Henry Fowler: Good afternoon, everybody. You are attending the Better Buildings Summer Webinar Series *What's Hot with Heat Pumps*. We'll be starting in just a few seconds. There are I'm sure a few people joining as we speak right now. And so I'll go ahead and get started. It's one minute after the hour.

So again, this is a Better Buildings Summer Series Webinar *What's Hot with Heat Pumps*. Welcome to the webinar. In the Better Buildings Summer Webinar Series we are profiling the best practices of Better Buildings Challenge and Alliance partners and other organizations working to improve energy efficiency in buildings. Next slide.

My name is Henry Fowler. I'm a project officer for the State Energy Program of the US DOE. I currently manage the New England States and New York. Part of our job as project officers is to not only monitor the state's performance using federal taxpayer funds but also to connect them with resources and research and technologies, and heat pumps are a really cool technology I think. They are initially of interest to the New England States due to the predominance of oil heating.

As you know, oil heat is expensive and the price goes up and down a lot, and that's really hard on a typical homeowner when the price of your heating goes up and down so much. And Maine's electric grid, for an example, is quite clean. It's I think 50 percent renewable energy. And as an example, Maine in the last five years or so has installed over 50,000 heat pumps on residential homes, which I'm proud to say started with a little bit of funding from the State Energy Program.

It's been a great pleasure to put together this panel today on heat pumps. The panel I will introduce in a few seconds. Next slide please. First I wanted to give a little background on why a webinar on heat pumps I think is important. The first is really that heat pumps are a technology that I think is one of the larger pieces of buckshot that will help us solve our climate problem.

Just in terms of cooling, heat pumps are significantly more efficient than regular air conditioners, and as such we hope to increase, number one, your technical knowledge and policy knowledge regarding them. Second, we'd like to increase your engagement with this technology and with organizations that are working on this technology and help make connections with those organizations, especially the E3 Initiative of the DOE Building Technologies Office. Their email is below.

If you have a particular area of research that you believe should be pursued, please get in touch with the Building Technologies Office through that email so that you can help them address future research areas that need to be addressed. And the third is that we want all sectors of the building industry, whether it's new design or new construction or for a retrofit of a building, we want the industry to begin to ask the right questions regarding heat pumps. They work well in some areas, but other areas they're not quite up to snuff yet.

There's a lot of success stories, certainly more success stories than places where they're not working. I had a lot of help on this webinar today, chiefly from the DOE Building Technologies Office. Adam Hasz, for instance. And I will introduce their program in just a few seconds. If you could go to the next slide please, Allie. So the US DOE E3 Initiative, if you could go to the next slide, aims to accelerate high performance heat pump solutions for both residential and commercial buildings.

The E3 Initiative launched in May of this year with the following activities. The first is to partner with the Advanced Water Heating Initiative to transform the water heating market to significantly increase the sales of high efficiency grid-connected heat pump water heaters. The second is implementing the residential HVAC Smart Diagnostics Tools Campaign to support contractors in commissioning new HVAC systems more efficiently to ensure that they're finding malfunctions in existing systems through the use of those tools. And thirdly, they're implementing the Cold Climate Heat Pump Challenge with heat pump manufacturers to develop new technology specifications for high performance heat pumps followed by a field validation and pilot program with utilities to address insulation challenges and grow demand.

And to repeat – next slide please – the E3 Initiative wants to engage stakeholders such as utilities, manufacturers, governments, the building trades and efficiency organizations to accelerate heat pump adoption throughout the country. And to participate or learn more, please email them at that email address as well. So next slide, Allie. Thank you. So we are excited to announce that today we'll be using an interactive platform called Slido for our Q&A and polling.

Please open a new window on your mobile device or a new window on your internet browser and go to www.slido.com, and when you get there today's event code is #DOE, all caps. And if you'd like to ask our panelists any questions, please submit them any time throughout the presentation in the Slido app. We'll be answering those questions near the end of the session. You can select the thumbs up icon for questions that you like that other people have asked, which will result in the most popular questions moving to the top of the queue so that we can see them and address them.

So slide nine, if you could – or the next slide, Allie, thank you – so we're going to start things off with a poll today we can learn a little bit more about you, our audience. Please join us over at Slido to respond to the polls. So the first question in the Slido poll is what sector are you from? And hopefully everybody can see the numbers bouncing around a little bit. If you look at the upper right-hand corner you can see that about 90 people have answered questions so far, the questions so far.

It takes a few seconds for everybody to find it and get in. So we have state and local government coming in first. It's hard to – we can't see all of the choices on this screen, but you can see at the very bottom we have a few folks that are – you can see them on your Slido screen but you can't seem them on this screen. So it looks like the biggest predominant group is government followed by industrial and manufacturing, then contractor, service provider, other – somehow we'll have to find out what the other sector is – and then nonprofits, multifamily housing, higher education, federal government.

Let's see what commercial real estate is coming in at. Allie, if you can scroll down a little bit. Commercial real estate is at 4 percent and then we have K-12 schools, single-family residential, healthcare, retail, food service and grocery, and financial services. Thank you. That's good to know. Let us go – I'm glad to see a large presence from the industrial manufacturing group. That's great to hear.

So the second question in our Slido polls is what is your function within your organization? And you get to mark all that apply. *[Laughs]* So energy manager, energy services jumped out right in front with just a few people answering. This one might change a little bit as we move forward. Allie, if you could scroll down, let's just take a look at some of the choices down below.

