Appendix J

Heat Pump Analysis and Considerations

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By Ian Burnes, Laura Martel, and Lauren Scott
6/30/2024

Introduction

1. What is the purpose of this testimony?

The goal of this testimony is for the Trust to share key elements of the analysis and considerations that influence the Triennial Plan VI program designs for heat pumps. The testimony also will describe how the Trust defines a heat pump and or heat pump system, especially as it pertains to meeting climate council goals.

2. Who is introducing this testimony?

The testimony is provided by Ian Burnes, Laura Martel, and Lauren Scott. At the Trust, Mr. Burnes is the Director of Strategic Initiatives, Ms. Martel is the Senior Research and Evaluation Manager, and Lauren Trapani is a Strategic Initiatives Manager.

3. Mr. Burnes, please state your name, title, and business addresses.

My name is Ian Burnes, and I am employed by the Trust as the Director of Strategic Initiatives. My business address is 168 Capital Street, Suite 1, Augusta, ME 04330.

4. Please summarize your educational and professional experience.

I have a Bachelor of Arts Degree in Economics from Wesleyan University. I have been working at the Trust since 2009. My responsibilities include the oversight of the strategic initiatives team that implements the Trust's customer tracking database, maintains the Technical Reference Manuals, oversees the program evaluations, and manages the Trust's resource in ISO-NE's Forward Capacity Market. Before coming to the Trust I worked at the Governor's Office of Energy Independence and Security.

5. Ms. Martel, please state your name, title, and business addresses.

My name is Laura Martel, and I am employed by the Trust as the Research and Evaluation Manager. My business address is 168 Capital Street, Suite 1, Augusta, ME 04330**.**

6. Please summarize your educational and professional experience.

I have a Bachelor of Science Degree in Ocean Engineering from Florida Atlantic University and a Master of Engineering in Acoustics from Pennsylvania State University. I have over 20 years of technical leadership, project management, and research and evaluation experience. I was hired by the Trust in 2014 to design and implement impact and process evaluations for energy efficiency programs. Prior to joining the Trust, I was with Lockheed Martin in Manassas, Virginia, where I served in various engineering, management, and technical leadership roles.

7. Ms. Scott, please state your name, title, and business addresses.

My name is Lauren Scott, and I am employed by the Trust as a Research and Data Analyst. My business address is 168 Capital Street, Suite 1, Augusta, ME 04330.

8. Please summarize your educational and professional experience.

I have a Bachelor of Science Degree in Environment and Natural Resources from the Ohio State University. Between my school studies and roles as a research assistant and teaching assistant, I have three years of experience in benefit-cost analysis, environmental valuation, sustainability education, and carbon emissions tracking. I was hired by the Trust in 2020 to support the Strategic Initiatives team.

Background

9. What measures are the subject of this testimony?

The measures addressed in this testimony consist of a variety of types and models of space heating equipment that transfers heat in and out of buildings using ambient thermal energy as a heat reservoir. the Trust refers to this family of measures as "heat pumps."[1]

Heat pumps extract thermal energy from outside a building and deliver it indoors using a refrigerant cycle and heat exchangers. In cooling mode, they reverse this process, extracting heat from indoor air and delivering it outdoors.

The Trust's programs incentivize a wide range of high-efficiency heat pumps, including but not limited to ductless mini-splits, ducted split systems, Variable Refrigerant Flow (VRF) systems, and Packaged Terminal Heat Pumps (PTHPs). This testimony is focused on mini-split heat pumps except where otherwise indicated.

While heat pump technology is also employed in high-efficiency appliances used to provide domestic hot water, heat pump water heaters are not the subject of this testimony.

10. Does the Efficiency Maine Trust Act (the statute) provide any direction on the Trust's heat pump activity specifically?

Several provisions of Maine statute have an impact on the Trust's heat pump planning and budgeting. First, the statute directs the Trust to "identify the maximum achievable cost-effective energy efficiency savings [MACE]… pursuant to sections 10110 [of the Act]"[2] and to develop and implement programs to procure MACE efficiency resources.[3] In some purchasing scenarios, heat pumps constitute a cost-effective electric efficiency measure where the heat pump is replacing or offsetting less efficient electric

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[1] The Trust's programs recognize eligibility for a wide variety of heat pump applications. These include systems that use the ambient, outside air as a thermal reservoir ("air source" heat pumps), as well as those that use the ground or water as a thermal reservoir. They also include systems that distribute heat (or cooling) through a building using flexible lines (tubing) in a "ductless" distribution system, as well as those that use ducts. For purposes of this testimony, unless otherwise indicated, use of the term "heat pump" refers to air source systems using a ductless distribution system. This testimony does not address the application of heat pump technology for domestic water heating.

[2] 35-A MRS §10104(A).

[3] 35-A MRS §10110(4-A).

heating and cooling. To the extent heat pump HP installations are cost-effective as an electric efficiency measure, the Triennial Plan must develop programs to promote them, and they must be included in the Electric Efficiency Procurement budgets.

When heat pumps are being installed in place of combustion heating systems or to offset combustion heating, heat pumps may be considered a “beneficial electrification” measure.

> "Beneficial electrification" means electrification of a technology or process that results in reduction in the use of a fossil fuel, including electrification of a technology or process that would otherwise require energy from a fossil fuel, and that provides a benefit to a utility, a ratepayer or the environment, without causing harm to utilities, ratepayers or the environment, by improving the efficiency of the electricity grid or reducing consumer costs or emissions, including carbon emissions.[4]

For beneficial electrification measures that are cost-effective and reliably reduce electricity rates over the life of the measures, the Triennial Plan must develop programs to promote them, and they must be incorporated into the Electric Efficiency Procurement budgets together with the classic electric efficiency measures.[5] Please refer to Appendix H for additional information.

