Integrating load reduction with heat pump design to reduce the cost and risk of residential decarbonization

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ABSTRACT

Installation of heat pumps is critical to reducing the carbon impact of residential buildings. Properly sized heat pumps installed with comprehensive load reduction can reduce heat pump installation costs, lower the risk of increased energy bills, and reduce peak grid impacts.

The authors worked on three projects to validate this approach. In the first two, the authors supported the New York Energy Research and Development Authority (NYSERDA) to develop a pilot aimed at decarbonizing residential buildings, combining weatherization measures with heat pumps. Lastly, the authors worked with a residential new construction program in Wisconsin to evaluate prediction of savings. The authors monitored the actual heat pump energy usage compared to an EnergyPlus simulation prediction using actual equipment detailed performance specifications. Performance verification reduces the risk that tenants or building owners will see higher bills from problems in sizing and equipment selection of heat pumps or in the heat pump installation or operation. With funding from US Department of Energy and NYSERDA, the authors developed the advanced heat pump calculation tools deployed in the pilot using simplified input EnergyPlus simulations that have been adopted into the New York State Technical Resource Manual. This tool provides load calculations combined with savings calculations and equipment selection assistance, providing an all-in-one modeling/sizing/selection tool enabling rapid heat pump project optimization. This paper presents the initial results of performance verification and contractor and building owner feedback on the impact of the integrated load reduction and heat pump design process on sales and energy savings.

Introduction

Background

Decarbonization of residential buildings by switching to electricity for all energy end uses is an important factor in reducing man-made greenhouse gas emissions. Electrifying a building involves switching all space heating, water heating, and appliances to use electricity instead of fossil fuels. Cold-climate (or variable speed) heat pumps (ccASHPs) have made it possible for cost-effective decarbonization of the residential building sector in heating dominant climates (Langevin 2019; Shoukas et.al. 2022). While the technology of ccASHPs has greatly improved to the point of making it possible for heat pumps to be cost effective in cold climates, they are much more complex than conventional heat pumps and challenges remain that prevent more widespread adoption of this technology. Challenges for weatherization assistance program (WAP) agencies to utilize ccASHPs include additional overhead in funding fuel switching jobs, low savings to investment ratios, and the high cost of materials and labor to install (Desai and Wu 2022).

Air source heat pumps use a refrigerant that is alternately compressed and allowed to expand to transfer heat from one location to another. Heat pumps have improved in several key ways: use of refrigerants with lower boiling points, more efficient compressors, including variable speed compressors, and larger heat exchangers (Crownhart 2023). This allows the ccASHPs to meet high heating demand during extremely cold temperatures while still maintaining minimal energy usage during more moderate temperatures. A heat pump will short cycle on and off if the demand is below the minimum capacity of a heat pump, reducing its efficiency, so minimizing short-cycling is critical for achieving significant energy savings (Shoukas 2022).

The technology is still new and the factors to consider when installing cold-climate heat pumps to replace existing HVAC equipment are still being determined. "NEEA, NEEP, Natural Resources Canada and California utilities lack confidence that the existing performance metrics for air-source heat pumps (HSPF and SEER) provide the necessary information to adequately characterize heating and cooling performance under all operating conditions" (Northwest Energy Efficiency Alliance (NEEA) 2022). Initial studies have shown that adoption of ccASHP's has slowed due to concerns for the possibility of higher energy bills. These concerns include that actual energy savings from ccASHPs are not as high as predicted (Amero 2020) and that if energy efficiency measures are not included, energy costs will increase (Earle 2022). This paper will present a building modeling approach to address these concerns and instill confidence that actual savings will match the predicted savings. This increased confidence then allows contractors and their customers to make decisions based on accurate information about cost effectiveness of different approaches to decarbonize their homes. The first part of the paper will highlight the validation studies the authors performed to confirm the modeling approach. The second part of the paper discusses some of the findings regarding contractor and customer behaviors uncovered during the validation studies.

Validation Studies

These validation studies are not intended to replace or replicate a program evaluation study. Whereas program evaluation is intended to affirm program logic and goal realization, validation will seek to assess applicability of, and adjust the energy savings methodology as needed. This paper will compare predicted usage to actual usage from three incentive programs:

1. Sustainable Finger Lakes, Clean Energy and Equity (CEEP) – Low Income, Multifamily, Retrofit
2. NYSERDA Comfort Home – Market Rate, Single Family, Retrofit
3. Wisconsin Focus on Energy – Single Family, New Construction

For the two retrofit programs, a selection of buildings were modeled in EnergyPlus using a method developed by Performance Systems Development (PSD) with support and funding from New York State Energy Research and Development Authority[1], and the US Department of

[1] The authors gratefully acknowledge NYSERDA's funding and point out that NYSERDA has not reviewed the information contained herein, and the opinions expressed in this report do not reflect those of NYSERDA or the State of New York.

Energy. The method has been approved by the New York State Department of Public Service for adoption into the New York State (NYS) Technical Resource Manual (TRM) version 10[2]. The TRM is the rulebook for estimating energy savings from ratepayer-funded energy efficiency programs. A detailed writeup of the method can be found in the TRM starting on page 1048. For the new construction program in Wisconsin, the case study used a similar process using OpenStudio/Energy Plus but using a process appropriate for residential new construction.