Code development, marketing, code compliance, product research, building operations and maintenance, engineering, building engineering and design. Let's go back up to the top. Certainly our biggest group so far is energy managers or energy services, and by that we meant energy services companies and maybe everybody understands that. But second on the list is sustainability manager. Let's give it a few seconds.

Then we have consultants coming in third, consulting folks, policy development folks, strategic planning folks, HVAC design, building engineering and design. Wonderful. Thank you. That's great. I really appreciate everybody's participation in this. And I can't remember if we have a third question or not, Allie. Ah, yes. Okay. *[Laughs]*

Thank you. So third question is what is your most important goal in attending today's webinar, ranking one through four, with one being the most important goal. Did you want to learn more about policies regarding heat pumps that you might apply, learn more about the heat pump technology and how it might work in your facilities, or find success stories, information sources and contacts? I'm sure most everybody is probably kind of looking at all three of these.

So it looks like with 114 or so folks responding that it is to learn about the technology and how it might work in your facilities, with a second and third coming up close on its heels. What we might do is ask you if you have other reasons for attending the webinar today, maybe you could put it in Slido as a question or comment. But technology is winning out. Thank you, everybody, for answering the poll questions. It looks like we're leveling out.

Let us move onto today's presenter. We have a great lineup of presenters today who I really appreciate taking the time to work with us over the last few weeks to come up with great things to say. With that, let's get started. So the first presenter today is Walter Hunt, who is a senior research engineer in the Energy and Environment Directorate at the Pacific Northwest National Laboratory, PNNL.

Walt serves as the capability manager of PNNL's Environmental Chambers and is a lead researcher at PNNL's Laboratory Homes, which he explained to me part of it is two homes that are built to be exactly the same and they can test equipment on each home and have a control home, which sounds pretty darn interesting. Walt's research supports the Department of Energy's Residential Buildings and Appliance Standards Areas. He is a licensed professional engineer and an active member of the American

Society of Heating, Refrigerating and Air Conditioning Engineers, ASHRAE. Take it away, Walt. Thank you.

Walter Hunt: Alright. Thanks, Henry. Hello, everyone. This portion of today's webinar will serve as a technical introduction and highlight the broader landscape of available heat pump technologies. This content will set the stage for our next two speakers who will be diving into specific heat pump technologies and specific applications. Over the next few minutes we'll be discussing the basic operation of heat pumps, the efficiency advantage of heat pumps compared to other forms of heating, heat pump types and common heat pump configurations, and then finally discuss some industry themes around heat pumps in buildings.

Next slide please. So here we have a basic schematic for an electrically-driven heat pump, and there are four basic components of a heat pump – the compressor, two heat exchangers, one of the right and left side of the screen, and then an expansion device in the lower portion of the screen. In the heat pump, refrigerant flows through these four components, and that enables the system to move heat between the two heat exchangers from one location to another. In one heat exchanger, shown here on the left side of the screen, heat is absorbed into the refrigerant from an air, water, or ground source, and that heat and energy is then moved to the other heat exchanger and rejected into an air, water, or ground.

As an example, an air-to-air heat pump in heating mode would move heat between the outdoor and indoor air. So heat would be absorbed from the outdoor air and then released into the indoor air. Air-to-air heat pumps are commonly used for space conditioning and are designed to operate in either space cooling mode, where heat's rejected outdoors, or space heating mode, where heat is rejected indoors. Another example would be an air-to-water heat pump where heat is absorbed from surrounding air and then rejected into a water supply that could be used for domestic hot water or for hydronic space heating.

And part of the secret sauce in the efficiency of heat pumps is the ability of refrigerants to change phase from a vapor to a vapor liquid to phase into a liquid. That phase change process utilizes a lot of energy. The phase changeability of refrigerants and the overall design of a heat pump system allows it to move one to four times the amount of energy than it consumes. So a heat pump's components consume electricity through the compressor, through fans or pumps or other ancillary components, but the heat that it's able to move is one to four times greater than the electricity that it consumes.

So in contrast to other heating technologies it may generate heat through the combustion of a fuel, such as a gas furnace, and those technologies generate less heat than the fuel they consume. But when you hear the word heat pump you probably don't think about the basic components of a heat pump, the basic schematic of a heat pump. You probably think about a particular heat pump configuration. So on the next slide we'll look at some common configurations for heat pumps in the residential and commercial applications.

So this slide's broken down into four sections. The two upper sections are providing common examples for air-to-air heat pumps and the two lower sections are providing common examples for air-to-water heat pumps. The first point that I want to illustrate with this slide is just the range of available heat pump technologies across residential and commercial applications, across space conditioning applications and water heating applications, hydronic heating applications. You may be more familiar with a particular HVAC configuration or application, but know that there is a wide variety of heat pumps that are available that can be implemented in residential buildings for space conditioning and for domestic hot water heating.

I'll touch just on a few of these configurations that are most applicable to our webinar today. First is the ductless mini split system. This system has become a populate candidate to consider in residential buildings when you're looking to implement a high efficiency heat pump to supplement and offset an inefficient existing space conditioning system. So one of our other presenters will be diving deeper into that technology.