Second, the statute calls for the Triennial Plan to “promot[e] the purchase of high-efficiency heat pump systems to achieve by 2030 the goal of at least 115,000 households in the State wholly heated by heat pumps and an additional 130,000 households in the State partially heated by heat pumps.”[6] This directive is in support of the Maine Climate Council goal to transition to cleaner heating and cooling systems.[7]

Note that the statute goals are inclusive of all heat pump technologies including ductless mini-splits, ducted systems, Variable Refrigerant Flow (VRF) systems, and Packaged Terminal Heat Pumps (PTHPs).

11. What heat pump measures qualify as electric energy efficiency measures?

Several of the Trust’s incentives target heat pumps that are installed to replace, or in place of, electric resistance baselines. The C&I Prescriptive initiatives for the hospitality sector specifically target retrofit projects that replace existing packaged terminal air conditioners (PTACs), which run on electric resistance heating elements, with Packaged Terminal Heat Pumps (PTHPs). C&I prescriptive initiatives that target hospitality, congregate housing and multi-family include incentives for variable frequency refrigerant and vertical packaged terminal heat pump equipment where the baseline may be electric resistance or less efficient heat pump equipment. These projects qualify as electric energy efficiency measures.

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[4] 35-A MRSA §10102(3-A).
[5] 35-A MRS §10110(4-A)
[6] 35-A MRS §10104(4)(F)(7).
[7] *Maine Won’t Wait, A Four-Year Plan for Climate Action*, Maine Climate Council, December 2020.

12. What heat pump measures qualify as beneficial electrification?

Please refer to Appendix H.

Heat Pump Program Changes

13. What changes have been made to heat pump programs during Triennial Plan V?

The Trust has shifted its program design away from using rebates for heat pumps installed as supplemental heating. Under the new program design, in order to qualify for rebates heat pump projects must be designed to serve as the primary heating system for the entire building or zone in which they are installed. To meet this requirement, the program requires that the total installed capacity of the proposed heat pumps must be equal to or greater than 80% of the design load[8] and existing heating systems that remain operational must be configured for emergency back-up use only.[9]

The residential heat pump programs have, for the foreseeable future, removed multizone heat pump systems from eligibility for program rebates. The commercial heat pump programs have limited multizone heat pump systems to only two or three indoor units per outdoor units.

14. To what extent have the Trust's programs promoted messages, education, or training to help customers and installers understand operational practices that will improve the cost-effectiveness of supplemental heat pumps?

Prior to FY2019, the extent of the Trust's education and training for heat pumps was minimal. It involved setting minimum requirements for proper installation and maintenance and providing scholarships for heat pump installer training at community colleges. However, the Trust did not deploy any significant education and awareness campaign regarding best practices for maximizing savings.

Around FY2019, it became clear to the Trust that there was a lack of consumer awareness about how best to operate a heat pump efficiently, and that there were notable public misconceptions about modern heat pumps' technical capabilities. The Trust's HESP Program Impact Evaluation of prior years' installations found that a significant portion of heat pump users were underutilizing their heat pumps, thereby failing to capture the measure's full benefit.[10] the Trust also learned that many heating technicians and homeowners were under the mistaken belief that it is better to turn off heat pumps in the winter months and rely entirely on central fossil-fuel fired systems during that period. At the time, this message was being conveyed by fuel dealers across the state.[11]

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[8] Design load is defined as the heat loss of the home at the 2021 99.6% dry bulb design temperature defined by ASHRAE. This is the temperature for which 99.6% of the hours of the year are above. https://ashrae-meteo.info/v2.0/

[9] Configurations for emergency back-up may include turning off all connected thermostats, turning off and covering service or emergency shutoff switches, connecting existing heating system directly to a generator, and, for commercial only, installing integrated controls that prioritize the heat pump system.

[10] West Hill Energy and Computing, Efficiency Maine Trust Home Energy Savings Program Impact Evaluation - Program Years 2014-2016, August 23, 2019, p. 5-5.

[11] "Heat pumps in Maine: Set it and forget it? Or turn it off in the winter?" *Portland Press Herald,* October 28, 2018.

In light of this information, the Trust commenced a comprehensive education and training initiative for heat pumps starting in FY2019. This effort focused on sharing strategies for maximizing the benefit of a heat pump and debunking performance myths. First, the Trust developed and published a set of heat pump "User Tips." The Trust required that heat pump installers provide each program participant with a copy of these User Tips upon completing a job. The Trust also followed up with program participants after installation, emailing the User Tips and mailing a Heat Pump Tip Kit. The Trust also made the User Tips available on its website, along with other helpful videos and links. It leveraged Google and Facebook ads to drive customers toward this information. Finally, it further disseminated this information through energy fairs, at presentations, and at other events across the state.

Second, the Trust significantly expanded its outreach and training efforts with Maine's heat pump installer community. It developed the "Efficiency Maine Annual Heat Pump Basics Module," a webinar that highlights best practices, reviews system siting and selection considerations, and dispels common myths. The Trust now requires that all qualifying third-party heat pump installation trainings for its Registered Vendors include this module. Additionally, at least one installer on every residential heat pump job crew must have proof that they have watched the module in the past year. The Trust still uses most of these education and training tactics in the current program and intends to extend their application throughout Triennial Plan VI.

The extensive outreach on how to get the most out of a heat pump has generally done a good job raising awareness among Maine's heat pump users. To illustrate the point, consider the results of the customer survey used in the C&I Heat Pump Impact Evaluation. In that evaluation, the survey:

> ... asked respondents to indicate whether Efficiency Maine's mail or email materials on how to operate their heat pumps was very, somewhat, or not at all helpful. Most respondents (70%) recalled receiving Efficiency Maine's materials, and of those, 87% found it to be at least somewhat helpful.[12]

Similarly, the Residential Heat Pump Impact Evaluation included a survey of ten participating contractors that asked about changes to business practices attributable to program participation. The survey found that "using Efficiency Maine's heat pump tips to train customers (8) and recommending qualified heat pumps (7) are the most common changes trade allies made."[13]

Despite reported awareness of the Trust's Heat Pump tips, *in situ* metering of heat pumps showed heat pump usage is significantly lower than anticipated by the Trust and then the technical potential of what the equipment is capable of delivering.

