# ComEd Cold Climate Ductless Heat Pump Pilot

# Ductless Heat Pump Final Report

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**Prepared for: ComEd Energy Efficiency Program Emerging Technology**

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# 1 EXECUTIVE SUMMARY

CMC Energy Services, Inc. (CMC) is excited to present our findings for the ComEd Cold Climate Ductless Heat Pump (ccDHP) pilot and overall conclusions for expanding the pilot to more ComEd customers. The pilot was administered by CLEAResult and implemented by CMC Energy Services, Inc. (CMC). CMC project partners included Franklin Energy to identify and recruit buildings, Mitsubishi Electric to procure high performance ccDHPs, Four Seasons HVAC to install ccDHP units, and Mad Dash to provide sub-metering installation support, cellular services, and smart thermostat connectivity.

The ccDHP pilot tested displacement of resistance heat in income-eligible multifamily units with the use of ccDHPs. The specific research questions the pilot sought to address follow:

- Can ccDHP technology operate effectively to displace electric resistance heat in low- and moderate-income (LMI) multifamily buildings within the targeted climate zone?
- What is the overall energy impact for DHP technology in LMI multifamily buildings primarily using electric resistance heat?
- What is the field efficiency of ccDHP systems in harsh weather environments compared to rated efficiencies?
- What is the replicability of results and can these results be used to inform future program design while considering cost-effectiveness?

The CMC team installed 80 single-head or multi-head ccDHPs units in seven LMI multifamily buildings with existing electric baseboard heaters. The pilot was designed to test a variety of scenarios to determine how effective the ccDHPs are in the typically rugged Chicago winters. Following installation of the ccDHPs, CMC monitored systems and electricity usage and analyzed the results to determine the feasibility of extending the pilot to more homes. The analysis considered a variety of topics including cost, customer satisfaction with the heating and cooling system, effectiveness of the ccDHP in cold weather, cost-effectiveness testing and the ability to reduce costs for the DHPs through bulk purchasing and other means.

## 1.1 Key Findings

Of the 80 multifamily units, 78 were included in the final analysis. Two sites were removed due to inadequate pre-AMI data. CMC was able to correct for occupant turnover as unoccupied ranges were removed from the data set, accounting for those cases within this recommendation.

The pilot results indicate a weather-normalized mean heating energy impact for the 78 sites of 1,637 ± 547 kWh with a precision of 33.4 percent at 90 percent confidence. This equates to a mean percentage reduction of 24.56 percent across all sites. The effect of AMI pre-heating usage (defined for this pilot as pre-evaluation period AMI heating usage) was statistically significant and accounts for 28 percent of the variation in all heating energy impacts. Sites with a mean pre-heating value of less than 4,000 kWh had a mean normalized heating energy impact of -181 kWh. Twenty sites identified as having ideal ccDHP operation with low electric resistance heating had an overall reduction of 48 percent, with a mean heating energy impact of 2,728 kWh. These sites generally had similar characteristics as those across the entire pilot, indicating occupant behavior may have driven the more positive results. The polar vortex event had a moderate impact on the pilot, with a 2.2 percent more negative heating energy impact overall for 54 sites with adequate sub-metered data, compared to removal of the event from the dataset for sites. Overall electric resistance heat use during this event was highly variable.

There was a statistically significant relationship between post electric resistance and heating energy impacts, with electric resistance use accounting for 16 percent of the variation in heating energy impacts. Evaluation period electric resistance heating use was highly variable. 20 sites received ambient lock-out, with the rest of the participant apartments relying on customer education. Both were effective in specific scenarios, with ambient lock-out sites and some education-only sites showing above average heating energy impacts. However, the overall mean normalized heating energy impact for sites with lock-outs was 1,853 kWh, a 34 percent reduction, compared to 1,563 kWh for education-only, a 22 percent reduction.

Multi-head units showed a positive mean heating energy impact of 1,705 kWh, a 22 percent reduction, versus 1,621 kWh, a 25 percent overall reduction, for single-head systems. Multi-head installation sites had 19 percent higher pre-heating AMI usage. Linear regression predictive coefficients estimate that multi-head sites underperformed against predicted heating energy impact by 14 percent based on pre-heating AMI usage.