Another configuration to highlight is the packaged rooftop unit. So this is a common system that's in small commercial buildings such as office buildings, retail, restaurants, and big box stores, for instance. Most all of the existing rooftop units are air conditioners with a gas furnace for space, cooling and heating, respectively. But there are packaged rooftop units that have heat pumps that can heat and cool a building through the heat pump components.

Another system that we'll highlight is heat pump water heaters. These are available in both the residential and commercial sector for their specific applications. Heat pump water heaters use the heat pump system to heat hot water for domestic hot water needs.

And that provides an efficient alternative in heating hot water compared to existing methods. One of our presenters will be diving deeper into a new heat pump water heater technology for commercial applications today.

Next slide please. And then finally, we're highlighting here a few industry themes around heat pumps and buildings that are driving the research, driving industry, and the implementation of heat pumps into buildings. These are in no particular order, but the first one there is exploring heat pumps for specific building types and climates. So in any given HVAC configuration, there's a range of available products as well. Some products have higher efficiency.

Some products have better heating performance that may be more suitable for cold climates. So navigating the available products and what type of heat pump configuration and characteristics for that heat pump that best fit a building type and climate is an area of interest. Secondly is the integration of heat pumps into existing buildings. I mentioned the packaged rooftop unit. So that's kind of a like-for-like replacement, going from an air conditioner and gas furnace to a packaged rooftop unit, and it's very similar in swapping those two out.

But another application in residential buildings and commercial buildings that may be more challenging from a mechanical standpoint, from a control standpoint, to integrate a heat pump into an existing building. Third is the incorporation of low GWP refrigerants. So the refrigerants that are commonly used today in air conditioning and heat pump systems are R-410A and R-134A. Both of these refrigerants have higher global warming potential, so looking at new refrigerants that have low global warming potential, that reduce that environmental impact, is definitely of interest there.

And then fourth is automated diagnostic systems that can verify that a heat pump or other HVAC system is installed efficiently and correctly, and then capturing any faults that may occur in that system over time, alerting the building owner of those so that corrective actions can be made and the system can maintain its efficient operation. And then lastly, heat pumps that are grid connected and systems that can be used as a flexible resource for our energy system, scaling up, scaling back based on the needs of the electric grid and our energy system.

So this material serves as a broader view of heat pumps for today's webinar. Now I'll hand it back over to Henry to continue our presentations.

Henry Fowler: Great. Thank you so much, Walt, for that introduction. I just wanted to say that we should probably not forget that the automobile industry is also moving into heat pumps as well in the EV sector and that there are several manufacturers that are using heat pumps in their EVs, including Hyundai, Kia, Tesla, Nissan, Audi and VW, Jaguar, BMW, Toyota Prius Prime also has a heat pump as well as the new VW ID.4, but only in Canada so far because I guess it's colder up there.

But now we will hear from Muhammad Hassan, who is lead of Trane's Strategic Accounts Variable Refrigerant Flow, or VRF, team. He started with Trane in the New England office where he sharpened his VRF skills and expertise by supporting engineers with VRF design and application support. Today he works directly with Trane's national sales team as well as customers to provide VRF and ductless design assistance, application support, and post-sale fulfillment. Mohammad is passionate about the future of sustainable buildings, decarbonization, and renewable energy policy. As a Virginia Tech graduate, he received his bachelor's in aerospace engineering and is currently working on his MBA. Go ahead, Muhammad. Thank you.

Muhammad Hassan: Thanks, Henry. So I'm going to talk, as Walt mentioned, about a domestic hot water product that we're bringing to the US market. It is primarily focused on the commercial and the multifamily market, but let's go ahead to the next slide. So I want to step back a little bit and talk about why we're bringing this product to the market. What's the need for heat pumps?

If you imagine decarbonization as a three-legged stool, the three legs of that stool are better refrigerant, electrification, and more efficient solutions on site. And this product touches on all three of them. The decarbonization drive is primarily driven by both local and federal policies. And these are the most prominent examples, but not the only ones. New York City Local Law 97 mandates decarbonization for buildings above certain sizes.

Carbon-Free Boston. The city of Boston is targeting to be carbon neutral by 2050. And then Canada, even though it's not US it's our northern neighbor, all of the Canadian provinces have signed onto a federal greenhouse gas pricing act, which they're going to tax carbon emissions as a broad adoption measure. The reason to adopt heat pumps is that they move emissions from the point of use, which is your building, your house, something like that, to the point of generation.

They are moving emissions upstream on the grid and then allowing for the grid operator to wholescale remove carbon from the source of power. Federal policies have also been revised. The US has rejoined the Paris Climate Agreement. We have committed to 50 percent greenhouse gas emission levels by 2030. And then the EPA was recently given the authority to regulate high GWP refrigerants. All of these efforts will be incomplete as long as we have emissions onsite, which is why it's incredibly important that we as consumers and as an industry encourage the adoption of heat pumps.

Next slide. So this is our new product. It's called the Heat2O. Even though the word is a heat pump, this is only for domestic hot water heating. It utilizes CO2 as a refrigerant. The primer driver of that choice is the fact that CO2 has a GWP of one. GWP is the Global Warming Potential of a refrigerant. As a reference, the Global Warming Potential for R-410A is 2,088, which means it traps 2,088 times more heat than CO2.

It is a very high efficiency product with COPs up to 4.11, which means that it can give the water 4.11 times more energy than it takes in from the grid. It can supply very high hot water temps. The important thing to remember here is that this is a constant leaving water temperature device and not a constant volume device. So what I mean is you're not going to get 176 Fahrenheit of five GPM water.