The C&I Heat Pump Impact Evaluation found that 85% of survey respondents reported using heat pumps in the categories of "all heating season days" or "most cool and all cold days" but 29% percent also

[12] DNV, C&I Heat Pump Impact Evaluation, 2023, https://www.efficiencymaine.com/docs/DNV-Efficiency-Maine-CI-Heat-Pump-Impact-Evaluation-Report-April-2023.pdf

[13] Ridgeline Energy Analytics, Residential Heat Pump Impact Evaluation, 2024, https://www.efficiencymaine.com/docs/Efficiency_Maine_Residential_Heat_Pump_Impact_Evaluation_Report-2024.pdf

reported they still used their pre-existing heating system frequently. The metering data showed that the heat pumps installed in commercial applications provided an average heating output of 9.8 MMBtu/year compared to the 25 MMBtu/year assumed in the Trust's Technical Reference Manual (TRM). The modeling used to inform the TRM expected that the first heat pump installed in a commercial application would be sized to meet the design load of the space it served and would be used as the primary heating system

For residential applications, the TRM predicted heat pumps used in a supplemental application would provide, on average, 27.9 MMBtu/year. The evaluation metering found the average heat provided by supplemental heat pumps was only 16.6 MMBtu/year, or 20% of the heating load for an average Maine home.

Despite the extensive education and training for the customers and installers, the evaluations showed that supplemental applications of heat pumps were not being operated to anywhere near their full potential. This finding contributed to the Trust's decision to transition the program away from supplemental heating systems to whole-home and whole-building heat pump systems.

15. Why has the Trust transitioned its residential heat pump program design to promote whole-home heat pump systems and to move away from incentives for partial/supplemental heat pump solutions?

There are multiple reasons that the Trust decided to shift its focus to whole-home heat pump systems.

As noted above, evaluations showed that supplemental heating systems, while performing very well in cold temperatures, were nonetheless not being used enough to achieve their full potential. A whole-home heat pump system performs better and provides a better return on investment for the homeowner than heat pumps that are used to supplement an existing furnace or boiler. When an existing furnace or boiler remains active in a home, it frequently forces heat pumps to shut off prematurely. In other cases, homeowners have been incorrectly instructed to turn them off manually during certain seasons or outdoor conditions. Either situation causes the home to use the more expensive furnace or boiler. The 2017 Home Energy Saving Program Impact Evaluation and the 2024 Residential Heat Pump Impact Evaluation both found that heat pumps installed as supplemental heating systems are underutilized, largely due to the competition with existing heating systems, which resulted in the home realizing less energy savings than anticipated.

Current heat pump technology designed for cold climates has been operating over the past decade in tens of thousands of Maine homes. When properly sized and properly designed, whole-home heat pump systems have demonstrated that they are able to heat an entire home for an entire Maine winter.

The Trust commissioned a metering study of ten homes in Maine that rely on heat pumps as their primary heating system. The key findings from that study are as follows:[14]

[14] DNV, Whole Home Heat Pump Study, 2021, https://www.efficiencymaine.com/docs/DNV_Whole_Home_Heat_Pump_Study_2021.pdf

- The metered heat pumps met the needs of the homeowners as year-round, primary heating systems;
- Seven out of 10 homes did not use supplementary heating to any significant degree in addition to the heat pumps;
- All homeowners were satisfied or very satisfied with their heat pump systems and the comfort of their homes;
- The coefficient of performance (Energy Output/Energy Input) for the heat pumps ranged from 1.7 to 3.9 for the performance measured over the study period; and
- Heat pumps functioned as the primary heat sources in a number of different kinds of homes, of varying ages.

In 2023 shortly after a severe cold snap in February, the Trust surveyed homeowners that had heat pump systems installed as the sole source of heat under a pilot study of whole home heat pump systems. During the first weekend of February 2023, Maine experienced some of the coldest temperatures it had seen in more than five decades, with wind chills reported as low as -60 °F. The homeowners surveyed reported no issues with their heat pumps and comfortable indoor temperatures throughout the cold snap. Here are direct quotes from some of the survey respondents.[15]

> "I live on the top of a mountain in Waterford, Maine, where it gets pretty windy. That's not a challenge for my heat pumps, which during the February cold snap kept me warm without backup even during -49 °F wind chill! I'm also saving around $300 a month using heat pumps instead of propane." Frank D., Waterford, ME

> "I've saved thousands of dollars by heating my entire home with two heat pumps. In fact, I haven't had an oil delivery since the fall of 2021." Paul N., Van Buren, ME

> "We live in a small 1930s cape cod and it routinely gets down to -20 °F in the winter. We replaced our failing, 25-year-old oil furnace with heat pumps. When we had forced hot air with an oil furnace, we were always adjusting the temperature, and now we set the heat pumps and forget them. The heat pumps are also saving us money. This past February when it was -25 °F, our electric bill was only $281 for the month, and we were very comfortable. It's also really inexpensive to run the air conditioning. This technology is great." Cathy and George H., Dexter, ME

> "I love my heat pump! It's in the closet where my furnace used to be and uses the existing ductwork. It keeps the entire house a steady, comfortable, toasty warm temperature even on bitter cold days. Even with higher electricity rates, the cost is nowhere near the cost to buy 100 gallons of oil. It has so many benefits: no oil delivery and no need to shovel a path to my oil tank to read the gauge. And I don't have to put my air conditioners in anymore!" Michelle W., Freeport, ME

> "We replaced our oil furnace and have a heat pump that uses our existing duct work. The heat pump worked well during the cold snap, keeping our home at a steady,

[15] https://www.efficiencymaine.com/docs/Cold-Snap-2023-Heat-Pump-Performance.pdf

comfortable temperature. Compared to the cost for oil usage, the heat pump is less costly and the maintenance is minimal. And we like that it's more environmentally friendly; it's quieter and cleaner." Rita D., Freeport, ME

Furthermore, focusing on whole home heat pump installations is a faster and more efficient pathway to reach the State's goal of 115,000 whole home heat pumps by the year 2030. It provides a clearer message to consumers and contractors that the ultimate goal, for the economic best interest of the consumer, is to fully convert the entire home to a heat pump system. It also saves on overall project costs by reducing travel time, sales calls, and administrative costs that would be required through a piecemeal approach.