This aligns with lower coefficient of performance (COP) on these systems. There were instances where multi-head ccDHP units performed well, which may be a result of distribution or sizing issues in single-head applications. Calculated seasonal COP for all systems where sub-metered data was available was 2.36, where single-head system COP was 2.63 and multi-head systems were 1.47. This is a significant differential; overall system COP was slightly lower on single-head systems and significantly lower on multi-head units, than stated COPs.

Shell treatment was found to be a significant factor in energy savings performance. While the sole site treated with insulation and air sealing had a mean heating energy impact of 724 kWh, a 21 percent reduction, this was a result of low pre-heating AMI usage. Linear regression predictive coefficients estimate that the building exceeded predicted heating energy impact by 51 percent based on pre-heating AMI usage.

**Table 1. Pilot Summary Table**

| Site | Units | % Treat of Total Units at Site | Mean Normal Pre-Heat (kWh) | % with Lock-out | % with Multi-head | % with Shell Treat | Mean Normal Heat Energy Impact (kWh) | Precision @90% Confidence | Mean Seasonal COP | Mean Normal Cooling Energy Impact (kWh) | Mean SEER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Group 1** | **32** | **100%** | **5470** | **25%** | **38%** | **25%** | **1223** | **(±35.72%)** | **1.9** | **-190** | 16.7 |
| **1-A** | 8 | 100% | 7673 | 0% | 50% | 0% | 1429 | (±50.13%) | 1.7 | -223 | 13.2 |
| **1-B** | 8 | 100% | 3470 | 100% | 0% | 100% | 724 | (±91.38%) | 2.2 | 46 | 14.0 |
| **1-C** | 8 | 100% | 5706 | 0% | 100% | 0% | 814 | (±117.53%) | 1.4 | -372 | 17.1 |
| **1-D** | 8 | 100% | 5032 | 0% | 0% | 0% | 1925 | (±55.62%) | 2.6 | -127 | 20.3 |
| **Group 2** | **46** | **58%** | **7495** | **26%** | **7%** | **0%** | **1925** | **(±45.45%)** | **2.8** | **-363** | 16.5 |
| **2-A** | 15 | 50% | 10399 | 53% | 20% | 0% | 2476 | (±70.58%) | 2.4 | -415 | 15.8 |
| **2-B** | 15 | 100% | 8137 | 24% | 0% | 0% | 1812 | (±97.05%) | 3.3 | -135 | 20.2 |
| **2-C** | 16 | 50% | 4171 | 0% | 0% | 0% | 1514 | (±70.49%) | 2.5 | -567 | 13.8 |
| **All** | **78** | **72%** | **6664** | **25%** | **19%** | **10%** | **1637** | **(±33.43%)** | **2.3** | **-349** | 16.6 |

Where cooling is concerned, the DHP pilot provided a 50 percent increase in capacity. The mean cooling energy impact was negative for all sites in this study, with a mean energy impact of -349 kWh. The mean cooling energy impacts for sites beneath 500 kWh pre-cooling were negative. The mean SEER rating was 16.6, which is below stated SEER for ccDHPs installed. Small variations in seasonal baseload may have a minimal impact on heating and cooling energy impacts as a static baseload was used. The Calculation Methodology section explains the approach on determining baseload.

## 1.2 Summary of Recommendations

CMC recommends the expansion of the ccDHP pilot to a full-scale program. Based on equipment performance in the pilot, ccDHPs are a viable technology for the ComEd service territory. However, considering the relative complexity of ccDHP systems, selecting a manufacturer-distributor channel with a robust technical training infrastructure in place, as well as selecting at least two highly qualified HVAC installers that specialize in installing ccDHPs, will be essential for minimizing costs and maximizing the cost effectiveness of a full-scale program.