The unit is going to target 176 Fahrenheit, but the flow rate is going to be variable depending on the ambient temperature. So in the middle of the summer you might get very constant flow, but in the height of winter the unit is going to be producing the set leaving water temperature, but especially in a northern climate like Boston, Maine, Chicago, the flow rate's going to be low. Essentially the only thing that that mandates is that we use storage tanks in the buildings. We have an example project after this that talks about that.

It's operatable at very low temperatures, minus 13 Fahrenheit. That covers the design conditions of most of the lower 48 states. So it's rated to – we have capacity tables at minus 13. Below minus 13, the unit will continue to operate until minus 35. We just will not guarantee an output. It maintains 100 percent heating capacity at 36 Fahrenheit.

It is connectable to VMS systems via the standard BACnet protocol. There are three capacity settings on the same chasse, and those are upper limits to the capacity and they correspond to efficiency settings. What's important to realize is that even at the least efficient setting, which is the 60kW, your COP is still going to be greater than one. So you are going to get more energy out of the heat pump than you're putting in through the grid.

You can have up to 16 units combined piped in parallel. Touching back on the need to adopt grid-connected solutions, the unit has a CTA 2045 compliant connection. To make sure that we support this product properly, it will initially be only offered in the four listed markets. We are training up internal staff and the customers that we partner up with to make sure that these get installed properly. Next slide please.

So this is what a system schematic would look like. This particular schematic shows two units piped in parallel with separate heat exchangers that are then combined to tanks. You have two 500-gallon tanks and a smaller 120-gallon tank. It is important to size the tanks to your load. So for example, in a dorm building you might want to size to 7:00 AM on a Monday morning when everybody's taking a shower, making sure you have enough hot water to cover that, and then the heat pumps can generate the capacity to continuously heat the water.

The reason for having separate heat exchangers is because the unit is not rated to have glycol. So in colder climates, to bring the water from the heat pump to the heat exchanger, all of the pipes that are outside the building will need to be heat traced, which is essentially a small electric resistance element that will prevent flash freezing. The unit is also capable of controlling external pumps. Next slide.

So this is a pilot project in the Pacific Northwest, specifically Seattle. This is a public housing building. The existing system is six electric resistance water heaters. They have 100 occupants in 13 stories. This is a retrofit. We are taking six hot water heaters and replacing them with just one of our unit. Next slide.

So the existing mechanical equipment is six hot water heaters, 696 gallons of storage, with a total capacity of 102 KW. The new system will be one unit, two 500-gallon storage tanks, and then two smaller expansion tanks. So we went from 102 KW of capacity to 40 KW of capacity, but larger storage. The storage was sized for the whole building, so this is larger than their existing storage, but they were able to find space in the building to accommodate that.

The COP of the system is above two for the Seattle design connection. Next slide. So moving back a little bit, the unit that I just spoke about is a domestic hot water heater for space conditioning. What we're introducing now, and we've had this for a long time, is our hyper-heat technology. This is for space, comfort cooling, comfort heating. The long-term misconception about heat pumps is that typically they do not have a lot of capacity below 40 degrees.

Thanks to the adoption of flash injection compressors and some other improvements, we are now offering a hyper-heat product that allows for 70 percent capacity at minus 22, and the unit's operable to minus 31. What's specifically shown in this graph is our 6-tonnage. However, we also have this in residential and larger or commercial capacities as well. Next slide.

If you want more resources on this, on what I spoke about, you can contact the Trane account manager through www.trane.com/VRF, or we have a landing page that is specifically dedicated to the domestic hot water. It's heat20.com. But otherwise, back to you, Henry.

Henry Fowler: Fantastic. Thank you, Muhammad. Really appreciate you taking the time. We will now hear from Karen Fenaughty, who has been a research analyst with the FSEC Energy Research Center for 12 years. During this time, she's been principle investigator or co-PI on several US DOE grants and has conducted over 100 residential energy audits.

In addition to conducting retrofit energy use analysis and peak load impacts, she participates in project design, develops outreach and recruitment of research partners, communicates with project participants, provides technical assistance to sponsors, and publishes research findings. Fire away, Karen. Thank you.

Karen Fenaughty: Thank you very much. Well, I am sure many of you are familiar with the growth that's been discussed in the ductless mini-split heat pumps, especially in warmer climates with the driver toward electrification and decarbonization. But what I'm going to talk about today is the application of the min-split as a supplement in a warm climate for cooling. And this could be a potential solution, for instance, if the central system still has some useful life and it wouldn't be cost effective to change out outright.

Next slide please. The FSEC Energy Research Center is a research institute of the University of Central Florida. Our buildings research division has been involved in applied research for over 30 years. We've done several studies investigating the performance of variable capacity space conditioning systems. We do development and field testing and we look at overcoming market barriers for many new high-performance building technologies.

The work I'm going to talk about today has been funded by the US Department of Energy Building America Program. Next slide please. We began our work investigating this supplemental mini-split heat pump design in 2014, and our idea was to look at installing a supplemental mini-split to really be a first line of defense to take some of the load away from the less efficient central ducted system. And so we're not just moving load from the inefficient system to a more efficient system, but we're also reducing the losses associated with moving the cold air through a hot attic, which is the typical design in this region.

