[Begin transcription at 0:00:37]

Nora Hart: Hello. Thanks for joining the webinar today. We're going to give folks another moment to log on and we'll be starting soon.

[No conversation, 0:00:41 to 0:01:14]

Okay. Let's go ahead and get started. Welcome to our first Better Climate Challenge Technical Assistance webinar. These webinars are a chance to dive deeper into decarbonization topics and technologies. Today's webinar is called Using Heat Pumps to Electrify Existing Buildings. And we'll be presenting case studies from the field. Please note today's webinar will be recorded and archived on the Better Buildings Solution Center. We will follow up when today's recording and slides are available.

And next I'd like to let attendees know that you are in listen-only mode, meaning your microphones are muted. If you experience any audio or visual issues throughout the webinar, send a message to the Q and A box located on the bottom of your Zoom panel.

So we are very excited about this webinar because heat pumps have been a very popular topic for the Better Climate Challenge partners, and I'm sure this is also a topic of interest to other Better Building partners on the line. Next slide.

So now I'm going to introduce today's speakers. My name is Nora Hart. I'll be your moderator today. I work for Lawrence Berkeley National Lab, and I provide support to the Better Climate Challenge. And fun fact, this is my first time hosting a webinar, so we'll see how this goes, and hopefully I get invited back. *[Laughs]*

And I am joined today by an amazing lineup of presenters. All of the presenters that you see hereon this slide are technical account managers for the Better Climate Challenge. So first we have Alper. He is a technical account manager, or TAM as we call them for short. He's an LBNL affiliate and he works for PAE. For the Better Climate Challenge, he works with our multi-family partners.

Next we have Dan Luddy. He's also an LBNL affiliate who works for PAE. And he is working with our state and local government partners on the Better Climate Challenge.

And finally we have Stet, who you may have seen before. He's done a lot of these webinars, and he is also an affiliate. He worked for Smith Group. And he works with our Better Climate Challenge partners. Next slide.

So this is just a short meeting agenda to let you know we will be doing a Slido poll to kick things off. I'll have a couple of slides on heat pump fundamentals and the bulk of the time will be spent on the four heat pump case studies. Next slide.

Okay. So today we will be using an interactive platform for Q and A for polling. So please go to www.slido.com on your mobile device or by opening a new window in your Internet browser. And today's event code is DOE. If you would like to ask our presenters questions, please submit them any time throughout the presentation, but we will be saving all of them for the end. And you can select a thumbs-up icon for questions that you like, so those will result in being the most popular questions moving to the top of the queue, and we'll answer those first.

Okay. So please join us over at Slido to respond to the following questions. If you're having any issues, message our tech support team by using the Zoom Q and A function. So this first question is what barriers did you encounter or are you currently facing on your heat pump projects? And we'd like you to select all that apply.

So there are a couple things we have listed out here that may be potential barriers: cold climate operation, cost of electricity, electrical service constraints, difficulty communicating benefits to leadership, heat pump footprints, or maybe you're just unclear on heat pump options and you want to learn more.

So it looks like a lot of these are getting similar responses. We're kind of jumping around a little bit between what's the top selected response. But it looks like a lot of these are barriers for everyone on this column. So I'll give it just a couple more seconds to see if something jumps to the top. Okay. It's looking like upfront costs is the biggest barrier.

And just so you know, we're kind of using these polls to better understand our audience, but also to help us build out resources in the future. So with that, let's move to the next poll. Okay.

So this one's more simplified. But we just want to know what heat pump technology are you most interested in learning more about: air-source heat pumps, water-source heat pumps, variable refrigerant flow systems, or ground-source heat pumps? And again, we'll use these responses to help us develop potential case studies in the future or things that we know you want us to focus on in future webinars.

So it looks like for this poll, air-source heat pump is winning out, which is great because some of the case studies that you'll see later focus on this type of heat pump. Okay. Great. With that, I think we will jump back to the slides. Thank you all for participating in Slido. And as a reminder, you can enter your questions in Slido throughout the presentation.

So now I'm just going to give a brief overview on heat pump fundamentals to kick us off. So heat pumps are key to the electrification of HVAC. And here, I'm giving a simplified visual on the difference between a boiler versus a heat pump for heating. And what I want to highlight here is the fact that boilers create heat, whereas heat pumps are just moving heat.

Heat pumps are transferring heat from a source – in this case, the outside air – into the building to warm the space. So for this visual we're showing the heat coming from the outside air, but it could also be the water or the ground in different heat pump types. And heat pumps can also be used for cooling. So in that case the process would be reversed. You can go to the next slide.

So why heat pumps? Why are we so focused on this for electrification? Mainly because heat pumps are highly efficient. So natural gas combustion converts one type of energy into another type, which results in some losses and has a max efficiency of 96 percent. So heat pumps, they're not converting from one form of energy into another. They're instead, as I said before, moving heat from one place to another using the refrigeration cycle. This makes them a lot more efficient.

And they can be up to 500 percent efficient compared to boilers. So this means for every one unit of electricity used, it can create four or five units of heat. Now while that may be slightly less efficient in cold temperatures, heat pumps can still operate below freezing without backup heat. And finally, when combined with onsite solar PV, they can result in significant greenhouse gas reductions; even in a region with a dirty grid. Next slide.