Sustainable Finger Lakes (SFLX) is a local non-profit in upstate New York. They received funding from NYSERDA to run a pilot program focused on decarbonizing small, low-income multifamily buildings by combining weatherization measures with heat pumps, the Clean Energy and Equity Pilot (CEEP). PSD contracted with SFLX to provide measurement and verification tasks for the program. The program goal is to convert 100 gas income-eligible rental units heated with natural gas in Ithaca NY to air-source heat pumps and heat pump water heaters while leveraging utility rebates, NYSERDA residential retrofit incentives, and combined incentives from the pilot and SFLX's local carbon offset program - (FLCF) for funding. About 25 percent of income-eligible households are renters who live in single family homes and small multifamily buildings (2-4 units), yet this group has been underrepresented in retrofit upgrades (Apprise 2017). This market is hard to reach with typical energy efficiency programs due to the "split incentive" where the landlord pays for the building improvements, but the tenants see the rewards of lower utility bills. The purpose of the study was to test an approach to electrification that would avoid exposing tenants to increased housing and utility costs because of landlord energy efficiency investments, while providing tenant engagement and education to help them become responsible energy consumers.

The Comfort Home pilot program is a market rate whole building, residential envelope improvement program using a novel approach to recast traditional energy efficiency measures as load reduction packages. Comfort Home is administered by NYSERDA to help meet New York State's decarbonization goals (Schryer et al. 2020). Primary pilot goals were to make home heat pump ready providing incentives for envelope improvement packages utilizing a streamlined program delivery and to test the impact on sales to install cycle time and sales conversion rates. Highlights include incentives for pre-defined packages of load reduction measures, emphasizing the synergy between the load reduction and the installation of a right-sized heat pump for cold climate use. After a slow start due to the Covid pandemic, there have been about 3,500 completed home retrofit projects through the end of 2023. One of the goals of this program was to show that deeper envelope retrofits would reduce the size of the heat pump needed, thereby saving money on both equipment and annual usage costs.

The Wisconsin Focus on Energy Residential New Construction program provides incentives to home builders who reduce their buildings' energy usage by at least 20% relative to a reference home. As part of a side-by-side study for Net Zero Ready ENERGY STAR®, the authors installed a usage monitor in a new construction home to compare actual usage with modeled usage for this very tight home (ACH around 1.7).

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[2] Published in December 2022:
https://dps.ny.gov/technical-resource-manual-version-10-filed-december-30-2022-effective-january-1-2023

Verification of Savings for Cold-Climate Heat Pumps

Sustainable Finger Lakes, CEEP

As part of the Measurement and Verification process for the CEEP Pilot, PSD installed low-cost metering devices in participating rental units. The device allows for up to 8 electric circuits as well as whole home energy use to be independently monitored with data available via secure API. Building characteristics and installed measure details were also collected and used to model the predicted usage using the method documented in the NY TRM Custom Measure Category 6. Predicted usage and modeled usage was then binned by temperature to allow comparison between the building's expected and actual behavior. Additional building and measure characteristics were included as well.

Comfort Home

For this validation project, the authors validated the energy performance simulations and associated energy savings estimates for NYSERDA-incentivized envelope improvement plus NYS Clean Heat heat pump installation projects, using real-time home and equipment monitoring to calibrate existing models in the simplified input EnergyPlus modeling tool, Heat Pump Tool Kit. The goal of this validation exercise was to improve confidence in the modeled energy savings and in the simulation standards applied, allow assessment and fine-tuning of program assumptions and variables, and facilitate contractor feedback on their system design and operational support needs. Specifically, some of the key areas identified for investigation were:

- Improving the estimations of non-temperature dependent energy use assumed in the simulation and contributing as internal gains to reductions in heating load and increases in cooling load.
- Improving the assumptions around duct performance (leakage and R value) pre and post retrofit.
- Improving alignment between the simulation and actual performance for low load heat pump conditions that are below the minimum capacity rating of the equipment.
- Improving assumptions about the use of supplemental heat and enhancing understanding of time-of-day use of back up energy (impacting peaks)

Approach to data collection

1. Comfort Home participant sites covering a range of house style type, envelope packages, and heat pump brand and model (matched from the Northeast Energy Efficiency Partnership (NEEP) database using reported AHRI numbers) were included in the initial sample. Non-EV and non-solar/battery storage sites were preferred.
2. Invited contractors to offer select clients a free third-party, web-enabled energy monitoring device in exchange for energy data sharing, until a minimum of 60 appropriate sites were confirmed as participants. Ten contractors have been approached so far for the validation study. They were selected based on volume of projects and contributions to program savings. Three have enrolled in the study, two additional are interested but have not committed. The remainder either declined or have not responded. Reasons for not participating include concerns that data from monitoring device will

trigger customer complaints about the system operation, stipend does not cover costs of returning to site and installing, and insufficient staff availability.

3. Contractor and PSD installed low-cost energy monitoring device to track whole house power and energy use for up to 8 individual circuits, including the heat pump circuit(s). The device will allow homeowners to view real-time electric use by circuit, convert usage to real energy spend, and understand what systems are contributing most to energy consumption.
4. Comfort Home contractors were asked for additional data points required for TRM Category 6 measure documentation into PSD's Heat Pump Toolkit. Additional data points included:
    a. Envelope areas already meeting or not able to meet requirement, and their performance specifications
    b. Hot water heater location and details
    c. Duct details

Data Analytics

The authors downloaded the meter data for each participating site over a total of 16 months. Occasional data gaps were expected due to temporary power and Wi-Fi outages and were removed from the sample. Data was correlated with TMY3 weather temperature files for the site location, and with interior temperatures (when available from smart thermostats or temperature loggers). Specific tests included the following.