And the temperatures in Florida anyway can exceed 130 degrees in the summertime depending on the type of roof and how well the attic is ventilated. We looked at energy savings and peak demand reduction, and we also got a chance to see how well the redundancy, having a redundant system set up with your central system fails. We had a concern early on that there would be competition between the two thermostats operating the independent systems, and that could potentially lead to comfort issues. Our design was to install the mini-split in the main area of the house so it would have direct contact with the biggest area of the home, and also located as functionally and aesthetically pleasing as possible to the main return of the central system to encourage better air distribution.

Next slide please. So our first study involved 10 homes where we installed a supplemental mini-split heat pump. This was a one-ton, and it typically was accompanying a three or four-ton central system. We instructed the homeowners to set the setpoint 2 to 4 degrees below that of their central system for cooling and to reverse that for heating. We subsequently found out is termed droop, this delta temperature between the systems.

We found a median cooling energy savings of 33 percent. This ranged from 2 to 46 percent, and the 2 percent was really an outlier, and at that house, in fact, we saw a great improvement in the humidity control and we saw cooler temperatures maintained. And the heating savings came in at 59 percent, and that ranged from 8 percent to 82 percent, and that mattered substantially on what the central system was since about half of the central systems were heat pump technology and the others were doing electric resistance heating. We measured this in subsequent years.

So we found that there was persistence in the savings that we found that first year. And we also looked at peak demand reduction, finding 0.5 kilowatt reduction in summer and over 2 kilowatt reduction for the winter peaks. We were very interested obviously in making sure that comfort was maintained to our question about the competing thermostats. And so we did an analysis where we compared the temperature of the main living space where the thermostat was for the central system to the bedrooms of the house.

And what we found is we really didn't see any difference with and without the mini-split. What this plot demonstrates is it's a years' worth of hour lead data when the mini-split was running, and we see within a delta of 3 degrees from the living there was a very tight cluster, rarely exceeding that 3 degree delta. So the home occupants were able to maintain comfort with this supplemental design. Next slide please.

However, we did find that it fell short of all possible savings that maybe could've been captured. One of the problems we found was that the central system was sometimes short cycling the mini-split. And so you see on this plot we've got the green is the mini-split power and the red is the central system power divided by 10 for scale. And you can see the mini-split's on and then the central system comes on and it shuts off the mini-split, and this was a pattern we sometimes saw.

So we wanted to reduce the central system run time by trying to maximize the mini-split heat pump use. We also found that sometimes when the homeowners were not comfortable at night maybe when they originally got the system, but they achieved comfort by turning the mini-split off at night. So our idea was that we should be able to find a compromise where we can still maintain comfort but go after a little bit more savings by using some of the mini-split energy during the evening. Next slide please.

So our findings echoed that of others in that the savings of the simple supplemental heat pump design varied widely, and it was based on both the occupant behavior and also the existing central system. For example, in that heating example I mentioned if it was an existing heat pump or not. There was a largescale evaluation conducted by Cadmus that found that the simple supplemental mini-split design was not providing all the potential operating hours it could've, and that with an integrated control you could increase those savings. And so based on these savings we saw in our work, we believed that for about a price point of about $300.00 we could justify spending that on an integrated control if we could see an additional 10 percent savings or beyond, which we thought was achievable.

So we got additional funding from the Department of Energy Building America Program to test an integrated controller that would be easy to use, maximize energy savings and comfort, and allow zoning in the house. Next slide please. So we were looking to find a controller that would look at outdoor temperature, time of day, sensing temperatures in different locations of the house and also the delta between the thermostat setpoint and the living area.

And while we did see there are some controllers with some options for heating, we did not find any advanced controllers available for the cooling market. So we designed our own. We designed our own with the goal of operating the central system only if the mini-split could not satisfy the living area temperature and also that it would consider the different times of day so that occupants aren't getting overly hot at night. And we used a smart thermostat for the central system as well as the mini-split and their open APIs.

Then we developed an algorithm that would automatically adjust the mini-split setpoint. So we refer to this as a dynamic droop based on the input on our design input points. We also had remote sensors in the house so that we could alter what zone was the basis for the control. Next slide please.

The results from this second study, which we had tested in four homes – before I present them, I just want to be clear here. The savings presented here are savings above and beyond that simple design I described at first, so beyond that 33 percent that we found on those first 10 homes. So you've already got the mini-split saving you and now we have the integrated control.

And in the two sites where we were able to conduct a long-term study we found 12 percent and 13 percent cooling energy savings. We normalized this to typical meteorological year three weather data. Then at two of the sites, less robust analysis. We did not have a long-term before the controller period started. We measured 16 percent cooling energy savings and negative 15 in the other site.

I will note that at site 13 with the negative savings the homeowner was overly involved in the study and very much trying to outperform when we were doing the controller period. And in fact, the temperatures maintained in the home was different depending on who was in charge. We worked with each of these homeowners throughout the study to try to make sure that they were maintaining comfort and also to try to see if we could modify the inputs into our algorithm to improve the energy savings. Next slide please.

We looked at the equipment run time for each of the systems, and this helps explain why we found the savings that we do. If you're looking at a simple single-speed system, we can think of it in terms of just run time, but if you're looking at a system with modulating capacity such as the mini-split heat pump, it's a more complicated formula and we call that equivalent full load hours. And so looking at these equivalent full load hours we looked at the baseline period before the mini-split, and then with the simple mini-split design, and then lastly with the integrated control.