Okay. So this slide is introducing the four case studies that you'll see from our presenters. So we chose these case studies for a couple of reasons. They're all retrofits. So we want to show that it is possible to retrofit an existing building with heat pumps. They cover a wide range of commercial buildings and existing systems.

They cover a wide range of heat pump types. And finally, our speakers were involved with these projects, so they have lots of great details and can answer your questions.

So the first case study you'll be hearing about is an art museum transformed into an all-electric co-working lab. Then we'll be talking about a six-story mixed-use commercial building renovation. The third case study will be a boiler to heat pump in a historic landmark. And the fourth case study will be a net positive energy all-electric retrofit.

And I want to send a reminder to you guys about the Slido questions. At the very end, we will show this case study slide again to help you remember which case study you may have a question about. So with that, we can go to the next slide, and I'll pass it over to Alper to talk about the first case study.

Alper Erten: Thank you, Nora. Hi, everyone. So, yeah, today's first case study is UC Berkeley's Bakar BioEnginuity Hub, which is located in Berkeley, California. And we picked this one to show that even an existing building with challenging architecture and a challenging new program can be successfully electrified with heat pumps. Next slide, please.

So the project is a major renovation and consists of conversion of a brutalist style modern art museum into a life science startup incubator building. And the building has labs and office spaces to support these new life science startup companies. The new program includes around 20,000 square feet of molecular biology labs, 20,000 square feet of office space, and also support spaces that are support spaces totaling up to 90,000 square foot of total building area. And the construction for a new building began around 2019, and it had its grand opening earlier this year in 2022. Next slide.

So the existing building is, as I mentioned, is a modern-style concrete building. The majority of the envelope consisted of exposed concrete walls with little glazing on the vertical envelope. And it has single-pane skylights in the atrium area, which you can see on the image on the left, like in white areas, the area around the center is the skies around the atrium. And then around the perimeter you also have single-pane glass skylights, as well. And all the concrete walls in this building were load-bearing, meaning that the project team couldn't punch big holes for new ducts in the building. So that kind of drove the design decision for a new system in a certain way, which I'll get more into that. Next slide, please.

So the project had various sustainability goals, but the two main targets that drove the design direction was UC Berkeley's net zero carbon emissions goal by 2020 for scopes one and two. And then they also have net zero carbon including scope three by the year 2050. And again around the design timeline of this project, Berkeley – City of Berkeley – was also coming up with its natural gas ban, which was the first in the nation, where they were banning natural gas supply to new buildings. Even though there were some exceptions for existing buildings and some lab programs at the time, it still started the trend of going all electric that drove the design of the new building systems to be electric.

And in addition to carbon emissions reduction targets, UC Berkeley, again, had its campus policy to have a certain EUI target, which is short for energy use intensity of the building. So we had to be around 80 KBTU per square foot per year or less, which is quite low for a building that includes lab program. Next slide.

So starting the design, the design team did a bunch of improvements on the building envelope. And these were all low-cost improvements to help with supporting the building systems with all-electric design. And this involved adding roof installation on the roof, adding additional R-23 additional insulation there, removing the existing single-pane skylights and putting double-pane insulated low-E glazing.

And there was a small amount of windows on the vertical facade, which is hard to see from the images. But for these instead of replacing the windows, the project team brought in adding low-E film as a lower cost improvement option. And then lastly, which we can see in the image, as well, on the ground level there was some new additional space. And then for this space, we added insulated low-E curtain wall with Solarban 90 glazing. Next slide, please.

But the existing building systems were very highly integrated with the building facade and keeping in mind that was an art museum. And here you can see in the images some equipment being on the roof, and mechanical valves. And you're seeing on the right an image of a cooling tower and some other equipment. But the majority of the equipment were in the basement. Next slide, please.

So the equipment in the basement consisted of three large air handling units to serve the building. It was an old air system. And the building also used steam heat exchangers that was connected to the UC campus steam loop for space heating and the hot water heating. But having a steam loop in your campus doesn't really go hand-in-hand with the whole net-zero energy carbon goals. So our design team has chosen not to use that strategy anymore and install on-site heating system. For the cooling side, the building had a water-cooled chiller with the cooling tower, as we saw, on the roof. Next slide, please.

So as I was mentioning before the building posed challenges in the sense that we couldn't really change the facade openings or any other openings in between the concrete walls. So that kind of put limits on the air capacity that you can get into the building. And the existing building system included a total air intake capacity of 60,000 CFM from outside. So we were limited with this capacity, so we couldn't put additional louvers and additional risers to bring the air. And to serve all the loads in the lab program and other spaces the design team has chosen to go with hydronic cooling system approach.

So in this approach, we had a dedicated outdoor air system that was located in the roof, but coming from the outside air intake where you can see on the image, keeping the same 60,000 CFM capacity. And then the remaining of cooling and heating is provided with four pipe terminal units at each space. And these terminal units get heating hot water and chilled water from the central plant, the building central plant. And they have like individual heating coils and cooling coils at each zone. And the heating hot water and cooling hot water to these systems are provided by air source heat pumps that are located in the equipment yard outside the building. And this is a modular heat recovery heat pump system that consists of around five modules. And they can provide both simultaneous heating and cooling. Next slide, please.