The following are specific recommendations for improved design and delivery of a full-scale program:

**Program Design**

- Require all buildings approved for DHP installation in a scaled program to meet a minimum of 4,000 kWh per unit mean pre-heat usage. This will ensure less variation in results and allow ComEd to bolster cost-effectiveness for the program overall.
- Include ambient lock-out technology as part of an expanded program because it can be a cost-effective addition to ensure the appropriate level of electric resistance displacement. CMC recommends calculating load profiles and plotting de-rated DHP capacity to determine the outdoor temperature at which the electric resistance can be energized via lock-out control. This would be in place of the pilot approach, which was to use a static ambient temperature (15°F) lock-out for the control devices on 20 of the 80 ccDHP systems. This approach may have the two-fold benefit of assured occupant comfort and safety, along with encouraging the least amount of electric resistance heating usage.
- Build a clear line-of-sight into the buildings within ComEd's territory that have electric resistance heat. While ComEd has multiple programs that touch on the targeted multifamily buildings that would benefit from ccDHPs, there does not appear to be a coordinated effort to compile that information. For example, Franklin Energy has been capturing this data (and electric water heating) during the last several years of multifamily work. Working collaboratively with ComEd, and other stakeholders, this data could be collected in a central repository that would assist program marketing campaigns and customer acquisition.
- Implement a full pre-qualification system using tools like Google Earth to grade sites (e.g., target specific suburbs, garden apartments, etc.). This will streamline the process and result in more qualified sites.
- Include a customer acquisition model where the HVAC contractor(s) joins the program energy advisors on site visits before buildings are fully admitted to the program. The ability to vet the specific building conditions and align with a suitable ccDHP application will increase the accuracy of pricing, efficiency of installation, and performance of the ccDHP systems
- Implement the program during off-peak (shoulder) months when HVAC contractors have more capacity. This will enable the contractor to keep their crews on staff and engaged, without requiring layoffs. It also will lower program costs as many HVAC contractors reduce their prices during off-peak periods by 5-10 percent. A full-scale program should also consider schedule incentives for the property owners as well. Encouraging the work to be completed during the off-peak period is less impactful for tenants and contractors so a project discount, gift card promotion or credit to utility bill should be considered in exchange for off-peak scheduling.

- Consider alternate ccDHP manufacturers, as well as establish a competitive bid process to award multiple contractors. Having multiple contractors engaged through this bid process not only generates an opportunity for competitive pricing, but also provides redundancy should one of the HVAC contractors have performance or capacity issues

**Program Delivery**

- Include shell retrofits—or weatherization—to make ccDHP installation sites heat pump ready. This should include insulation whenever possible.
- Allow for time to correct/adjust building conditions prior to participation. For example, during the preliminary qualification for a ccDHP program participant, if electrical panel upgrades, pre-existing code violations, health and safety concerns have been documented, they should be addressed before proceeding with the ccDHP project. This will improve the speed of ccDHP installations and the readiness of facilities.
- Focus the sales process on property managers as opposed to tenants. Property managers would have a more marketable property with the upgraded technology, and that could lead to less tenant turn-over. Income-eligible customers typically may have less interest or financial incentive to participate in a ccDHP program because many are on fixed energy rates.
- Incorporate additional on-site instruction and leave behind materials with the tenants and property managers to enhance the overall customer experience. Many of the tenants' issues were behavioral so instruction on proper DHP operation is critical. In addition, the high rate of turnover in tenants and property managers warrants the need for leave-behind materials, and re-education for new residents. Finally, regular educational messaging to tenants could solidify the energy savings possibilities of ccDHPs.

# 2 INTRODUCTION AND METHODOLOGY

## 2.1 Pilot Background

CMC had three primary goals for this pilot, as noted below. We worked collaboratively with ComEd and CLEAResult to modify or customize these goals during pilot launch and throughout implementation as needed.

1. Design the pilot to test displacement of resistance heat in income-eligible, multifamily apartments with the use of high-performance ccDHPs. Critical design tasks included leveraging rich partner data for engineering analysis and examination of similar successful pilots, as well as utilizing our ComEd territory building models to understand common building characteristics.
2. Identify qualified buildings, complete an energy assessment and site survey, install ccDHPs in

customer homes using our existing local staff, educate customers and property owners/managers on the ccDHP, monitor ccDHP performance, resolve customer issues and measure customer interaction and satisfaction through customer satisfaction surveys.

3. Analyze data such as energy savings, ccDHP performance levels to provide viability for potential pilot expansion, savings and cost recommendations for a full-scale program.

The pilot's project path had two distinct phases:

- Phase 1 covered the tasks above.
- Phase 2 of the project involved data gathering, project performance analysis and final pilot scalability recommendations.