And what we found was with the integrated control we were able to greatly reduce the amount of run time we got from the central system and increase the run time with the supplemental mini-split. This plot on the right is an example, site seven, where you see that after the installation of our advanced control in 2018, that we were able to reduce the central system run time substantially and greatly increase the mini-split run time. Next slide please.

Lessons we learned. We did design our algorithm so that it would work in reverse and it would work for heating as well. However, we had very little cold days in our area and we really did not have enough to do any kind of robust analysis on that. As I mentioned, we had worked with our occupants to try to tweak the inputs to maximize the results. Market-ready solution would have the flexibility ideally so that these inputs could be altered at setup, considering characteristics of the house and occupancy desires.

We were able to overcool the central area with the mini-split and still see savings from that, but only to a point. At some point we were overworking the mini-split and that would, in fact, erode savings. The mini-split heat pump performance curve is less efficient at its maximum output. Related to that, we did see consistently larger savings at the more mild temperatures. So when it was really hot out and we were asking the mini-split to crank, we saw less savings from that.

And that's again tied to that performance curve not working as efficiently at the really, really hot temperatures. So we're often asked about doing the central fan cycling to try to encourage the distribution of the air throughout the house, and we did test this and honestly did see some small benefit in the temperature in the room when we ran it. However, considering the tax on the fan energy and also that you're taking cooled air and running it through the hot attic, and then finally the potential of bringing moist air from the coils back into the house when the central system isn't running, we felt that it was questionable benefit and we left that out of our ultimate design.

Lastly, we built a simulation model to test what would be the best option at the end of the life of the central system. Was that a full design of mini-splits or a more efficient central system? And what we found was there was less benefit with replacing it with a highly efficient central system, and this was because the very efficient mini-split was taking on so much of the load itself. Next slide please.

We have a final report, including the work on this integrated controller and some additional content to the Building America Solutions Center that is to be finalized soon. We also have content into a larger paper on the subject of mini-split that was published, ACEEE Summer Study this last year. We're still not aware of commercially-available solution in the cooling climate for droop. And there are some incentives offered in the Northeast to perform droop or to perform a changeover, a system changeover based on the outdoor temperature, but with limited control functionality.

We are involved currently with a couple of studies up in the Northeast, one with NYSERDA and one with Efficiency Maine, and the controls being used in those studies include Resideo and Flair Pluck with Ecobee. And we are still unable to find a manufacturer. We'd love to find a manufacturer or partners who are interested in exploring the dynamic droop in the cooling application. Thank you.

Henry Fowler: Thank you Karen very much. I have some questions for you if nobody else does. *[Laughs]* Thank you. So at this time, we will begin our discussion and we'll begin taking your general questions. Again, please go to www.slido.com and enter the event code #DOE to submit your questions. And we do have some questions here and some comments as well.

We've got folks that are interested in learning about solutions for cold climates, and that's good to know. And some of our presenters may have some answers to that question. One of the other questions that came to the top was a comment, and perhaps this will be answered, but how are heat pumps more efficient than air conditioners as they are essentially air conditioners? So that's a good question.

I've had that question myself. And maybe Walt can take that one. Why is it that heat pumps are more efficient than air conditioners?

Walter Hunt: Well fundamentally a heat pump functions as both an air conditioner, which is space cooling, and a source for space heating. So when it operates as a heat pump it can just operate for both sources. So it operates in reverse cycle to provide space heating and just as a normal air conditioner to provide space cooling. So you can have identical efficiency air conditioners and heat pumps provided and produced by the same manufacturer, which is very common in the market today.

A heat pump is electrifying your space heating, so if you're comparing that to an inefficient method of space heating that may be coupled with an existing air conditioner, that's where the efficiency could be made from the space heating perspective.

Henry Fowler: Thank you, Walter. I appreciate it. So we had another question here. The second one down is how can governments better educate the contractor community on the benefits of electrified heating? And I think – why don't we go to – well, Karen, Walt, or Muhammad. Any one of you take that one.

Muhammad Hassan: I'll take that one.

Henry Fowler: Okay. *[Laughs]*

Muhammad Hassan: There's a couple things that governments could do, right? And the first and foremost is to support trade schools. We have a shortage of skilled tradespeople in the country, and treating trade schools as important as community college or a regular four-year degree and for high schools to present that as a viable career path, because they are viable career paths. That's important. On a broader level, I'd like to see better, more consistent standards for heat pumps.

I would like to see more rebates for heat pumps to help contractors actually convince the owners to go that path. And then all amounts of education helps.

Henry Fowler: Thank you, Muhammad. I appreciate that answer. Part of that answer might be – you might get a little bit of that answer if you go to the Better Buildings Summit website and replay the June 8th webinar on beneficial electrification. I think that's a great webinar to get started on the benefits of electrification.

So we have one more question, which we really only have time for one more, which is that there's a concern with heat pumps that there are many more moving parts – circuit boards, valves, et cetera – as compared to a traditional water heater or gas furnace. How are these reliabilities or potential reliabilities being addressed? I think Walt might be the best for that.

Walter Hunt: Yeah. So heat pump water heaters have been in the market for a number of years for both residential and commercial applications. Many of those products have a similar warranty to the baseline electric and gas heating systems. So it's certainly a different method as far as servicing those technologies over their life, but I think manufacturers have invested in products and made them reliable and backed those with similar warranties.