So adding this system resulted in we looked at the benchmarks that the average building uses, for that building in this area you have a median of 220 KBTU per square foot. With the proposed design, we were able to achieve an EUI target of 78 KBTU per square foot, and that's like a 35 percent reduction from the baseline system. Next slide.

And looking at more detail about where these savings are coming from – and in these graphics you can see the breakdown for each end use – most of the savings came from heating energy through the use of heat pumps, as well as we had some fan energy savings – again using four pipe terminal units – and we also put LED lighting in the building so we have some savings on the lighting, as well, lighting energy. And next slide.

And in terms of the carbon comparing if we had a new building, if we had built this building as a new building with typical chiller and boiler, like a water-cooled chiller and a gas boiler central plant and comparing that to reusing an existing building and going all electric for that; the overall carbon emissions reductions including a rough placeholder for an embodied carbon for the building over the 50-year building life cycle we can achieve we were able to achieve 47 percent of reducing and around 27, 30 percent of that carbon emissions reduction is coming from the energy, the building emissions did 20 percent coming from the reuse of the existing building. And next slide.

And then last is just to sum up, again, this example is here to show us you can achieve all-electric design in older buildings, even with challenging architecture and challenging new programs, including lab use. And in terms of the cost, since that was a question, the cost of the system, roughly speaking, was about 20 percent more than a typical new plant using air-source heat pumps. But as you have larger building areas what you are seeing is that costs out the kind of goes down and the cost of air-sourced heat pumps central plant systems kind of get closer and closer to typical new central plant equipment.

And thank you, and I'll pass it onto Dan for the next case study.

Dan Luddy: Okay. Thanks, Alper. You're right on time. So we're doing great here. Okay. I'm going to speak about one of my projects, which is called 419 Occidental, which is also its address. And it's located in Seattle, Washington. This is a seven-story core and shell building that's office spaces. It started life as a warehouse next to the Port of Seattle. It's a landmark historic building in the Historic Pioneer Square District downtown. And it's got one level – or first level and basement – that is retail and restaurants and sort of street-level options there. And then levels two and above is all being retrofitted for future offices. And they're particularly targeting start-up tech companies to come into this space. And so wanting to retrofit the building to make it more appealing there. Next slide, please.

The owner is a long-term owner, held it for awhile, wanted to do this major retrofit to appeal to newer tenants and to continue to hold this property for a long time. They were really sustainably-minded, as well, with the sort of decisions they wanted to make. SO the building itself, as I mentioned, it's land marked. So that presents certain challenges around what we could and couldn't touch on the structure of the building.

It was a full renovation of all of the interior. So we had that opportunity to completely replace mechanical systems, electrical systems as part of that refurbishment. There's an additional stairwell added to the outside for egress. That was a little bit of sort of new construction, which we could also build to a higher standard.

And as part of the sustainability targeting, the owner elected to pursue all-electric heating for their systems. They were really interested in that in order to have a really efficient building overall to partially commute their LEED targets – this project is LEED platinum certified – but also just from a viable standpoint, they wanted to have a high-performing building that has low operational costs for the long term. Next slide, please.

This is a graphic that shows some of the key items or sort of high-performance items that we included in the building and study. As I mentioned, because it's land marked, we were really limited in what we could do with the envelope, which is kind of counter to what we, the usual recommendation is when it comes to retrofitting buildings to make them electrified is usually the first step is get your heating and cooling loads down as low as you can so that your new equipment coming in can be a lower capacity, lower cost for that.

That means trying to refurbish the envelope as much as you can. However, we couldn't because of we needed to maintain that exterior aesthetic look to the building. The windows had to be sort of like to like, looking exactly the same as they were. So we couldn't really add insulation on the outside. On the interior side there was a desire to maintain sort of exposed brick look, as well, which kind of meant that a lot of these envelope assemblies are still uninsulated.

We worked with the architects to make improvements where we could, sort of at the roof level when they were placing a new roof, some of the windows in the store front first level were able to be retrofit, and they were able to find a good high-performance solutions that also meet the aesthetic criteria. So doing what we can around the edges to try to bring down the loads on the mechanical side. And we'll talk about it in a little more detail on another slide.

But the key things here was that we have dedicated outdoor air systems that deliver ventilation to all the floors. And the benefit there is that it has heat recovery on it. It provides a more efficient solution to delivering that ventilation and separates it from the heating and cooling, which means that those two systems – ventilation and heating/cooling – can be optimized and run more efficiently as separate systems. There is also PV on the roof. And we'll talk a little bit about the roof and the footprints around there, as well. And so, yeah, that's kind of where this project was ending up. So let's go to the next slide, please.

This is just an image showing some of the improvements made to the first level, where we could make improvements to the building itself. There was a new mezzanine that was put in that uses crop limited timber. So another approach to the project was to just have a relatively low embodied carbon emissions profile to the materials that were going in. And this is a good shot, too, of the newer storefront windows that were put in that have a higher performance than what was previously there. Next slide.

When it came to the mechanical systems and discussing the idea of going with a heat pumping system, there were some reservations around the performance of different heat pump solutions. The owner wanted to make sure that we were selecting something that has a good track record, that is reliable, and also this is a market-rate building, and so there was an emphasis on making sure that this came in at budget. However, we wanted the discussion to focus on other areas of the decision making besides just the first column.