1. Comparison of measured hourly and peak kW loads before and after retrofit to simulated pre and post kW loads, by time of day.
2. Comparison of daily and annual kWh usage before (via utility bills) and after retrofit to simulated pre and post kWh usage, by season, for all seasons.
3. Assessment of the impact of Category 6 default assumptions on simulated load and energy use, compared to actual load and energy use.

Figure 1 shows the results of a home participating in the Comfort Home program. This is a 100-year-old home that had been partially weatherized and had two ductless mini-split ccASHPs installed in January 2023. The consistency of the difference between modeled and actual usage across mild to warm weather temperature bins indicates a higher baseload usage than predicted (perhaps from a basement dehumidifier). Analysis of additional homes will indicate if this is a common issue with the model or if there needs to be a mechanism to adjust the baseload usage on a home-by-home basis. Looking at just the heat pump usage, we see a bump in the actual usage compared to modeled between 35 and 60 F when the heat pump would be short cycling. The other discrepancy is at the lower temperature range.

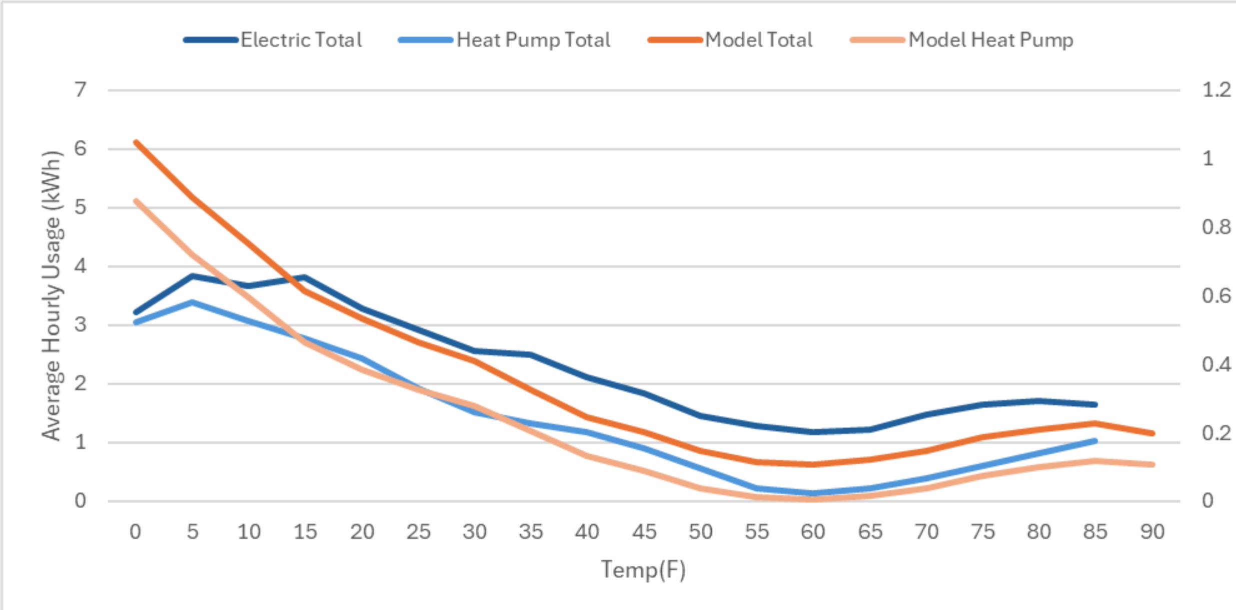

Figure 1: Actual vs predicted average hourly usage for existing single-family residential building

Figure 2 shows the total annual energy usage for each bin. This demonstrates that the total usage at low temperatures is very small simply because the home did not spend a lot of time at those temperatures. The total annual usage is calculated by multiplying the average energy usage shown in Figure 1 by the same actual hourly count for each temperature bin over the course of a single year. Figure 2 makes the increased usage at moderate heating temperatures even more apparent. This highlights the importance of selecting a heat pump based on the most impactful temperature and not designing specifically for extreme low temperatures.