Henry Fowler: Thank you, Walt. I appreciate that.

Karen Fenaughty: I'll just add to that. I'm aware that there is some investigation into fault detection to try to improve that, Building America funding for such.

Henry Fowler: Very good. Yes. Thank you, Karen. So one last question. I've heard that CO2 as an alternative refrigerant works well for heating but not for cooling. Is that the case? If so, are there other low GHP refrigerants that work for cooling? And I'll put that one up for grabs as well.

Muhammad Hassan: I can take that.

Henry Fowler: Thanks, Muhammad.

Muhammad Hassan: So, yes, that is true, that CO2 is a better refrigerant for heating and not so well for cooling, which is why the unit is a heater only. Yes, there are other low GDP refrigerants that are being considered. There's R-32. Honeywell just came out with Opteon as a refrigerant. There's no industry consensus on what the next generation of cooling refrigerant is going to look like that. That is yet to be worked out.

Henry Fowler: Well, thank you. I really appreciate you answering the questions, and I'm sorry we didn't get to all the questions. I apologize. I think I went over on my time. So thank you, everyone. So if you go to the next slide, Allie, please here are the additional resources, some of which our presenters discussed today. Once the slide deck is available online, which should be later today or tomorrow, feel free to click on these to explore more.

You can also see in the handouts section of the go-to webinar control panel, you'll see a handout with additional resources as well, and you can open that to an Adobe document as well. And then you can download your personal copy of the additional resources. So the next slide, as mentioned, this webinar is part of the 2021 summer webinar series. We have a great lineup of presentations through August. So visit the Better Buildings Solutions Center to register for any of them.

The next webinar, slide 40, next slide, we hope you'll join us Thursday, July 1st for the next webinar titled *How to Identify Combined Heat and Power Projects That Fit Your Goals*. DOE experts will share how to identify combined heat and power project opportunities and provide an overview of the development process as well as highlighting the overall benefits of CHP for your facility. Next slide please.

You can also watch recordings from the Better Buildings Virtual Summit, which took place in May, and the Better Buildings Webinar Series or technical presentations from our national labs by visiting the on demand webinar's library where all previously recorded presentations are archived. So, next slide. With that, I'd like to thank our panelists and the team that put this program together at the Building Technologies Office very much for taking the time to help us out on this.

Feel free, everybody, to contact our presenters directly with additional questions or if we couldn't get to your question during the Q&A period. I encourage you to follow the Better Buildings Initiative on Twitter for all the latest news. You will receive an email notice when the archive of this session is available on the Better Buildings Solution Center. Thanks again, everyone Have a great rest of your week.

[End of Audio]

Additional Speaker Q&A:

Better Buildings does not endorse or recommend any product or technology provider. The answers in this document are solely the opinions of the speakers based on their professional knowledge and experience.

Additional Questions

Audience Member:

I've heard that CO2 as an alternative refrigerant works well for heating but not for cooling. Is that the case? If so, are there other low GWP refrigerants that work for cooling?

Response:

CO2 heat pumps have been primarily developed for water heating applications. There are a variety of low GWP refrigerants being considered by industry for space cooling/heating applications. One example is R-32, which is being deployed in residential and small commercial HVAC in other parts of the world.

Audience Member:

Heat pumps are a point of interest due to decarbonization efforts. Currently, we find that heat pumps are limited to 20-ton capacity. Is the E3 initiative (or DOE) addressing this to advance heat pump technology?

Response:

Assuming we are focusing on the rooftop unit configuration for commercial buildings, it is correct that heat pumps are primarily available in equipment sizes less than 20 tons. In this segment, most HVAC manufacturers currently produce rooftop heat pumps in equipment sizes around 10 tons. An approximately 10-ton rooftop unit application is a common application for commercial buildings.

Audience Member:

Most economical whole house heat pump solutions in cold climates. Air to water infloor hydronic (basement/garage), heat pump water heater, heat pump dryer, mini split (main floor AC/heat) Can they work together/combine efforts to save money?

Response

There are multiple pathways technologies could work together. One is the aggregated control of individual technologies (to manage overall power demand for instance). Another is utilizing a single heat pump to serve multiple end-uses, such as space heating and water heating. There are some examples for both of these strategies, but it's primarily been in the research and development stages.

Audience Member:

Is there potential to use low GWP in existing systems?

Response:

This is referred to as a "drop-in" refrigerant replacement. This pathway has been considered in applications with large refrigerant quantities, such as supermarket refrigeration. For residential and small commercial HVAC, low GWP refrigerants are more likely to be introduced in new equipment.

Audience Member:

How do you compare cost to operate when comparing the relative cost of natural gas vs. electricity? Energy cost may be less with natural gas then a heat pump.

Response:

When considering costs for space heating (or water heating), you must consider the fuel cost and the efficiency of the two candidate technologies. Heat pumps are commonly more cost effective at milder temperatures, while natural gas furnaces are generally more cost effective at cold temperatures. A dual-fuel system (which contains both a heat pump and natural gas furnace) could be a good candidate to move toward efficient heating while managing the cost.

Audience Member:

Do heat pumps, in cooling mode, bring in fresh air from the outside, i.e. do they improve indoor air?

Response:

Air source heat pumps do not by themselves exchange air. Bringing in fresh air from the outside would need to be accomplished by other means than the heat pump itself. However, many commercial roof top unit (RTU) air conditioning packages have a fresh air intake system, which can use a heat pump to heat or cool the air.