That's usually the thing that is front and center. But we like to use this sort of weighted factor chart – we call it sort of a *Consumer Reports* style chart – where we work with the owner and the design team to identify the points, the metrics that make the most impact to them; whether it's first cost, whether it's aesthetics, whether it's the sort of physical constraints in the building and how much room we have for duct work and for piping, things like that, maintenance, some of these other considerations.

And go through as a team and weight what's really important from five being the most important to one being the least important. So that as we're making the decision as a team, we kind of understand where everyone is, and we can together kind of weigh these things, with cost being one of the components, but not the overriding component when we're looking at these systems. So this is successful in helping us as a team work out what would be the best solution. Next slide, please.

One of the key constraints that turned out from this exercise is that the roof – and with easily being overridden with all the equipment potentially with some of the different solutions. If we went down the route of how the VRF system or some of these others are distributed systems with a lot of outdoor condensed units, and that would add a lot of footprint mechanically to the roof space. And there's already a lot of competing interests between having amenities, say for tenants, having solar PV on the roof, with some of the other existing mechanical requirements, as well.

And that also impacted costs, too. Because if the owner can have a larger amenities space that they can include, and they can charge more in rent from the tenants from this additional perk. And so there was a competing interest in terms of sort of provide a solution that's compact enough, efficient enough, and still beats the bottom line. Next slide, please.

This is a quick overview summary of the proposed systems. The diagram on the right is very complicated, but I will just walk through it very quickly. There is a central air water heat pump that provides both hot water and chilled water and that distributes throughout the building. That is located in the basement on this diagram, but since then we ended up being able to fit it on the roof, where it can live happily. It is a, does have heat recovery, so it can simultaneously heat and cool and reuse the heat that's being rejected out of the chilled water loop. We put that into the heating for the building.

As I mentioned, there are dedicated outdoor air systems that provide the tempered ventilation air to all the floors that operates separately. And then when future tenants come in, they can add their own terminal units to the hot water and chilled water loops. They can put in fan coils. They can put in more efficient options like a chilled beams, actual chill beams, to condition their space.

And I'll also point out that the owner, as sort of a belt-and-suspenders backup to this whole system, elected to put in gas fire condensing boilers to back up the air and water heat pump. Those boilers are meant to run only when the system may be down for maintenance. If it's down for maintenance for an extended period of time, those blowers can turn on and provide a backup.

In Seattle it's a cold climate, but it's a relatively mild cold climate. We don't see days below zero degrees Fahrenheit that often. So we are comfortable designing a system around a heat pump that this particular heat pump can operate down to those temperatures that we see in a winter condition in Seattle and do so comfortably. In a colder climate it could also be possible to use those boilers as a backup situation where they could automatically turn on and provide supplemental heating on the coldest of days if the heat pump wasn't able to meet the capacity.

So there are hybrid solutions available out there, too, where the heat pump is the first stage, covers most of the heating. And then on the particularly cold days, you could have a feature of gas backup. Next slide, please.

This is just a quick shot of the roof showing how successfully we were able to manage everything. What you'll see here is some of the amenity space, some of the green space that's included as part of that amenity for the tenants. Over on the left you'll see the solar panels that are above some of the bulkhead space, which provides some offset for the energy use in the building. And what's conspicuously absent, or maybe you can see a part of it over to the right, is the mechanical equipment, which was successfully hidden away from view from any of the tenants, and we were able to keep that footprint relatively small. Next slide, please.

In terms of the performance of the building, it's performing – these are modeled results. This is what we're expecting it to look like once the tenants have all moved in and filled up. The EUI – as Alper mentioned, energy intensity – for a typical existing office building in our climate, we would anticipate that EUI would be about 89 or 90. That's using the AIA 2030 baseline. We're about 50 percent less in terms of energy usage for that, where EUI is coming in at about 44, which is a bit better than the LEED baseline and the code target that we have. Seattle Energy Code is relatively aggressive compared to a lot of energy codes throughout the country. So we had to meet that and exceed it a bit, as well, which we were successful with. Yeah. Next slide.

Then finally I'll just mention in terms of carbon emissions reductions, this is looking at the 20-year operational carbon profile of the building compared to an existing building that has gas boiler heating. The red in this chart is emissions associated with burning natural gas onsite. And then the blue is the emissions associated with the electricity usage.

You can see that the chart's dominated by the red, the gas usage onsite. Because we're eliminating it from the space heating and the hot water heating, what's left is basically the gas use associated with the cooking in restaurants on the basement level. And then the blue, we are lucky in Seattle in that our existing electrical infrastructure is normally based on hydro power. So we have a relatively clean electric grid, clean amount of electricity to begin with. So it does mean that our emissions profile, what we burn onsite has an outside impact.

And as my last point, I will just say that a lot of you around the country may have a different profile due to the way that your emissions between electricity and natural gas look. But this is likely the direction that we're headed in as the grid gets cleaner, as more utilities bring more renewables online, the decisions we make with what we burn onsite starts to have a greater outside impact. So with that, I will turn it over to Stet to present the next case study.

Stet Sanborn: Great. Thanks, Dan. So I'm going to be talking about the electrification retrofit with heat pumps for a registered historic landmark; and similar to Alper's example, a challenging building.