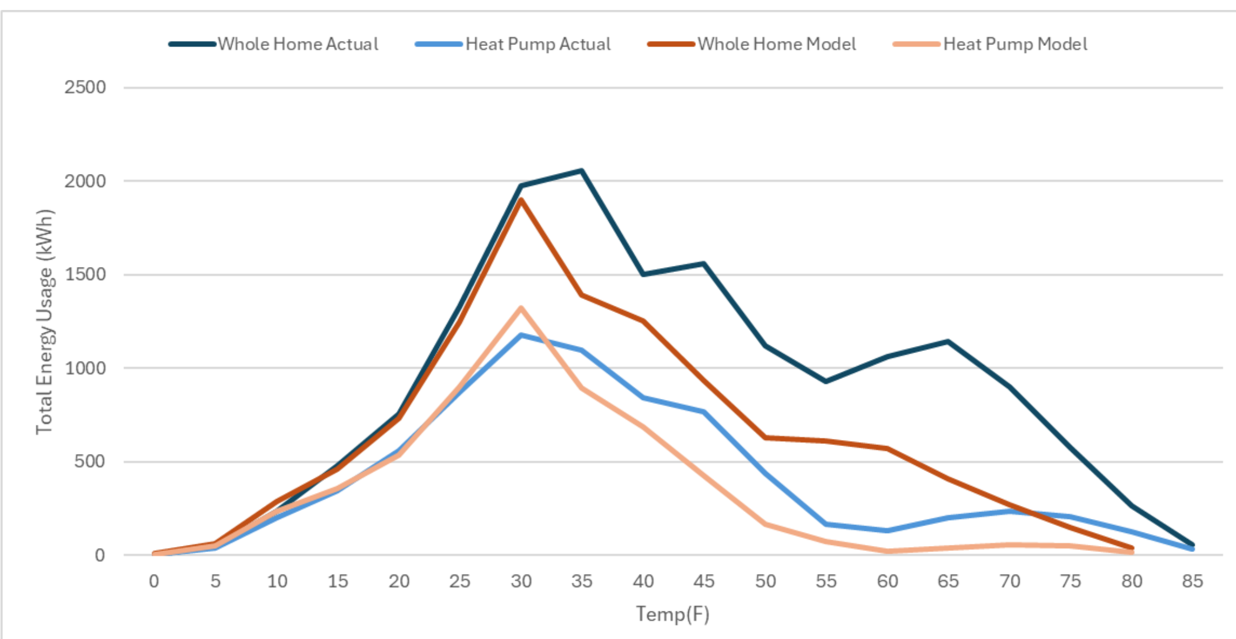

Figure 2: Actual vs predicted total energy usage for existing single-family residential building

For a second home, the same analysis was performed. Figure 3 shows the comparison of the predicted and actual usage along with the qualitative analysis describing the different operating zones the heat pump goes through as the temperature drops. We see this pattern repeated in many of the sample homes we have analyzed.

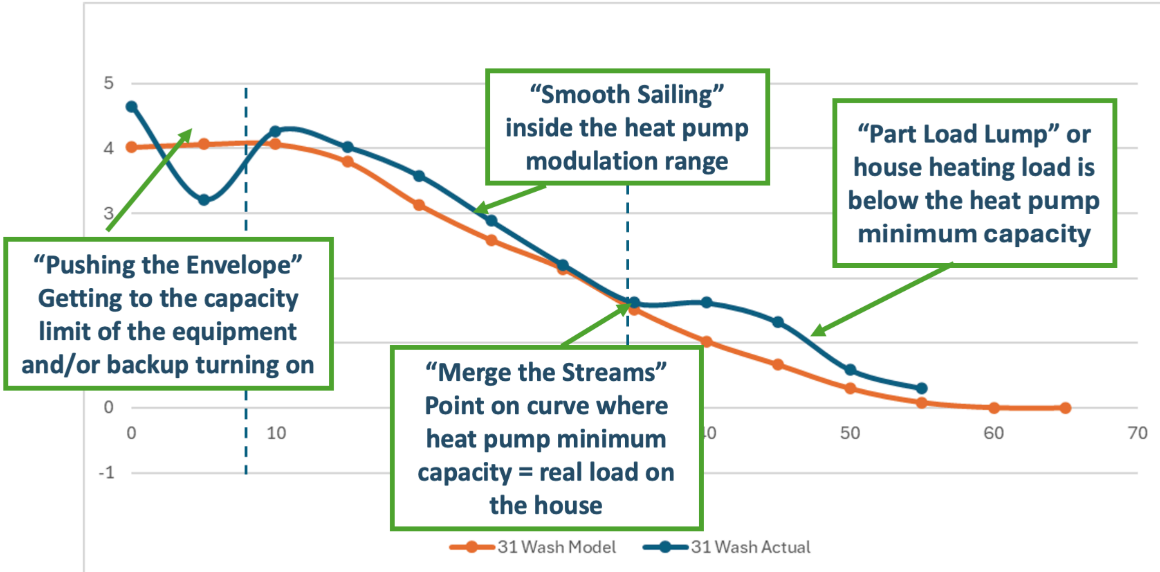

Figure 3: Actual vs predicted showing qualitative analysis

Starting from the right side of the graph, as the temperature drops, the heat pump starts heating the home, but the load does not reach the minimum capacity of the heat pump. This shows up in the actual usage being higher than the predicted usage with this "bump" shape. As the temperature continues to drop, the building load increases until it reaches the minimum capacity. After that, there is smooth sailing as the heat pump operates in the designed temperature range. If an alternate fuel backup system exists, then once the temperature drops below the cutoff temperature, the actual usage will drop compared to the predicted usage.

Wisconsin Residential New Construction

PSD manages the Residential New Construction program for Focus on Energy in Wisconsin. As an enhancement to that program, PSD built a transformer to map the residential building modeling inputs from the program's REMRate software to the more transparent EnergyPlus/ OpenStudio building energy simulation to allow the program to have more consistency over the savings calculation process. For New Home programs, savings is calculated relative to a reference home that meets the energy code requirements in that state. As a state updates its energy code, the reference home needs to be updated. PSD built a reference home for Wisconsin and used that detailed model to generate load calculations for a Net Zero Ready ENERGY STAR new construction residential home relative to an ENERGY STAR new construction home. For one of those homes, a Sense meter was installed in February 2023 to monitor the whole building usage. Figure 4 shows the comparison of that meter data to the simulated usage.