One of the pilot's biggest challenges was the truncated timeline for ccDHP installation. Within a three-month window, CMC and our support team identified seven buildings for pilot participation, secured the necessary equipment and installed ccDHPs in all 80 of the proposed multifamily apartments—all during the height of HVAC busy season.

## 2.2 Project Team

CMC chose four well-qualified partners to conduct the pilot:

- Franklin Energy to help identify and recruit potential buildings
- Mitsubishi Electric to procure high-performance ccDHPs in the short installation window and provide access to their Diamond Contractor network
- Four Seasons HVAC, a Mitsubishi Diamond Contractor, to install ccDHP units
- Mad Dash to provide sub-metering installation support, cellular services and smart thermostat connectivity

We also coordinated with Navigant to facilitate analysis of the existing Illinois Technical Reference Manual (TRM), evaluate the effectiveness of weatherization to the one building chosen for that treatment and conduct an impact evaluation.

## 2.3 Pilot Design

The primary research question driving pilot design is: Can ccDHP technology operate effectively to displace electric resistance heat in LMI multifamily buildings within the targeted climate zone?

This question can only be answered by investigating additional, critical underlying questions:

- What is the overall energy impact for ccDHP technology in LMI multifamily buildings primarily using electric resistance heat?

- What is the field efficiency of ccDHP systems in harsh weather environments compared to rated efficiencies?
- What is the replicability of results and can these results be used to inform future program design while considering cost-effectiveness?

### 2.3.1 Population

The target area was the ComEd territory, which contains the target population of an estimated 48,000 income-eligible, individually metered multifamily homes with electric resistance heating. Based on the ComEd-established target of 80 units installed, CMC sought to create a sample that would be representative of LMI multifamily buildings in the target area to ensure scalability. We utilized our ComEd territory building models to understand common building characteristics and reviewed more than three dozen prior DHP studies to help inform the design process.

CMC also leveraged partnerships with existing multifamily energy efficiency (EE) program implementers in the target area, combined with additional marketing analysis, to develop an initial limited sampling frame that included thousands of known buildings. We then segmented the buildings into geographic areas identified by ComEd as low-income.

### 2.3.2 Sample Groups

Of the available buildings that met basic design criteria of geographically appropriate LMI multifamily housing, CMC further filtered results by searching for buildings with electric resistance baseboard heat and likely single-zone window or through-the-wall air conditioning. Low-rise buildings were of particular interest to this study, as a large portion of the Chicago area's multifamily buildings are low-rise structures. For instance, in Brighton Park, New City and South Lawndale, 2-4 apartment low-rise buildings account for up to 70 percent of all apartment types. Larger rental buildings, over 50 apartments, account for only eight percent of the housing units in Chicago and only two percent in Cook County[1]. High-rise buildings were omitted from the sample due to the small scale of this pilot, the higher potential cost for installation in these buildings and the low percentage across the target territory. CMC then analyzed building age, stories above grade, building construction, and mean living area to develop two potential sample groups.

The sampling design divided potential treatment sites into strata with specific characteristics that aligned with the pilot goals and adequately represented the population. Sample group one design consisted of four small low-rise apartment buildings, all two stories, with 10 apartments in each building. Sample group two design consisted of three large low-rise apartment buildings, two or three stories, with 20 apartments in each building.

In addition to building type and general electric resistance displacement analysis, CMC added several

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[1] DePaul University, 2014

additional testing elements to each sample group based on consultation with ComEd and third-party evaluator, Navigant, to create a meaningful basis and the most opportunity for planned analyses. This included an early decision to leave existing electric resistance heat in all the apartments as a supplemental backup. This was done to ensure occupant safety as well as to align with likely future real-world conditions and corresponding program guidelines. In addition, CMC paired the existing resistance heat with lock-out controls (in 20 apartments in three separate buildings) that were set to only allow electric resistance heating to be energized when outdoor ambient temperatures dropped below 15°F. These elements expanded upon the initial research question to consider the additional variables that are important to any scaled programs. Specifically, what is the energy impact of:

- Education-only approach versus ambient temperature lock-out devices for supplemental electric resistance heat. Education-only, briefly, means residents only received information about the ccDHP unit without any additional measures to prevent the residents from using the supplemental electric resistance heat.
- Multi-head versus single-head installations
- Building shell treatment completed in coordination with ccDHP installations
- Single-zoned air conditioning displacement or no existing air conditioning

The final pilot design, shown in Table 2, provided the necessary samples within the 80-sample limit to test the key research questions with comprehensive data analysis.