So this particular building, if you want to go to the next slide, is a religious facility in the city of San Francisco, and it includes two major components. So it is a sanctuary. The core of the building is an 1800's sanctuary. So to Dan's earlier point about let's focus on the envelope, this couldn't be a worse envelope. *[Laughs]* There were no air barriers in the 1850's, let alone insulation. So there is this historic portion of the building, which actually made it through the 1906 earthquake in San Francisco and the big fire. So it's definitely a prominent building.

And then in the 1960's, also very similar to Alper's example, they had a brutalist modern expansion, which pretty much quadrupled the size of the facility, where they added offices, administrative services, as well as a year-round school. And then this site also provides for seasonal homeless shelter, as well as commercial kitchen facilities.

I will say that this particular client, who I've been lucky enough to work with for almost 15 years, has been going through continuous greenhouse gas emissions strategies and implementations over the course of the last 20 years; the biggest of which was the installation of a solar PV system on their roof – and I want to say it was around 2012 or so – to offset as much of their electrical load as they could fit.

One of the key challenges with this building, just similar to one Dan mentioned, is that as a registered historic landmark we couldn't have any equipment be visible from the street and we weren't allowed to essentially touch the aesthetic bounds, if you will, of the building. The existing building, which is not too dissimilar from a lot of projects that you're probably seeing, currently runs on a natural gas boiler. This one is naturally aspirated and it has a supply water temperature through the building of 180 degrees, which is for the bay area, for California, is unnecessarily high. But that's what the building was designed around.

And then one key element that will go into whether we have an impact on electrical service is that this particular building does not have air conditioning. And so the electrical service at the building is not sized to pick up any cooling load, even though there definitely is a cooling load now as San Francisco begins to warm up. Next slide.

So as we approach a project, especially retrofits with heat pumps, there's kind of like this dream list that we like to go through that really involves understanding sort of in a deep way the energy use and hourly demands for the building. And then going through a whole series of recommendations around efficiency measures before we get into the equipment selection.

As Dan mentioned, our dream is to get the loads under control before we move into an area where we are trying to pick equipment. Because of the number of the questions in the comment on Slido are bringing up, if we just try to do a hot swap of a boiler straight to a heat pump, you're likely going to run into some cost barriers. And so one of the key things that we can do for both life cycle improvement as well as greenhouse gas emissions reductions is try to right size that equipment, but first focusing on efficiency measures.

So if you go to the next slide, for this particular building, we had already gone through – oh, back one. Sorry. We had already gone through a series of audits with this project. They've already gone some air sealing work, some selective installation improvements. They had done a controls upgrade. They'd already kind of gone through sort of the low-hanging fruit, and now they're really ready to do sort of the main equipment replacement.

And so for our project, we really focused on a data collection portion, a cold weather stress test – which I'll talk about in a second – and then looking at load shifting; in some cases, heat recovery, but especially a load-shifting scenario to try to minimize the heat pump size. And then we can focus on the actual piece of equipment. Next slide.

So as I mentioned – and actually one of the questions in the Slido brought this up, as well – the supply water temperature that we send from a heat pump, if it's an air to water heat pump, is really, really critical in helping us select equipment that's not only efficient, but works in our climate zone. So as I mentioned, this building has typically been served by 180 degree supply water temperature, which was excessively high for the bay area.

So the first step that we actually went through on this project is we took an entire heating season and every two weeks we reduced the supply water temperature. We call this sort of a wintertime thermal stress test. You can call it a sort of wintertime supply water reset test. The idea is essentially to run a limbo on your building's heating hot water temperature. How low can you go and still meet your heating demand? And the key is to let everybody know this is happening, and make sure that people have an opportunity to raise a flag if their spaces that they're working in or certain other areas in the building aren't able to meet comfort levels.

We also trended the thermostats and tracked them to check at what point temperatures weren't able to be met. And then we made sure that that winter season was sufficiently deep enough that it represented sort of what we would call a typical winter. So the further to the right that you can go, the lower that water temperature you can go, you're going to have more options for which heat pumps, which manufacturers you can work with.

More and more heat pumps are serving higher temperatures. But the bulk of them are better to serve at low water temperatures. And so in this case we are able to go from 180 degrees down to 150 with no problem. And we're going to probably be spending this year doing another test to see if we can go even further down. Next slide.

So buckle up. I'm going to walk you through a whole bunch of graphs. They're not meant to be painful, but I want to walk you through sort of the process that we used to right size equipment and try to reduce our electrical loads. So these are actual measured electrical loads from that building for an entire year.

And you're going to see this chart format sort of show up a couple times. It's from the morning that's at the bottom, evening is at the top, and from left to right, it's January to December. That big blue swatch in the middle is actually where this particular project, where they export energy to the grid. So those are all hours where they're producing more power onsite than they consume from their PV system. Next slide.

We also took a year-long worth of data and actually measured the energy use coming off of their boiler. So this is a true profile for this building. It's not modeled data. This was actually coming off of measured data. You can see that 5:30 AM, they kick on their boilers through the whole winter season. They do the morning warm-up. And you can see in the summertime the boiler is completely shut off for this particular site. Next slide.

One of the questions that comes up a lot is how do heat pumps perform under any cold weather or cooler weather? How does that impact performance? So one of the key things that we're doing when we do one of these analyses is actually looking at a temperature profile for a site. We can use either typical meteorological files, or more recently we're also looking at sort of extreme years, where we've seen extreme lows or extreme highs.

