?
  - That's a good questions and I pointed and mentioned it briefly with the part of the install costs with getting it into the house and figuring out how to get it installed in a way that's aesthetically pleasing. And so like I mentioned we only had two ductless sites, one of those houses made the main decision to go ductless before the project, and we sort of jumped in there. The other one had all electric resistance and we were recruited to do the mini-split. Both of the sites really liked them, they thought that it heated very well in the areas that they were targeting. They did have a good integration with the electric resistance and only a small separation of when they came on and so the heating was really uniform. It's obviously a really small sample size of only two houses, but I guess in general they do seem like the have a good and growing market share so the reviews aren't too negative obviously. They provide pretty consistent heat and they have really long runtimes so they have the performance that we tend to see with systems that people tend to like and feel comfortable with. Aesthetics really comes down to what people like or can handle. The units are becoming more attractive, they've come a long way since they've come into existence, pretty well contained and they don't have any weird parts. They look well designed, and they're not that big, they're a couple of feet long by maybe a foot tall, so they can go in a lot of different places. In general, people seem to be pretty happy with them.

- **Slides 46: CARD Project Resources**
  - The answers to the questions that we didn't have time for will be posted on the MNCEE Website. The recording for the webinar and final report will be available on the Department Research and Development webpage which is shown here. When it's available, there should be a link to them via the webinar quick link, or the CARD search link which is indicated on this slide. The R&D page also has additional information and resources related to the CARD program and the CARD research projects, which you may want to check out on the Department Research and Development webpage.
- **Slide 47: Thank you for participating.**
  - We have four upcoming CARD webinars:
    - **11/14 Energy efficient operation of indoor swimming pools**: CEE will be presenting again on their results from their project which developed quality installation and quality maintenance guides for energy efficient operation and recommissioning of pools in Minnesota.
    - **11/29 Performance-based design and procurement in new construction**: Seventh Wave will be giving a webinar on their investigation and strategies to enhance new construction programs through performance based design and procurement.
    - **12/7 Ongoing commissioning in out-patient medical clinic**s: Michael's Energy will be discussing their project that tested two ongoing commissioning approaches to improve the efficiency of out-patient medical clinics in Minnesota.
    - **12/14 Evaluation of moisture and heat transfer furnace retrofit**: The Center for Energy and Environment will be back again to present a webinar on their field study to determine the increase in efficiency resulting in from the installation of an innovative moisture and heat transfer retrofit device on residential furnaces.

- Announcements on upcoming webinars and other news related to the Minnesota Utility Conservation Improvement can be found in our CIP newsletter. To sign up for or receive the CIP e-news on a range of other energy topics, there’s a link on this slide for the e-mail list sign-up on the department’s website. In the meantime, please feel free to contact me if you want more information on how to sign up for more of these webinars or if you have questions or feedback on the CARD program. You can also let me know if you have any suggestions on how to make these webinars more useful to you. Thanks again and have a great day!