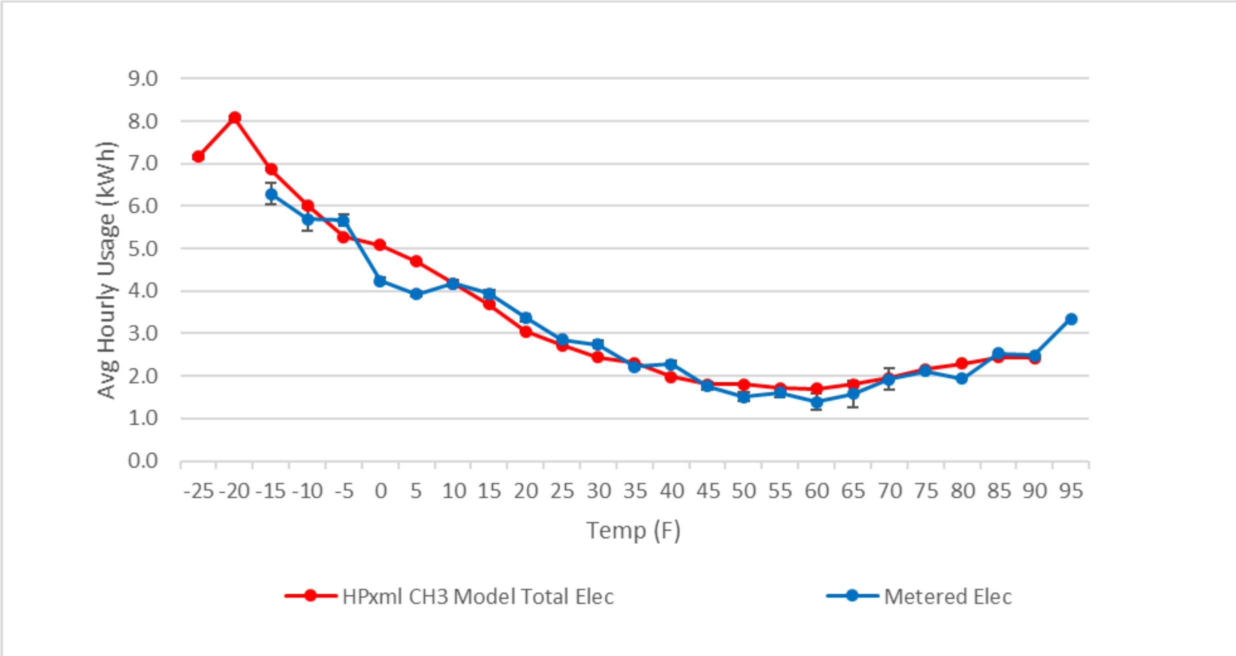

Figure 4: New Construction comparison of Actual to Predicted

To better understand what was happening at low temperatures, a heat pump specific sub-meter was added at the beginning of the 2023-2024 heating season. That data has not been analyzed yet.

Impact on Sales Process

One of the main concerns in the sales process is the fear that switching to heat pumps for heating, especially from efficient gas systems will lead to an increase in utility costs. The main driver of this fear is the uncertainty in accurately predicting the energy usage of homes with a ccASHP installed. The high price of electricity relative to natural gas leaves little margin for error in the savings prediction for homes with natural gas heating systems. A significant degree of uncertainty is introduced when contractors use HSPF/HSPF2, industry performance metrics derived under specific testing conditions, as the main variable in determining the performance of a ccASHP. As part of this study, the authors concluded that these single metrics are not sufficient, and a different approach is needed. Figure 5 shows the total energy usage from EnergyPlus for each heat pump in the Northeast Energy Efficiency Partnership (NEEP)'s Cold Climate Air Source Heat Pump List[3] plotted against their reported HSPF2 value for two different locations. The simulation used the detailed equipment performance characteristics in the NEEP database as inputs and auto-sized the heat pumps to match the load needed for the building to allow comparison across the entries independently of the size of the system. The results show that there is almost no correlation between the HSPF2 value, and the total energy used by that heat pump. The results were run for two different locations in the northeast where PSD has offices: Ithaca, NY and Philadelphia, PA. Not only is there no correlation between HSPF2 and total energy usage; the systems behave differently in the two locations. This further reinforces

[3] https://neep.org/heating-electrification/ccashp-specification-product-list.

the idea that a single, nation-wide, number may not accurately reflect the expected performance of a variable speed heat pump. It is not sufficient for a contractor to select the “best” heat pump based on HSPF, they need to be able to select the “best” heat pump for that location and that home. This requires more information such as that captured in the Northeast Energy Efficiency Partnerships (NEEP) database of cold-climate heat pumps as well as a more detailed sizing and selection process such as described in (NEEA, 2022) and detailed below.