**Table 2. Initial Pilot Design**

| Sample Group | Site | Target Units | % of Units Treated | % with Multi-head | % with Shell Treatment | % with Lock-out |
|---|---|---|---|---|---|---|
| | **Small Low-Rise (2 Stories Above Grade)** | | | | | |
| Sample Group 1 | 1-A | 10/ 10 | 100% | 50% | 0% | 0% |
| | 1-B | 10/ 10 | 100% | 0% | 100% | 100% |
| | 1-C | 10/ 10 | 100% | 100% | 0% | 0% |
| | 1-D | 10/ 10 | 100% | 0% | 0% | 0% |
| | **Large Low-Rise (3 Stories Above Grade)** | | | | | |
| Sample Group 2 | 2-A | 10/ 20 | 50% | 25% | 0% | 50% |
| | 2-B | 20/ 20 | 100% | 0% | 0% | 25% |
| | 2-C | 10/ 20 | 50% | 0% | 0% | 0% |

## 2.4 Sampling Methodology

### 2.4.1 Overview

The CMC team recognized the need to make generalizations about a very specific population, even though probability sampling was determined to be unfeasible and undesirable for the pilot study. The research team employed a non-probability purposive sampling, which was selected due to the research questions and goals posed for the pilot study and to develop a profile for what may be commonly found when ccDHPs are introduced to LMI multifamily buildings as displacement technology. While there are strata involved, the strata were not mutually exclusive, i.e., a single-head DHP system could exist in a building with shell treatment, only 50 percent of single-head ccDHP systems within the same building may have had ambient lock-out systems, etc. As such, it is not a non-probabilistic stratified, or quota, sample.

This sampling plan is representative of typical case purposive sampling in that CMC selected the apartments to be studied to compare findings with other similar ccDHP application scenarios, along with expected outcomes. This provides a basis for reliability in the study approach. Based on this approach, CMC examined the pool of available buildings derived from market research and selected those most appropriate to the pilot design for inclusion in the study. CMC actively sought to control bias based on factors such as time and cost, though sampling bias in non-probability sampling is possible and must be acknowledged as a potential limitation or influence.

### 2.4.2 Statistical Inference

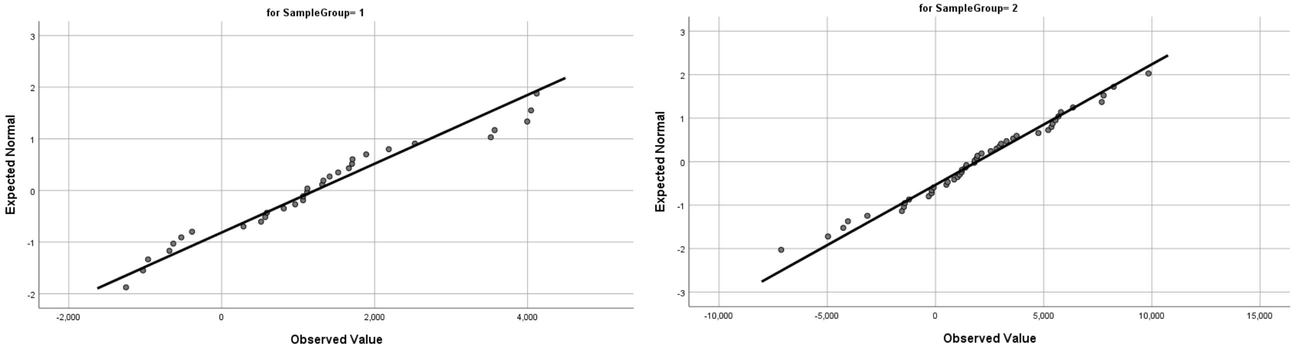
The goal for the sample design results was a 90 percent confidence level with a +/- 20 percent precision and +/-25 percent for subsets. Non-probability sampling may generally limit the statistical inferences made about the behavior of the general population of multifamily occupants utilizing DHP technology. However, analysis of energy impacts and the technology's performance will be extremely useful in developing scaled programs. In addition, non-probability sampling does not preclude a calculation of the probability of the test samples taken when the results are normally distributed, which was the anticipated outcome based on pre-pilot energy modeling. CMC performed a Shapiro-Wilk test of normality on the overall resulting heating energy impacts and found the results to have a significance of >0.05, indicating the results are normally distributed. See Table 3. In this case, percentage confidence becomes applicable.