In the next slide you'll see how that starts to play out with performance of equipment. So most folks know that air-source heat pumps, their performance curve or how efficient they are is dependent on two things: the supply water temperature that we're sending out – which is what I talked about earlier – and also the air source or the temperature of the air that's coming into the unit from the ambient air.

So most manufacturers, you can extract this curve from them. It's often painful, but it's doable. You can get this performance curve. And you can map that over outside air temperatures, and then use that relative to our actual weather file. And the graph on the right is what we produced to sort of look at what is the effective heat pump COP given our current weather conditions? And so you can see it varies widely. And this is for the bay area, which is considered a relatively mild climate.

But the COP that we would expect for this building delivering between 150, 160 degree water from an R513 refrigerant ranges all the way from 2.4 up to almost 3.5. So we see a pretty big variety. In a colder climate, you can expect those to actually get down into the 1.5, 1.6 range for COP. Next slide.

So all of that combined – our weather file, our true load profile – we can actually fold that into our performance curve of where we think a heat pump is actually going to provide energy for our site. So this is our prediction of the heat pump sizing or sort of the demand on the electrical side for the project. Next slide.

So we'll fold that, then, in our actual greenhouse gas marginal short-term emissions rates for our grid. And similar to Seattle, California has a really favorable grid for electrification. So for us there's less drive to focus on COP to make sure that our greenhouse gas emissions are reduced. But as you look in, say, the middle of the country in sort of the Chicago region or Indiana, states like that, the grid is about twice as dirty on an annual basis. And so their COP is going to matter even more, and focusing on those low-supply water temperatures that your COP or the efficiency of the heat pumps can go up as high as possible.

On the next slide we'll show our hourly emissions profile. So again, this is the boiler burning onsite. You can convert the usage of the boiler to an emissions profile. And the key is we're trying to drive down the overall emissions for our project.

So on the next slide you can see what happens when we take that COP of the heat pump, we apply that short-term marginal emissions rates for each hour, and for our site where we know that we're actually overproducing power from our own PV system, and we can actually now look t the delta, the difference between the emissions before the boiler and what they were coming from the heat pump.

I want to point out, though, that those January hours, sort of January, February 6:00 AM, it's cold outside. It's our wintertime. It's also early in the day. And we're asking the heat pumps to do the most amount of work right at that time. So as a design engineer, that's where I begin to focus if I'm truly trying to reduce emissions and right-size a heat pump, those short-term bursts of energy. I don't necessarily want to pick a heat pump or size a heat pump just for that load. Next slide.

This is just the conversion comparing each of those emissions profiles next to each other. And you can see that the overall greenhouse gas emissions for this particular project we saved about

31 percent just by doing the conversion from the boiler to a heat pump. Now, those savings are going to vary across the country. We just finished an analysis similar to this in Chicago where we're seeing about annually a five percent savings on today's grid, but projecting out in the future more significant savings going forward. Next slide.

Some of the key challenges around electrification retrofits, especially around historic buildings, is just finding space for the equipment. So here we used modular heat pumps similar to the other projects so that we could do a sort of a custom fit. These ended up located on the roof, away from all the sight lines.

But I did want to highlight because this building did not have air conditioning, the electrical service was way undersized to meet this new heat pump load requirement. So we did end up having to upgrade the service. And we couldn't do it lightly because the actual service – existing service for this building – was original to the 1960's expansion, and so nobody was willing to touch it. *[Laughs]* So it is going to be getting a full upgrade. Next slide.

One of the key things I think from an implementation standpoint that I just want to highlight that's really important is that those key hours in the morning, for us we were able to actually downsize the heat pump just by adding a thermal energy storage tank. So we added, I think, around 2,000 gallons of storage for this particular project to get through those first three hours in combination with changing the morning warm-up start point.

So we could actually save significant amount of costs. Because as you can see, of course, across the rest of the year, the peak load is not that high. So sizing on a peak currents that's very short in duration is not what we want to do for a cost-effective design. So I encourage everybody to think about thermal energy storage or targeting appropriate warm-up start times to right size your heat pump applications. Next.

So the second project – and I'll go a little bit quicker – and kudos to everybody who lasted through all those graphs. *[Laughs]* But for the next project I want to talk about a net-zero energy retrofit, or actually net-positive energy retrofit to an existing building. And this is the DPR Construction Headquarters in Sacramento. Next.

Just really quickly, the before building and after. So not only was this a retrofit, but this was also an expansion. We added about a third of the building size was actually added as part of the retrofit.

So it was expanded as well as electrified and taken to net-positive energy. The measured EUI of this project over the last year has been an EUI of 14, which is really phenomenal for the central valley of California, which gets both exceptionally hot as well as quite cold. Next slide.

Just some floor plans so you can get a sense. There's a ground floor tenant space, and the addition is shown on the right of going up and out for the project. So square footage increased as well as decarbonizing the existing systems. Next slide.

One of the key things that was done for this project – both to be sort of climate smart, but also to improve indoor air quality and wellness – was this building is considered mixed mode. So we have both operable windows, operable skylights, as well as a VRS system with DOAS. So when the weather is beneficial, the building can close down and be air tight, and then the DOAS system can pry ventilation with VRF providing the heating and cooling. But for large portions of the shoulder seasons we don't have a significant humidity load in the central valley in California for some of the shoulder months, and so we're able to naturally ventilate the space. And that's one of the key things that led to the low, ultra low EUI. Next slide.