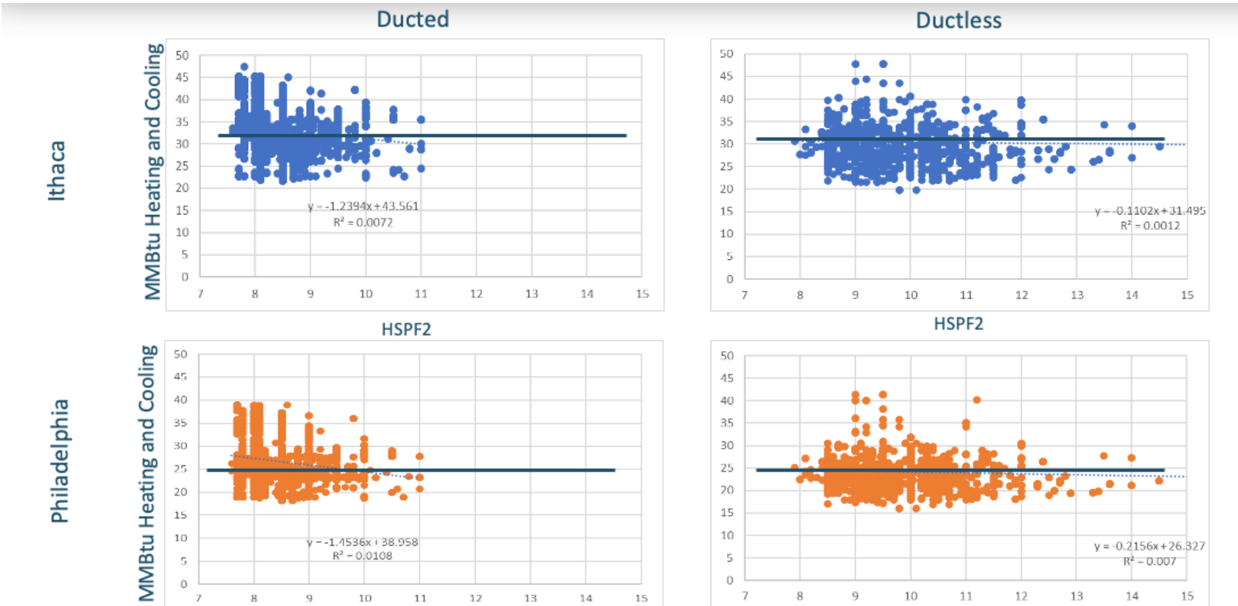

Figure 5: Total Energy Usage vs HSPF2 for ccASHPs in NEEP database

One of the offshoots of the efforts to document the validation of the NY TRM measure was to build out more efficient methods to compare the impact of specific heat pump equipment on specific buildings. In developing the TRM measure, the interface to the EnergyPlus simulation was enhanced to support additional equipment specific metrics, including Minimum Heating Capacity at 47°F, Maximum Heating Capacity at 47°F, Maximum Heating Capacity at 5°F, Maximum COP at 5°F, Minimum COP at 47°F. As a result of these updates, the savings calculations reward contractor equipment performance choices based on a more comprehensive set of ccASHP performance data. The resulting savings better represent both low temperature COP and capacity performance, as well as COP and capacity performance under low load conditions. This impact can be seen in Figure 6 which shows the detailed performance of three heat pumps where the ccASHP with the highest HSPF2 is the worst performer from a total energy use perspective.

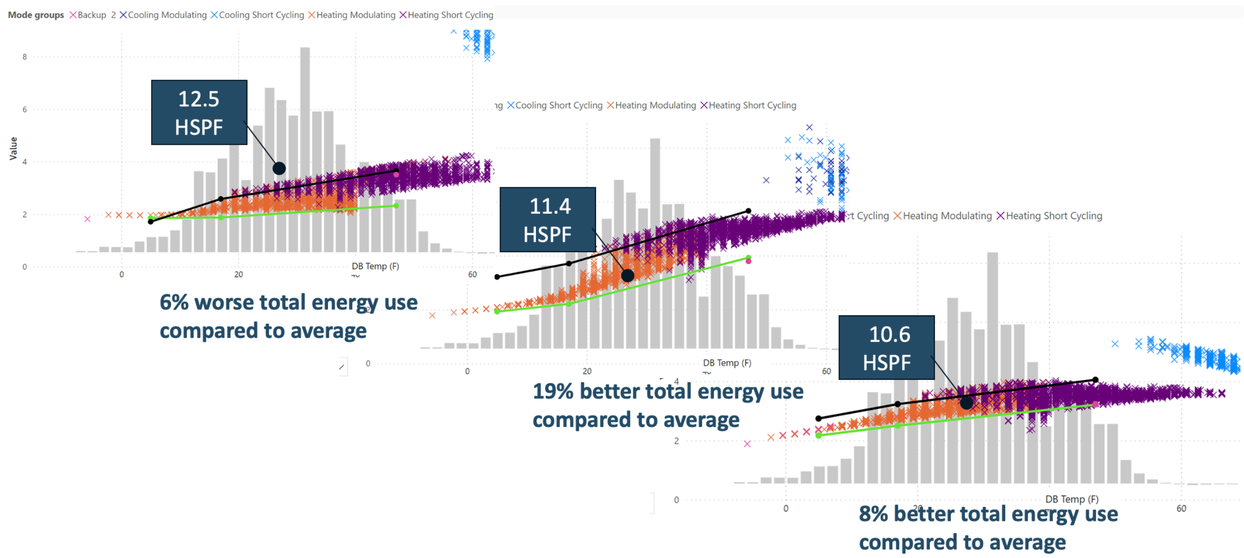

Figure 6: Detailed comparison of three heat pump performance

What this means is that the heat pumps being installed in programs have a wide variation in actual performance. Figure 7 shows that variability. The ccASHPs in the NEEP database were grouped based on their detailed performance characteristics. A sample of each group was simulated in a home in Ithaca and in Philadelphia. The relative performance of each sample equipment's total energy use was plotted relative to the average energy use for that group of ccASHPs. The blue line shows that performance from the least performing to the best performing in Ithaca. Overlaid is the orange line which shows the relative performance for the same group in Philadelphia. The fact that the orange line is so noisy shows that one cannot make assumptions about the performance of one heat pump from one location to the next. The noisiness of the orange line indicates the site-specific nature of the score. For example, there are several sets of ccASHPs (see red boxes) that are just above average performance in Ithaca, but those same heat pumps are 20% below average in Philadelphia. This can help explain why some customers are seeing higher energy bills after having heat pumps installed coming from anecdotal evidence talking to contractors. Customers are getting high bills because contractors rely on HSPF/HPSF2 and are influenced by incentives that are tied to HSPF or capacity maintenance or both. Neither of these numbers correlate well to the actual energy use by the homeowner.