Finally, starting in 2023, the federal government began providing a tax credit of 30% of the cost up to $2,000 for an eligible HP (and another $600 for wiring/panel upgrades), making the Efficiency Maine rebates redundant for supplemental systems. As an example, a single-zone heat pump installed for supplemental heating that costs $4,800 and could receive a federal tax credit of $1,440 which is more than double the incentive previously provided by the Trust for a non-low income customer.

16. How has The Trust designed its offerings to make heat pumps accessible to low-income customers?

The Trust offers three levels of incentives for whole home heat pumps to support accessibility of heat pumps for all Maine homeowners regardless of income level. Incentives are based on total project cost, including the cost of all single-zone heat pump units, electric panel upgrades, heat pump warranties, removal of an existing boiler/furnace/tank, and any other directly related costs. Low-income households[16] qualify for incentives of 80% of the total project cost up to a cap of $8,000. Moderate-income households[17] qualify for incentives of 60% up to $6,000. Non-low or moderate-income households qualify for incentives of 40% up to $4,000. Income eligibility is verified through an online form on the Efficiency Maine website.[18] A letter is sent to the applicant verifying their income qualification, which verification is valid for a year. The homeowner can provide that letter to their installer to demonstrate that the applicable incentive should be applied to their project. For low-income customers, incentives are paid directly to the installer. In reliance on that, the installer provides an instant discount to the homeowner on their invoice for the project work. For all other customers, the customer and contractor have the option to decide which party will receive the incentive.

For low-income customers living in single-wide manufactured (mobile) homes in qualifying towns,[19] the Trust offers rebates to fully replace the existing heating system with a ducted heat pump. Participants may choose to pay a co-pay of $2,000, or to finance the customer's co-pay by making payments of

[16] A household qualifies as low-income if the homeowner or homeowner's household member participates in MaineCare, HEAP, SNAP, or TANF.

[17] A household qualifies as moderate-income if the homeowner's Adjusted Gross Income (AGI) is up to $70,000 for individual tax filers, or $100,000 for joint filers.

[18] https://www.efficiencymaine.com/income-based-eligibility-verification/

[19] https://www.efficiencymaine.com/docs/Eligible_Towns_for_MHHP_Pilot_5-2-2024.pdf

$50/month for 50 months. If the customer elects to finance their co-pay, then the full project cost is paid by the Trust directly to the installer and the monthly payments are made to the Trust.

Low-income households may not have sufficient tax liability to take advantage of the federal tax credit and they may not be ready to commit to a whole home heat pump system. For those customers, the Trust offers an incentive of 80% of the project cost up to $4,000 for the first single-zone heat pump installed in the home. Homes that receive this supplemental heat pump incentive remain eligible for the whole home heat pump incentives, subject to the $8,000 lifetime limit. This allows a home to install a single heat pump first and then later add sufficient heat pumps to fully heat the home.

The Trust also offers unsecured, low interest rate loans for income-eligible customers. These loans provide a way for low-income households to install heat pumps with no upfront costs and low monthly payments. For example, a $10,000 whole home heat pump project in a low-income household would receive an $8,000 incentive and require a $2,000 loan to cover the balance. At an illustrative 5.99% APR for a 10-year loan, the monthly payments would be less than $25 per month.

17. Why has the Trust transitioned its commercial heat pump program design to promote whole-building/whole-zone HP systems and to move away from incentives for partial/supplemental heat pump solutions?

Similar to the Trust's experience with heat pumps in residential buildings, the 2023 C&I Heat Pump Impact Evaluation found that supplemental heat pump systems are underutilized, and energy savings are underachieved when the heat pumps operate in competition with existing heating systems. Focusing on whole-building/zone heat pump solutions eliminates competition between heating systems, resulting in higher realized energy savings.

18. Why has the Trust moved away from rebating multizone heat pump systems in residential projects?

Multizone units have the ability to work well when properly sized and balanced, but there are strong indications that a multi-zone system is less efficient in many situations than a single zone and offer very small advantages in terms of installation cost. Generally, single zone heat pumps can modulate down to 10% of their maximum capacity. By contrast, some models of multizone heat pumps can modulate down only as far as 30% of their maximum capacity. In low-load conditions, such as during mild shoulder seasons, only one indoor unit might be calling for heat. On a multizone heat pump, the outdoor unit will respond to that one unit, but because multizone heat pumps must circulate a minimum amount of refrigerant through all indoor units even if heating (or cooling) is not being called for from a particular indoor unit, the result may be overheating (or overcooling) in some rooms. This can lead to comfort issues and excessive on-off cycling as the outdoor unit is unable to modulate down low enough to meet the lower demand for heat. In extreme situations, the indoor units in a multizone system cannot dissipate enough heat, disrupting the refrigerant cycle, resulting in coefficients of performance (COP) that have been observed falling below 1.0.

The excerpt below is from the Residential ccASHP Building Electrification Study, prepared by Cadmus on April 22, 2022, that metered homes in New York and Massachusetts. It shows that the measured seasonal COP for multizone units were significantly lower than other configurations studied.