Audience Member:

How can Heat pumps be used in heating-dominated existing buildings? Upgrading the envelope and the radiation in the building is invasive and costly, so with limited budgets we go back to a gas boiler.

Response:

Because heat pumps are building, climate, fuel, equipment, and electricity cost specific, answering this frequently asked question would require further information. The answer could be a hybrid system, that calls for heat pump heat above certain temperatures, and boiler heat below that temperature. Another benefit of a system like this could be the ability to provide AC if needed during summer.

Audience Member:

What are some of the best ways to "hide" the mini split indoors so it doesn't look so obtrusive?

Response:

While FSEC used the 'wall warts' in our study, there are ceiling cassettes and small ducted cassettes on the market which are less obtrusive.

Questions for Muhammad Hassan, Trane Technologies:

Audience Member:
Do you have model training programs?
Response:
Yes we will have training programs specifically for the Heat2O unit. We also have separate training programs for designers and installers.

Audience Member:
Which kW (40, 50, 60 kW) is the H2O heater primarily for commercial use?
Response:
It depends on the building. These are all capacity settings on the same unit that correspond to efficiency levels so it really depends on how fast the user wants the tanks to be filled.

Audience Member:
Can you explain CTA 2045 further?
Response:
CTA 2045 is a standard connection being adopted for use on heat pump water heaters so they can communicate with utilities for demand response.

Audience Member:
Can these Trane HPWH's be used in single family homes?
Response:
These units are too large for use in single family homes. However, Multi-Family is a great application for this.

Audience Member:
Can the TRANE hot water unit also be used to heat floors hydronically?
Response:
Unfortunately, this unit is not suitable for hydronic floor heating since it is a Variable flow device i.e. the amount of hot water being produced is dependent on the ambient temperature, hence also the use of storage tanks.

Questions for Karen Fenaughty, FSEC Energy Research Center:

Audience Member:
What is the remaining benefit of the central air distribution system if/when the central heating/cooling components wear out?
Response:
If one were to replace the central system with a new central system, then the air distribution system would often be reused – depending on what shape it is in and assuming there is no change to the size of the equipment as a change in air volume could indicate a different duct size. If a choice is made to go all ductless then the central air distribution system can be abandoned, but that is more

expensive than replacing the central system when it dies. Since a high efficiency mini-split is in use, the replacement central system need not be the most efficient.

Audience Member:
What is the usual 'central' system to supplement down in Florida?
Response:
A typical residential system in an existing home in central Florida is a single-speed, attic-ducted, split system. Electric resistance heat is common in central Florida and south Florida. In Central Florida and north Florida, heat pumps are common. There are also gas furnaces in many parts of Florida, especially central and north. However, this study focused on electric space heating systems due to electric utility involvement. Nominal cooling efficiency ratings in the first study mentioned in my session were as low as 10 SEER.

Audience Member:
How does one decide where the MSHP should be located in the house?
Response:
We were targeting the main living area of the home so that the MSHP would have a direct impact on the largest living area. We also tried to locate it near the central system return if possible for better air distribution of the MSHP conditioned air when the central system was running.

Audience Member:
Why a mini split heat pump instead of a central ducted heat pump if there already is a ducted system?
Response:
Our investigation was to add the high efficiency MSHP to minimize runtime of a low efficiency central system that was not yet at end of life. The concept was to gain energy efficiency when the existing system performance is declining, but still working. Another benefit is redundancy at time of central system failure. Our simulation evaluation suggested that when the central system does eventually fail, the best cost/benefit solution is to install the least costly (read that lower SEER) central system. Installation of a more expensive (higher SEER) central system provides less benefit with the high efficiency, ductless, MSHP taking on much load.

Audience Member:
Did you analyze the building envelope of the 10 houses evaluated to adjust your results?
Response:
All homes were audited and their systems and building envelopes were characterized -- and certainly all these things influence the energy savings achieved. https://publications.energyresearch.ucf.edu/wp-content/uploads/2018/06/FSEC-CR-2019-16-R01.pdf The home sample was representative of typical existing homes in our utility partner’s territory. I contend that in our climate, the efficiency of the existing central system, including duct

leakage, are more important to achieve savings than envelope characteristics. Regardless, I’m not sure how one would adjust results based on these different characteristics, given there are so many variables to consider.

Audience Member:

Peak load reduction achieved by adding another heat pump? Please explain how the central system doesn't operate at the coldest and hottest temperatures. This is exactly when the central systems are necessary and when peak load is measured.

Response:

For the peak evaluations we analyzed the average monitored total cooling/heating power during the summer and winter peak hour reported by the utility provider, for the years before and after mini-split installation. These times are of most interest to utilities as they seek to reduce the need for expensive supply alternatives. We specifically tailored our evaluation to these hours for the utility, who was a funding partner in the study. For cooling, the mini-split thermostat is set lower than the central system, resulting in less central system operation even during the peak hour. Over shorter durations, say 15 minutes or less, it is possible that both systems would be operating at the same time. But in general, thermostat interactions (without an advanced controller) made it so the mini-split and the central system did not operate at the same time for very long. They would alternate with some overlapping runtime in between cycles. One more note on the winter peak (when we measured much greater demand reduction), keep in mind that some of the homes had electric resistance being offset by a heat pump.