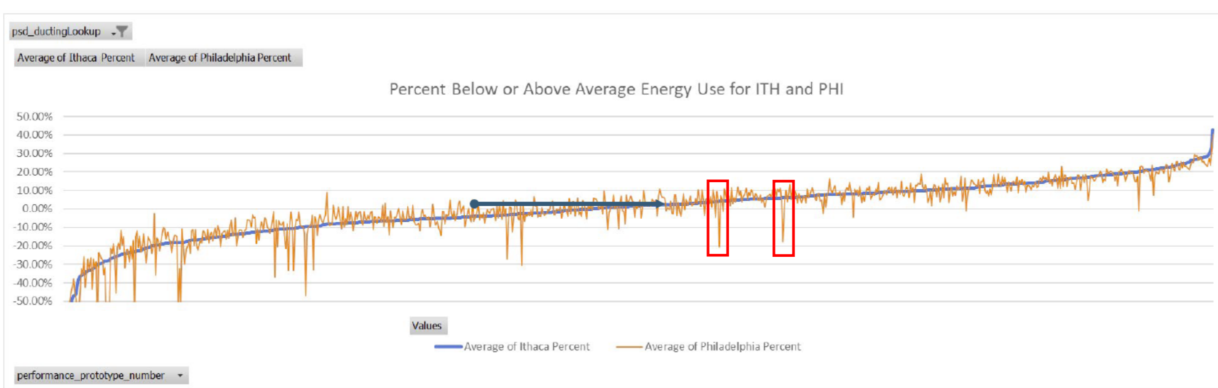

Figure 7: Distribution of ccASHP performance in Ithaca and Philadelphia

This information could be used in the proposal process as shown in Table 1. In this real example from the SFLX pilot, a landlord received three proposals for installing heat pumps. The first was well below the average cost, but the ccASHP performance was also well below average. The second shows a much better performing ccASHP, but the installation cost is nearly twice as much. The third is average in its ccASHP performance, and the cost is nearly as low as the first proposal. Incorporating both factors makes the third proposal the more cost-effective choice even though it is not the lowest cost or best performing ccASHP.

Table 1: Comparison of relative ccASHP performance to relative installation cost.

	Total Energy relative to average for that site	Proposed cost relative to average
Proposal 1 – Equipment A	+30%	77%
Proposal 2 – Equipment B	-5%	143%
Proposal 3 – Equipment C	+1%	80%

The fiscal impact of moving to even a slightly better heat pump is striking. A 5% improvement in the energy usage of a home that has a $2,000 annual electric bill comes out to nearly $1,500 in net present value using conservative values of 3% for fuel rate increase and discount rate and assuming a 15-year equipment lifetime.

$$Total\ NPV\ of\ energy\ savings\ = \sum_{year=1}^{lifetime} \frac{First\ year\ savings(1 + fuel\ rate\ increase)^{year}}{(1 + discount\ rate)^{year}}$$

When multiplied out across a program, the financial savings is staggering. For homes that are switching from gas equipment to ccASHPs, a change of the magnitude for Proposal 2 in Table 1 could make the decarbonization cost effective. This example was for a low-income property owner (the landlord and the tenants were all low income) where ensuring that switching to a heat pump does not adversely affect the utility bill is even more important. The upshot here is that picking the correct heat pump based on the expected heating/cooling load for that building in that location can easily make the difference in whether the decarbonization of that building is cost effective or not.

Observations of Human Factors Affecting LMI Rental Decarbonization

To install heat pumps in low-income rentals, significant levels of effort are necessary from three key groups, programs, landlords and renters, and retrofit contractors. The approaches to barriers to decarbonization and lessons learned here can help improve the rate of decarbonization in LMI rentals and help others reach even more households. The CEEP pilot project was designed in anticipation of significant barriers to electrification in 1-4-unit LMI rentals switching away from gas heating systems. Previous experience in the regional marketplace for residential energy efficiency, combined with interviews of local landlords, pointed to the need to address cost barriers, protection of tenants from increased housing costs, and tenant energy education. The pilot was designed in 2021 but was not funded and launched until 2023 when many market conditions were shifting. Additional factors involving constrained contractor capacity and obtaining the necessary work scope details became much larger barriers than anticipated.