Figure 1[20]

Comparison of Heating Performance by System Type and Indoor Heads

Ductless multi-zone systems with more than three indoor heads (some with branch-box control) had the lowest average seasonal heating performance during the metering period. Anecdotal feedback from the advisory committee and Cadmus' experience indicate that the more zones a multi-zone system serves, the higher the likelihood that some zones may be oversized, causing a greater differential between actual load and capacity.

In contrast, ductless single-zone systems had the highest measured performance.

System Type	Description	Number of Indoor Heads	Number of Outdoor Units	Average Utilization, %	Average Seasonal Heating Performance, sCOP
Ductless	Single-zone, Wall	1	19	57%	3.23
	Single-zone, Ceiling	1	1	61%	1.85
	Single-zone, Floor	1	1	80%	3.20
	Multi-zone	2	15	66%	2.24
	Multi-zone	3	13	72%	2.57
	Multi-zone	4	3	45%	**1.12**
	Multi-zone	5	3	70%	**1.52**
Mixed	Multi-zone Mix of Non-ducted and Ducted	3	1	98%	1.97
Ducted[1]	Single-zone, Central	1	15	41%	2.25
	Single-zone, Compact	1	1	6%	N/A
	Multi-zone	2	1	49%	2.29
Individual Outdoor Unit			**73**	**58%**	**2.50**
Overall Site-Level			**43**	**-**	**2.34**

Mitsubishi publishes Application Notes to provide guidance to installers to share best practices for heating system designs. The Application Notes for the multizone series MXZ-C states: "MXZ-C systems are a great choice for many applications but may not be the best choice for all applications. If your design has conditions that make using an MXZ-C system questionable, please consider using one or more of our other 1 to 1 systems to suit your needs." It goes on to say: "if there are only 2 or 3 small zones to condition, combining them and using a one to one system may be a better choice."

It also addresses causes of higher-than-expected energy usage:

> All split ductless systems, single or multi-zone, operate most efficiently when the outdoor unit is modulating smoothly to meet the heating or cooling load of the structure. Design or installation conditions that create a situation where indoor units cycle ON and OFF will in turn cause the

[20] Cadmus Group: Residential ccASHP Building Electrification Study, April 22, 2022, Slide # 22.

outdoor unit power input to go up and down. This produces energy spikes which in turn are the reason for higher energy use.

Richard Faesy and Bruce Harley performed a case study of a commercial office building that installed multizone heat pumps. They documented their findings in a presentation at the Better Building by Design Conference.[21] They found the multizone system installed was oversized. Replacing the multizone system with two single zone units with the same oversizing factor resulted in a 20% reduction in energy use.

Bruce Harley made this additional observation regarding another advantage of heating system designs that use multiple single zone heat pumps. It "not only improves efficiency but increases resilience in case of a failure (still have heat) and makes it far easier to run one unit on a generator."[22]

19. Why does the Trust still provide incentives for multizone heat pumps in multifamily applications?

The Trust recognizes that by their nature, multifamily buildings present different challenges and opportunities for heat pumps applications than single-family homes and duplexes. Allowing multizone heat pump units for multifamily projects provides greater flexibility and may lead more building owners to consider installing heat pumps. The commercial program team reviews and must pre-approve every heat pump project that involves multizone systems, which helps to avoid problems with oversizing and unbalanced system designs.

The Trust's C&I programs also limit incentives to multizone heat pumps with only two or three indoor units connected to each outdoor unit. This limitation avoids the risks of underperforming by large multizone heat pump systems that were shown to have relatively low COPs in the Cadmus Residential ccASHP Building Electrification Study.

Heat Pump Energy Impacts

20. What is the assumed baseline for heat pump projects?

The 2023 Commercial and Industrial Heat Pump Impact Evaluation and the 2024 Residential Heat Pump Impact Evaluation assessed customers' decisions in purchasing and installing heat pumps to determine the appropriate baseline for each project. The evaluation reports find that there is a blend of "retrofit" and "lost opportunity" baselines. The following figures show the breakdown of assessed baselines from those reports. The residential evaluation found that 79% of all projects were retrofits.

For a lost opportunity, the Trust's incentive encourages a customer who is already in the market for a new heating system to purchase a high-efficiency heat pump system. For a retrofit, the Trust's incentive encourages a customer to install a heat pump system to offset or replace their existing, functional heating system.

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[21] Energy Futures Group, Deep Energy Retrofit Update: EFG's Journey to Net Zero. BETTER BUILDINGS BY DESIGN CONFERENCE 2022, Richard Faesy & Bruce Harley, April 28, 2022

[22] Email correspondence between Bruce Harley and Laura Martel, October 16, 2023.