One thing I do want to point out is that all of the steps that lead to a heat pump – oh, you can go on. That's fine. That go into a heat pump retrofit, it's really about reducing loads. So in this case lighting load is reduced by doing extensive sky lighting with solar tubes, so a very low thermal impact but really big impact of reducing the electrical lighting demand during the daytime hours. So you can sort of see a before in the left and after on the right. Much better daylight condition in the right. And in person it actually looks even better than the construction photos. *[Laughs]* Next slide.

The most exciting thing, though, on this project – and again, it's all about trying to reduce the size of that peak load. We size systems based on peak. On the last project I talked about using thermal energy stores to reduce that peak or draw it out so we can right size a heat pump. In this particular project that peak load was actually a summertime load. In Sacramento actually just a few weeks ago we saw temperatures of 112 degrees. That's a pretty excessive temperature. And in the wintertime we also see temperatures below freezing.

This existing building actually had a whole underground concrete sort of bunker that we couldn't use in the retrofit to be inhabited. And so we actually turned it into a thermal labyrinth that we bring the outside air in. It travels through this concrete underground bunker, and we use it essentially as a tempering device.

And so we were able to see significant temperature peak reductions, both in the wintertime that thermal labyrinth actually warmed up the air by the time it gets to the heat pump or the VRF head units, and then the summertime we were able to reduce that summer peak, as well. And so that thermal labyrinth or preheating precooling strategy was a really effective way for us to downsize the size of the heat pump, reduce the impact on the electrical service, et cetera.

Similar strategies can be deployed through heat recovery ventilators. If you have a building that has a very high air change exchange rate, you should definitely be focusing on heat recovery first as a tempering device for all those loads. So again we can reduce the size and the peak sizing of equipment. Because that's going to drive your system costs across the project. Next slide.

Here you can just see sort of that new addition. So everything below the slab was existing building. We cut through the roof slab and actually added. The second story was done in cross-laminated timber, similar to both Dan and Alper's examples of trying to minimize the embodied carbon that's being thrown into the project, take advantage of what's already there. You can see the duct work from the DOAS system, et cetera.

On the next slide, though, I do want to highlight one of the other key things that allowed us to right size the heat pump and reduce its overall size. The first one is we added ceiling fans. And that increased air movement across the skin of the body, especially in wintertime, allows us to set the cooling set point up about three degrees.

So for this project, the cooling set point is actually 78 degrees instead of like a typical office building of 75, because that additional air movement provides that sense of comfort. That change in or adding ceiling fans plus the change in the set point allowed us to actually reduce the size of the heat pump, as well, to meet that peak summertime cooling load.

So I think that's my last slide, and I am handing it – oh wait. I have one more just showing that the building has trended for net-positive energy over the last year and a half or so that it's been fully operational. And then it did really well during COVID, but we kind of discount those years. *[Laughs]* But now I'll hand it back to Nora to jump into the Q and A.

Nora Hart: Great. Thank you, Stet. So you can see the slide here is showing a reminder of all the case studies that were just presented. And now I'm going to go over to Slido and pick out some questions to ask our presenters.

So the top question right now is what is heat pump efficiency/COP for heating in colder climates? How does the cost of heat pump compare to a gas equipment when delivering the same amount of heat in colder ambient conditions? So I know Alper spoke a little bit about this in the very first case study, saying that that system was 20 percent more expensive than a traditional system. So maybe I'll move over to Dan to see if you have anything to add about COP in colder climates or costs for your project.

Dan Luddy: Yeah. In general as the temperature goes down the COP of the heat pump also does down. However, modern heat pumps can go to lower temperatures than heat pumps we might have seen – I've talked to some people who installed them ten years ago and they didn't work in cold temperatures, but technology has definitely improved and made big steps. You can get ones that are rated down to like negative four degrees easily.

The newer technology that I'm interested in, too, is using CO2 as a refrigerant, which actually allows for much lower colder temperatures, too. That is only just starting to come on the market. So it's still in the early stages. But that is coming. And just in terms of cost, it is going to cost more than a gas boiler on a one-for-one basis. But if you look at your full-emissions, how you're accounting for emissions on a building level, it starts to make more economic sense when you look at the other's to do to also get your emissions down by the same level.

Nora Hart: Thanks, Dan. Stet, do you have anything to add?

Stet Sanborn: No. I think Dan nailed it. There is a lot of technology that is increasing the performance for cold climate heat pumps. Some of the things you can start to look for are inverter controls and the compressors, enhanced vapor injection on the refrigeration circuit. That allows the coil temperature that's outside to go far lower, and you get a better delta T relative to outside air temperature. And so that's going to drive up both capacity as well as your coefficient or performance.

So I'd say that's the area in the market where manufacturers are putting the most attention right now is in cold weather performance. And so each year we're seeing more and more products that can make higher temperature water and work at lower ambient air temperatures. I would highlight, though, that your existing building still has a lot of places that you can still heat from that can improve performance.