**Table 3. Test of Normal Distribution of Results**

| | Sample Group | Statistic | Df | Sig. |
|---|---|---|---|---|
| **Normalized Heating Energy Impact (Pre – Post)** | 1 | .946 | 32 | .110 |
| | 2 | .987 | 46 | .889 |

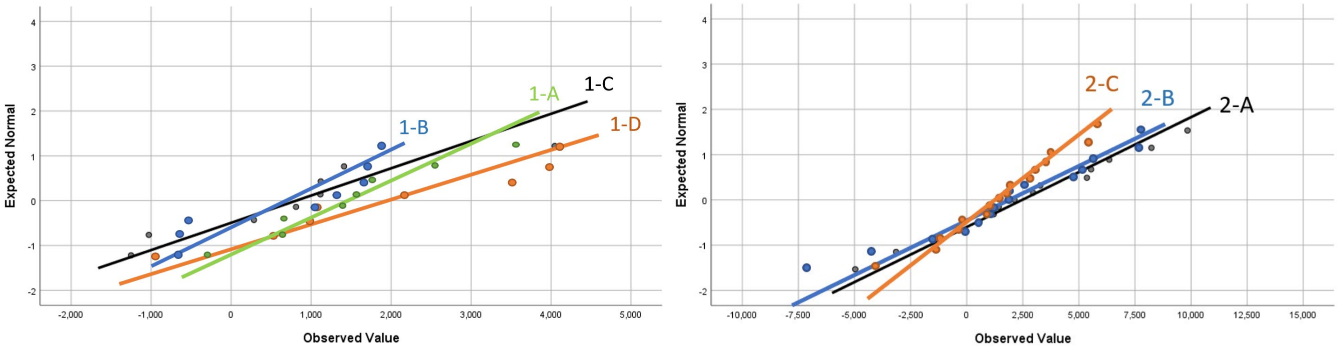
The quantile-quantile (Q-Q) plots found in Figure 1 demonstrate the results of the pilot for both sample groups fall into a normal distribution.

**Figure 1. Plot of Normalized Heating Energy Impacts – Sample Groups 1 and 2**



The heating energy impacts of each building subset also fall into a normal distribution, with only site 1-B not reaching significance, with normality testing at the 0.03 level. Figure 2 illustrates the distributions.

**Figure 2. Plot of Normalized Heating Energy Impacts – Building Subsets**



## 2.4.3 Sample Acquisition

CMC designed an outreach plan to engage buildings in each sample group. Section 2.5 discusses the plan's details.

- The final acquired sample group one consisted of four small, low-rise apartment buildings, all two stories, with eight apartments in each. The mean total living area in these buildings was approximately 5,000 square feet.
- The final acquired sample group two consisted of three large, low-rise apartment buildings, two or three stories, with between 17 and 32 apartments in each. The approximate mean living area in these buildings was 15,000 square feet. Apartments within sample group two were approximately 11.2 percent larger by mean square foot for each apartment.

The final percentage of treatments, by building site, of various pilot elements for the sample set can be found in Table 4 below.

**Table 4. Final Sample Set Treatments**

| Site | Address | Total Units at Site | Units Treated | % of Units in Analysis | Est. Shell Perform- Prior to Treat | Mean Unit Area (SQ FT) | % with Multi-head | % with Shell Treat | % with Lock-out |
|---|---|---|---|---|---|---|---|---|---|
| **1-A** | Grand Avenue, Waukegan, IL | 8 | 8 | 100% | Average | 507 | 50% | 0% | 0% |
| **1-B** | Lewis Avenue, Waukegan, IL | 8 | 8 | 100% | Poor | 600 | 0% | 100% | 100% |
| **1-C** | Centennial Court, Gurnee, IL | 8 | 8 | 100% | Good | 550 | 100% | 0% | 0% |
| **1-D** | 147th Street, Harvey, IL | 8 | 8 | 100% | Average | 400 | 0% | 0% | 0% |
| **2-A** | S. Bennett, Chicago, IL | 30 | 15 | 100% | Poor | 707 | 20% | 0% | 53% |
| **2-B** | 70th Street, Chicago, IL | 17 | 17 | 88% | Average | 622 | 0% | 0% | 24% |
| **2-C** | 16th Street, Zion, IL | 32 | 16 | 100% | Average | 400 | 0% | 0% | 0% |
| **All** | | **111** | **80** | **98%** | | **549** | **19%** | **10%** | **25%** |