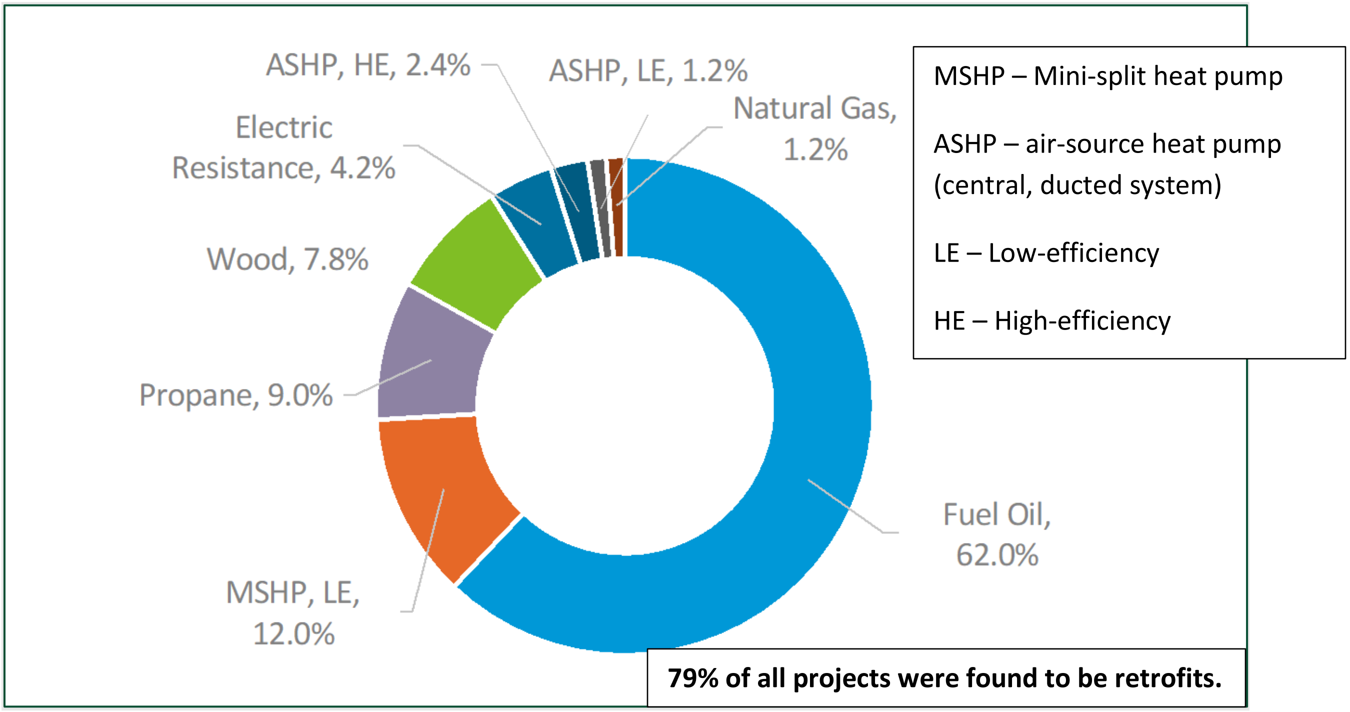

Figure 1 **Residential Heating System Baseline Fuel Type**

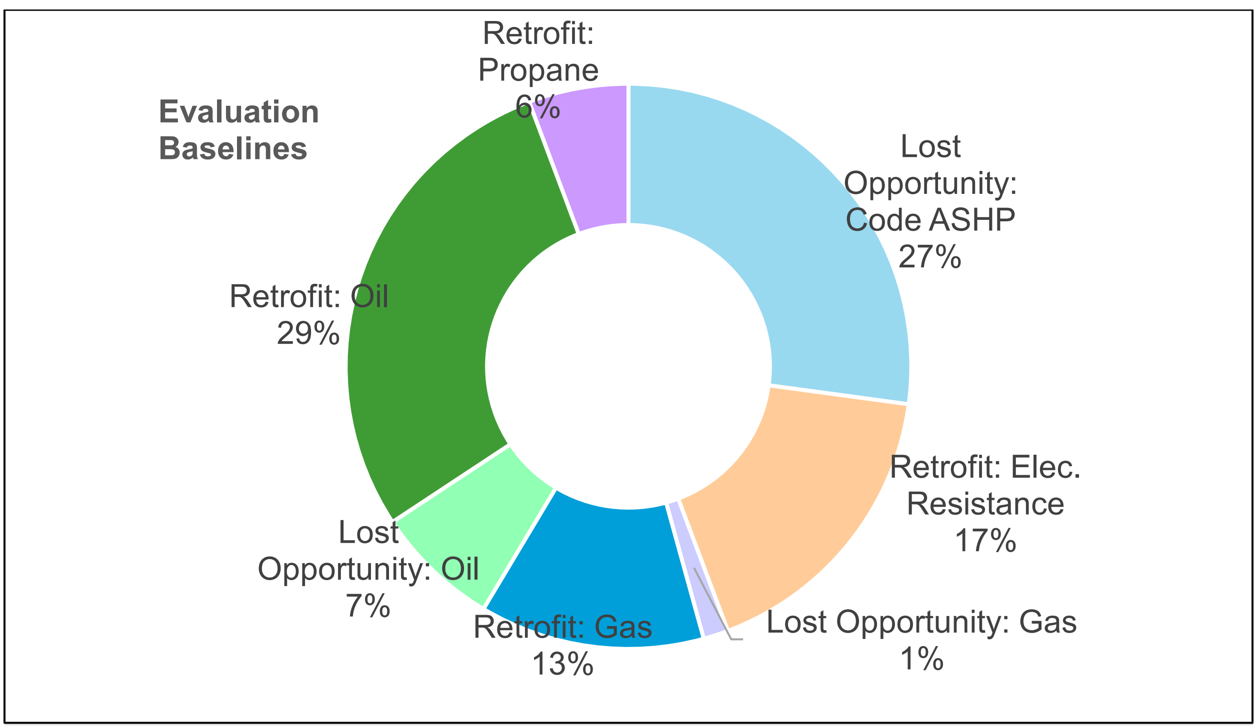

Figure 2 **Commercial Heating System Baseline**

21. What is the basis for cost and energy impacts for heat pump projects?

Costs and energy impacts are calculated as the difference between the installed heat pump solution and the assumed baseline.

For retrofit, the baseline is the continued operation of the existing system. The measure cost is the total installed cost of the heat pump solution. The retrofit energy impacts are the difference in energy consumption of the heat pump solution and the existing system. Where the existing system combusts unregulated fuels, the energy impacts are a decrease (savings) in unregulated fuel energy and an increase (negative savings) in electricity.

For lost opportunity, the cost difference is between the total installed cost of the heat pump and the total installed cost of the alternate heating system that would have been installed absent the program. The lost opportunity energy impacts are the difference between the energy consumption of the installed heat pump system and the energy consumption of the alternate heating system that would have been installed absent the program. Where the alternate system is a less efficient electric heating system, the energy impacts are a savings in electricity with no unregulated fuel impacts.

22. Can you explain in more detail the key assumptions and methods used in the residential heat pump energy impact modeling?