Market Conditions

The economics of fuel switching can be difficult to predict. For homeowners this can be one of the most crucial factors in choosing to electrify. These financial decisions become even more difficult when landlords and renters are both part of the cost savings equation. The CEEP pilot was designed to stack additional incentives for heat pump systems on top of existing incentives from the state. Since fossil gas prices are much lower than other fossil fuels on a $ per MMBTU basis, the installation costs need to be lowered to have a favorable lifecycle cost comparison to installing another gas heating system. The proformas for this pilot program developed in 2021 using typical equipment and fuel prices were favorable to choosing a heat pump system. By 2023, the bid prices coming from installers had increased considerably, from a typical $3,000 HPWH to $5,500, and from about $6,000 per ton ASHP to $8-10,000 per ton. Despite the generous pilot subsidy, these price increases were far more than those for fossil fuel equipment, and the impact of the pilot's subsidy was diluted. Another cost differential blow came when the local utility won approval for a much higher increase in the price of electricity delivery than the price of gas delivery (66% vs 16%). Since the pilot required landlords to not pass along any price increases to their LMI tenants, the cost risk of switching to heat pumps would be borne by the landlords. As a result, several landlords who were initially interested decided that the impact on cash flow was too detrimental to their profitability expectations.

Contractor Infrastructure Capacity

Another challenge to the pilot was a scarcity of certified installers with the internal or partner-based capacity to do both envelope work and equipment installations. There are dozens of HVAC companies who have added heat pumps to their offerings, but a dwindling number of envelope specialists in the marketplace. Four of the potentially interested installers declined because either they were already booked out months in advance, or they did not have the capacity or desire to deal with the much heavier paperwork to access subsidies for lower-income customers. This scarcity limited the pool of participating installers in the pilot to effectively just three firms – those which are already servicing most of the existing market rate and LMI homeowner jobs in the region. Bids from the more established contractor with significant capacity to handle the paperwork were often substantially higher than other bids and were rejected by landlords. Thus, most of the jobs ended up with a smaller installer with lower bids but internal systems which bogged down almost immediately in terms of processing the paperwork for LMI occupants.

The pilot does ask for considerable tenant engagement in pre and post surveys, an online home energy workshop, and being willing to share their stories. The assumption being that the benefits they would receive in rent protection for two years, improved comfort, and greater knowledge would be sufficient to warrant their time investment. That has been true of several tenants who welcome the emission reductions, summer air conditioning, improved comfort and addressing of ventilation and mold issues. But in other cases, tenants employ elaborate avoidance techniques or a general disinterest in making themselves available for the pilot process. There is a need to better understand tenant motivations to drive program participation.

Project Proposals and Detailed Energy Modeling

Heat pumps are more complex than traditional heating systems like furnaces. Although they offer the potential for significant energy savings, if not sized correctly or if poor performing models are installed, the costs of operation can be higher than expected even to the point of making utility bills go up. To achieve the best possible outcome more detailed modeling is necessary to help contractors understand the impacts of envelope improvements on the overall building load and to more accurately size heat pumps to the proposed state of the building.

In collecting and reviewing the proposals from the contractors, the authors quickly determined that the load sizing data collected was less detailed than desired for improved heat pump sizing. The reasons for suggested envelope improvements were not clearly communicated and the predicted load reduction and energy reduction was equally unclear. Basic terms and information like system size in tons, indoor system type, and system AHRI number were routinely omitted when communicating to homeowners. Contractor Manual J's and program reports were collected as source inputs for more detailed energy modeling. Despite the participants being some of the best trained contractors in one of the best programs in the country, the inputs were not complete or detailed enough to produce the kind of detailed energy model needed to improve the sizing and performance of the majority of heat pump installs. Information needed for proper sizing and informed decision making was scattered across multiple locations, often with missing pieces.

Conclusion

Variable speed, cold-climate air source heat pumps are a critical tool in reducing carbon emissions from buildings, but they are much more complex than the equipment they are replacing. Understanding how a specific ccASHP behaves in the specific location of that building is critical to achieving the best outcome. The modeling approach as documented in the NY TRM shows alignment between the predicted and actual behavior of a specific heat pump at a specific location. This alignment provides increased confidence in performance and more security that there will not be any unexpected increase in utility costs once the heat pumps are installed. Conversely, not considering the detailed performance characteristics of ccASHPs when selecting equipment is effectively a roll of the dice as to whether the selected heat pump will actually lead to higher or lower energy bills.

Confidence in the performance predictions however is only one barrier to installation of ccASHPs. Market forces and building out a well-trained workforce provide considerable challenges to the widespread rollout of ccASHPs necessary to affect the impact of climate change. Decarbonization programs should seek to combine envelope improvements to reduce building loads with decarbonization via heat pumps and other electrification. For contractors that do not offer both envelope retrofit services and HVAC services, the process of developing relationships with other contractors to offer the full suite of services is challenging. Coordination of services, communication of proposed future states of the building and successful program navigation becomes even more complex when multiple contractors from different trades are involved.

In decarbonization states where multiple programs are operating to drive electrification at multiple levels, the market demand for contractors and heat pump installs can easily exceed the industry's capacity to meet the demand for installs. As a result, the unique requirements of a pilot or a new type of retrofit work can be difficult for contractors to prioritize when more familiar install opportunities abound. To mitigate this, software that can collect all the required data and make credentialed and predictions of performance can reduce risks by leveraging performance information in equipment selection to reduce risk of high bills.

In summary, national standards for rating heat pumps will not lead to desired results. Selecting the right equipment for a specific home retrofit is a very complicated process that most contractors are struggling with. The tool described in this paper provides a solution to help contractors pick the best equipment without disrupting the sales process so customers can get better performance out of heat pumps and build market confidence.

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