### *Site Overview 1-A: Grand Avenue*

Waukegan, IL

The property is a two-story building with eight one-bedroom apartments located in Northern Illinois. We installed four single-head ccDHP units and four multi-head units in all eight apartments. The building was owner-operated and, although old with very little insulation, it was well maintained with very little tenant turnover. The owner was very involved throughout the project and was interested in retaining his tenants. This building allowed for a rather simple DHP install with minimal ladder work and outdoor units attached to exterior walls. Overall, tenants were interested in education and the building owners' involvement helped gain access to apartments for all necessary appointments.

### *Site Overview 1-B: Lewis Avenue*

Waukegan, IL

The property is a two-story building with eight apartments consisting of two-bedroom apartments located in Northern Illinois. We installed single-head ccDHPs in all eight apartments and provided transfer grills to the bedrooms from the main living space. The property is owner-operated and in fair condition but with minimal insulation. This evaluation prompted CMC to insulate and air seal as part of the pilot project. During the education process, the owners agreed to disconnect the wall air conditioners in the main living space, leaving the bedroom air conditioners to cool those spaces. As observed by our senior energy advisor (SEA), the tenants were overall receptive to the new heating and cooling systems and open to energy education.

### *Site Overview 1-C: Centennial Court*

Gurnee, Illinois

The property is a two-story building with eight two-bedroom apartments located in Northern Illinois. We installed multi-zone ccDHPs in each apartment with one indoor unit in the main space and another in the master bedroom with transfer grills installed for the second bedroom. The building was owner-operated, and the property was sold during the pilot program. The building was in overall good condition and the tenants were open to education and the idea of increased comfort and energy savings.

### *Site Overview 1-D: 147th Street*

Harvey, IL

This is a two-story building with eight total housing units located in a southern suburb of Chicago. We installed eight single-head ccDHP units in the main living space of each apartment. This building is in a high crime area and required the installation of protective security cages on the outdoor units. Customers were apprehensive about the new ccDHPs and, overall, not interested in education about the operation of their new heating and cooling systems. The building owner became very disconnected once the installation was completed and seemed uninterested in the tenants' needs.

### *Site Overview 2-A: South Bennett Avenue*

Chicago, IL

This property is a three-story building with 30 housing units composed of one-, two-, and three-bedroom apartments located in the southside of Chicago. We installed 12 single-head ccDHP units for the one- and two-bedroom apartments and three multi-head units for the three-bedroom apartments. For the larger apartments, ccDHPs were installed in the main living space and a second indoor unit was located in the master bedroom with bypass grills to the adjoining room. The building owner demonstrated interest in the tenants' comfort and savings as they had participated in other EE programs offered by ComEd in the city. However, the building was in overall poor condition with many air leaks and poor insulation. We noted a high rate of tenant turnover during the pilot program including some move-outs during the installation and start-up phase.

### *Site Overview 2-B: 70th Street*

Chicago, IL

The property is a three-story building with 17 apartments located in the southside of Chicago consisting of one- and two- bedroom units. This building was in a high crime area and the property manager decided to have security cages installed. Due to the building's construction, all outdoor units were installed in the courtyard, which required the property manager to relocate shrubs for ccDHP placement. Seventeen single-head ccDHP units, one in each apartment, were installed with transfer grills installed from the main living space to the bedroom(s). Many of the tenants were uninterested in energy education and demonstrated mistrust of the utility and the project. The building shell was in overall poor condition and our SEA observed frequent tenant turnover.

### *Site Overview 2-C: Zion*

Zion, IL

This property is a two-story building with 32 apartments consisting of studio and one-bedroom units located in Northern Illinois. CMC installed 16 single-head ccDHP units. This property was owner operated. According to CMC's SEA, tenants were overall open to education about the ccDHPs. The property owner seemed interested in the pilot program and the idea of her tenants feeling more comfortable while saving money.