In 2018, the Trust contracted Bruce Harley Energy Consulting, LLC to improve the in-house heat pump modeling being performed by the Trust. In making the model improvements for the Trust, Mr. Harley leveraged experience he had gained working with the Canadian Standards Association (CSA) to establish a new Dynamic [Heat Pump] Test Procedure. The modeling uses typical meteorological year 3 (TMY3) temperature bins with a behavioral model developed for the CSA Dynamic Test Procedure applied to avoid brief off-season periods of heating and cooling. This results in a heating and cooling temperature bin profile that models how heating and cooling is performed throughout a typical year. At each temperature, the capacity and coefficient of performance (COP)[23] of the heat pump is applied to the heat load of the building to calculate heat provided and energy consumption of the heat pump and the baseline system. Key assumptions in the model include:

- Program-eligible heat pump performance used in the modeling is derived from the Residential Heat Pump Impact Evaluation.[24]
- The actual heat delivered by the heat pumps for any given temperature is a function of the heat load of the building and the capacity of the heat pump.
- A factor (termed “Load Factor”) was introduced to model the interaction between the heat pump and the central heating system. This factor is used to adjust the point at which the heat pump cannot fully meet the heat loss of the area being served and triggers the addition of heat

[23] COP is a ratio of useful heating or cooling provided (output) to energy consumed (input) where input and output are measured in the same units. Higher COPs equate to higher efficiency, lower energy consumption, and thus lower operating costs.

[24]Ridgeline Energy Analytics, Efficiency Maine Residential Heat Pump Impact Evaluation, March 7, 2024.

generated by the central system. Since the heat called for at any given temperature is fixed, any heat provided by the central system is heat that cannot be provided by the heat pump even if it has the capacity to do so. The portion of the heat provided by the heat pump, when both the heat pump and central system are providing heat, is directly proportional to the capacity ratio between the heat pump and the central system. For whole home/whole building heat pump modeling, the capacity of the central system is set to the design capacity of the heat pump, and the "Load Factor" is set to 0.7. This results in the central system only being called for when the capacity of the heat pump falls to 0.7 of the heat load.

- A second factor (termed "Sizing Factor") was introduced to model the ratio of the heat pump's capacity at the design temperature to the heat loss at the design temperature. A sizing factor of 1 indicates that the heat pump capacity at the design temperature is perfectly matched to the heat loss of the area it serves. Inversely, the area served by the heat pump is matched to the heat pump's capacity at the design temperature. A sizing factor greater than 1 indicates that the heat pump system contains extra capacity for the area it is serving, which is also appropriate to handle infrequent extreme cold temperature. A sizing factor of 1.2 is used for whole building modeling based on the average ratio of installed heat pump capacity to design load reported for whole home heat pump projects between September 2023 and April 2024.

Because the design load is equal to the heat load at a temperature for which only 0.4% of the annual hours have a lower temperature, setting the Load Factor to 0.7 and the Sizing Factor to 1.2, results in the heat pump carrying 99.97% of the building's annual heat load.

23. How does a high-efficiency heat pump system compare to a typical central heating system furnace or boiler?

The high-efficiency heat pump offers efficiency advantages in two ways. First, it uses source energy to deliver useful heat more efficiently than a typical central heating system. At peak performance, the high-efficiency heat pump is delivering heat at a COP above 3.0. The "seasonal COP" in Maine's climate is the average COP of a heat pump over the course of an entire heating season, which is arrived at by taking the total heat delivered during the season divided by the total energy consumed. The 2024 Residential Heat Pump Impact Evaluation found the seasonal COP of installed heat pumps to be 2.57. That is equivalent to an efficiency of 257%, which is more than three times the efficiency of an average oil boiler in Maine. Even when the losses from the power generator and line losses across the grid are factored in, the high-efficiency heat pump is still significantly more efficient than a fossil-fired furnace or boiler. Secondly, the heat pump delivers heat directly into a room, avoiding some of the losses that a central heating system typically incurs from ductwork (in furnaces) or from the pipes leading to the radiators (from boilers) of the distribution system. Because the modern, highest efficiency heat pump models can efficiently produce heat even at very low outdoor temperatures, it is appropriate, from a cost-effectiveness perspective, for users to run the heat pump so that it continues to deliver heat throughout the entirety of the heating season. Compared to an average existing oil boiler, the average benefit-cost ratio of a whole home heat pump system is 1.7 where the increased electricity consumption is handled as a cost in the calculation. The lifetime benefits are $65,357, lifetime fuel costs (increased electricity use) are $23,139 and the measure cost (full installation cost) is $15,225 resulting in a net benefit of $26,993.

One exception to heat pumps being the least operating cost option would be in a space where the central heating system runs on natural gas. In a natural gas-heated space, a heat pump retrofit may not be cost-effective assuming current avoided costs. Whether or not the heat pump installation is cost-effective is dependent on the heat load being displaced and the cost of the heat pump system. Based on recent program data, heat pump projects replacing existing natural gas heating systems would have a benefit-cost ratio of 0.88 assuming the average heat provided and installation costs for projects installed between September 2023 and April 2024.

24. How does the Trust account for air conditioning costs and benefits in its heat pump cost-effectiveness calculations?

The residential heat pump modeling accounts for cooling impacts based on the findings of the recent heat pump evaluation. The following chart show the cooling baseline assessments from the 2024 Residential Heat Pump Impact Evaluation. The residential modeling assumes that 58% of homes would have standard efficiency mechanical cooling absent the heat pump installation. The modeling assumes that the other 42% of homes use the heat pump for cooling that otherwise would not have occurred (added load). The modeling does not make any adjustments for homes that would have used fans during the cooling season. The model calculates the electricity consumption for cooling for standard efficiency mechanical cooling and the consumption of the heat pump during the cooling season assuming that a constant temperature is maintained throughout the cooling system with a balance point of 70 degrees. That is, whenever the outdoor ambient temperature is above 70 degrees, cooling is called for proportional to the outdoor ambient temperature.