And one of my favorite if you're in the multi-family world is looking at wastewater heat pump or heat recovery heat pumps off of your wastewater stream, because that's a really high-quality source of heat. And so you can get a very small heat pump relative to an air-source heat pump because it's stealing heat out of 75-degree effluent, as opposed to pulling heat out of zero-degree air. And so you can buy a smaller heat pump, still make a ton of hot water for your building, and get exceptional greenhouse gas reductions. So it's about matching the right technology, I'd say, to the application and the climate zone that you're in.

Nora Hart: Thanks, Stet. I like that. Steal the heat from somewhere else. That's a good theory to live by. So the next question that I'll jump to is directed towards Alper. So did you have to deal with upgrades to electrical service infrastructure to incorporate the electric heat pumps?

Alper Erton: Yeah. So for this building the electrical structure had to be upgraded necessarily because they encourage electrical, but the program was changing into a lab program, as you can imagine. And overall, the electrical capacity actually tripled. But that's, again, because of the lab equipment. In terms of the conversion to electrification for the building plant, there was a water-cooled chiller there, so the air-source heat pumps, they are replacing that equivalent air-source pumps doesn't make a huge difference.

Again, this is for a cooling-dominated building in a temperate climate. So, yeah, if you are looking at a colder climate you may have to add like electric resistance backup for heating. So, yeah, that's definitely something to consider for other projects in other locations.

Nora Hart: Thanks, Alper. Dan, would you like to speak to that same question on the project you spoke about?

Dan Luddy: Sure. Yeah. With our project it was a historic building, so we did have to upgrade the electric capacity. It was already – because we were doing substantial renovation, anyway, it was already – part of slated to be on the installation, anyway. So that's just going to all electric meant we just had to look at additional capacity.

The one thing I'll mention, too, is it didn't happen with this project, but projects where you may have like underground parking or parking adjacent where you're also looking at adding potential EV charging, looking at increasing electrical capacity at the same time for all of these sorts of electrification initiatives, trying to focus it and do it once and add enough capacity for all that stuff is probably the best way to go, instead of realizing that you need more down the line later.

Nora Hart: Right. That makes a lot of sense. And on that note, Stet, you talked a lot about the electrical service upgrade in the historic landmark. Someone asked specifically if you know how that affected the cost of the project.

Stet Sanborn: Oh, that's interesting. So one of the – yeah. So it, obviously was, that cost was more than the heat pump cost, without a doubt, for this particular project because we also had to bring in a different phase of power to the building. *[Laughs]* But I would say that for that building, because the original electrical service was still the original 1960's service, they were actually running into a problem already of finding anybody who could touch it, maintain it, or do any service work to it.

So it was at end of life. To replace it in kind would have triggered a whole bunch of code violations for them because they actually didn't have a lot of front space clearance for their – they only had about 18 inches in front of the panel. So there were a whole bunch of other reasons why that service needed to get replaced, as well as to service a new elevator. There were a bunch of things. And so we actually, they wanted to just pair it and make sure that the new service that they were going to get was going to be right sized both for today and the future. So it was mostly aligned with a pretty big capital investment that they were going to need to do either way.

Nora Hart: Okay. Thanks, Stet. That makes sense. It kind of goes with what Dan said, trying to future proof the electrical service of the building. If you're going and doing all of that work, you want to do it at one time.

Stet Sanborn: Yeah.

Nora Hart: So something that I think was already touched on in a lot of the projects, but I'll just ask each of you to speak to it is are there concerns about peak load for any of these locations? So I'll start with Alper.

Alper Erten: Concerns about peak loads for any of these locations? You mean like, I'm guessing that the question is having an electric system. For the cooling side, we don't have any concerns. The air-source heat pumps operate very similar to air-cooled chillers. They can provide real low temperature chilled waters down to 44 degrees, no problem there. Heating, as Stet already talked about, you can't go above like 110 – in general, not advised to do so.

So, yeah. For our location, we didn't have any issues because the outdoor temperature doesn't go that cold in the bay area. Yeah. If you were in colder climates usually what we are doing in projects in other climates with electric-centered plants is either keeping the existing boilers as backup for back-up use or suggesting some sort of electric resistance type of back-up heating. Or geo is another option, geo loops, for wintertime. But as back up or thermal storage.

Nora Hart: Thanks, Alper.

Alper Erten: Mm-hmm.

Nora Hart: So, I actually misspoke. I will not be jumping to everyone because we have one minute left. So with that I'll close out the question portion of the webinar and we can jump to the next slide. And thanks to the speakers for answering questions.

So this slide here, we just have kind of a plug for the Better Climate Challenge. Like I said, everyone on this call is on that project. We have our technical account managers that were speaking and I also support the Better Climate Challenge. And so this is going on right now. The goal of the Better Climate Challenge is portfolio-wide reduction in greenhouse gas emissions of at least 50 percent within 10 years. So you can go to that link below if you're interested in joining or talk to your account manager. Next slide, please.

So here I just wanted to highlight the Better Buildings webinar series. There's a lot coming up and a lot of things going on around decarbonization. So take a look at the things that are coming up in the near future and sign up for more webinars. Next slide.

And here I just wanted to highlight the dates of the Better Buildings Summit for next year. That has been scheduled for April 11 through 13, 2023. We hope to see you there. Next slide.

And thank you. We really thank you guys for joining this webinar. We have lots of attendees, so many great questions we didn't get to. But we appreciate your support and interaction. I hope everybody has a great day.

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