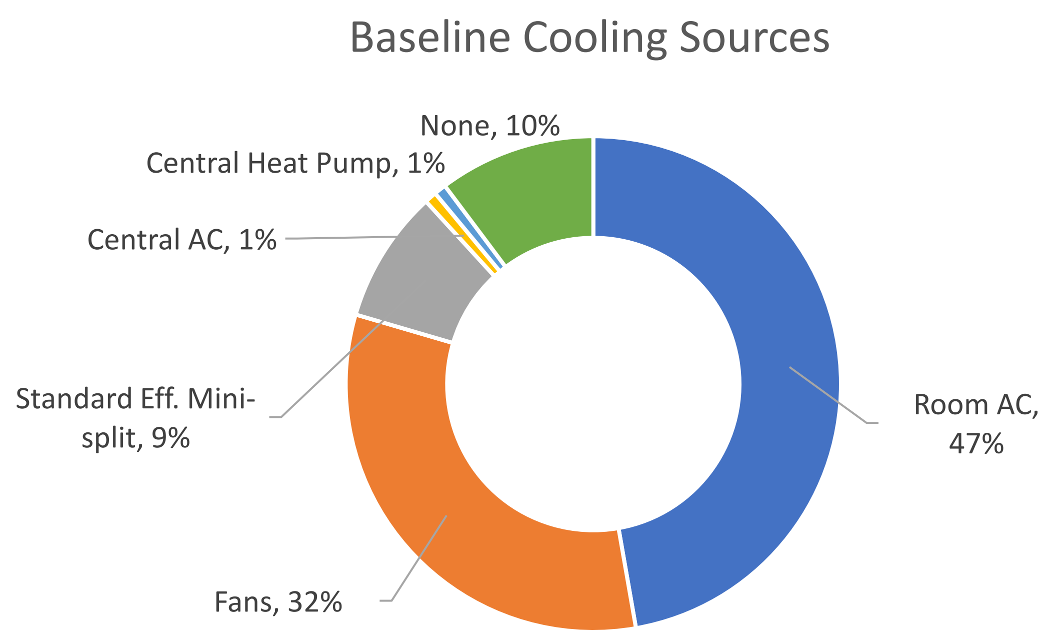

Figure 3 Assessed Cooling Baseline for Residential Heat Pumps

For commercial applications, the heat pump impact factors are derived directly from the 2023 C&I Heat Pump Impact Evaluation and reflect the assessed baseline cooling conditions. The chart below shows the assessed cooling baseline from the 2023 C&I Heat Pump Impact Evaluation.

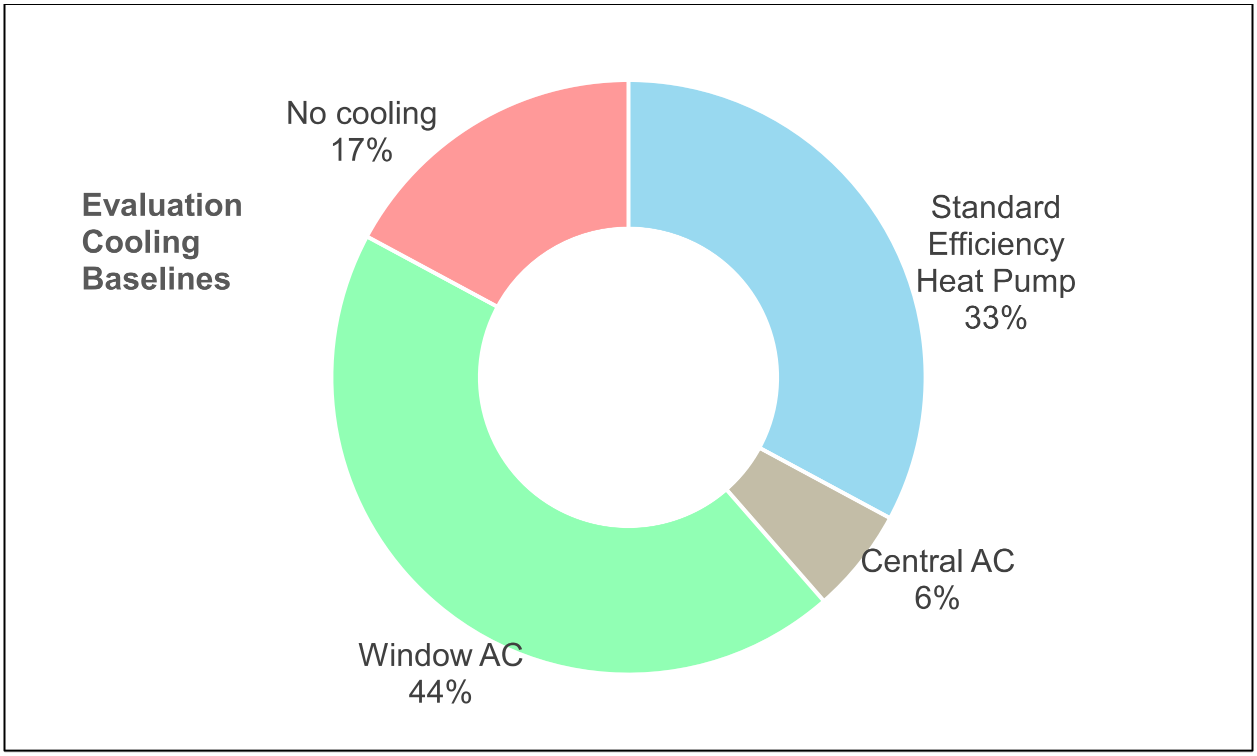

Figure 4 Assessed Cooling Baseline for C&I Heat Pumps

25. Does this conclude your testimony?

Yes.