## 2.5 Delivery

Due to the tight installation timeline and challenges of finding suitable mid-rise building participants, modifications were approved by ComEd to remove mid-rise buildings from the pilot, and CMC focused on securing appropriate low-rise multifamily buildings. The pilot modifications helped ensure a successful Phase One pilot implementation and a seamless launch and roll out. To further identify and engage qualified buildings and property owners for pilot success, CMC and our partners executed the following plan.

### 2.5.1 Marketing Plan

CMC and its partners utilized a Salesforce database to access past energy efficiency program participants for potential ccDHP pilot program matches based on the sampling plan. In addition, ComEd provided pre-approved income-eligible areas by ZIP Code. We leveraged this data to begin our outreach process. Properties were filtered based upon key criteria such as eligible ZIP Code, building type, electric resistance heat and past program participation. The team then cold-called, emailed and visited property decision makers.

Ideally, appointments were scheduled, but to expedite pilot communications, CMC's SEA also made "drop in" visits if calls and emails were not returned. As CMC and Franklin Energy joined forces to conduct field visits, we also canvassed neighboring properties to expand the pool of potential pilot participants.

**CMC Senior Energy Advisor (SEA) Anthony Tortomasi, above, served as the project lead for the ComEd pilot.**

During our outreach process, CMC's SEA utilized an information sheet, provided in Appendix A - Field Materials, to share information about the pilot program and ccDHP technology with potential participants. If the property manager expressed interest after meeting with the SEA and learning about the program, a site assessment was scheduled.

### 2.5.2 Site Assessments

Representatives from CMC, Franklin Energy, Four Seasons HVAC and Mad Dash evaluated sites, including determining the appropriate-sized ccDHP unit for the dwelling, based upon the program parameters defined in the sampling plan as well as their ability to install the systems and associated materials, such as sub-metering and smart thermostats, in an optimal way. Overall, 13 site assessments were conducted. Six sites were deemed not fit; seven sites matched the pilot design criteria.

Sites were rejected primarily due to logistical issues, such as:

- Limited roof access and/or crane may be required for outdoor unit installation
- Roof not under warranty and roof repair costly
- Inability to run refrigerant line set/electrical conduit behind walls
- Exposed tubing not acceptable to owner
- Interior apartments lacked floor plan needed for optimal equipment mounting and functionality

If installation was approved, the team conducted a more detailed walk-through to provide participants a deeper explanation about the ccDHPs, installation details and preliminary usage information. Some items considered and reviewed for a “go” installation were marking the smart thermostat’s location, electrical panel, ccDHP head, line set, condenser and bypass grills; access to units, securing of pets and informing tenants; and wall penetrations and parties responsible for patching/repair, if needed.

Equipment installation followed the below process:

1. Landlord and/or property manager approved
2. Scope of work approved, and installation date scheduled
3. Property manager notified of installation date and tenants given 48-hour notification
4. Coordination with roofing contractor when appropriate
5. Day of installation:
    a. Property manager received reminder/notification
    b. Crew lead coordinated with maintenance contact
    c. Lay down equipment/prep
    d. Clean up and system start-up

Same-day installations by Mad Dash were not always possible. For example, if too many people were be on-site at the same time or if the installation crews finished late in the day, Mad Dash would return on another day to install a cellular modem and eGauge and to connect a smart thermostat while the SEA conducted customer follow-up and education.

QA/QC test-out occurred at installation completion. Four Seasons HVAC utilized manufacturer-provided checklists to fully commission and check post-installation, under CMC supervision. The QA/QC process included:

- System start up by CMC's SEA, including educating customers on system functionality
- Performed between install and education
- Additional customer surveys

### 2.5.3 Customer and Property Manager Education/Start Up

To provide pilot education and help complete installation start up, CMC created and provided educational materials, conducted equipment trainings, and performed QA/QC inspections. Tenants and the maintenance team were trained on system functionality and routine maintenance (such as filter replacement). Mad Dash provided demonstrations on ecobee smart thermostat functionality as well, including heating and cooling functionality and use.

Educational material copies are provided in Appendix B – Tenant Educational Materials.

# 3 DATA GATHERING AND ANALYSIS

## 3.1 Data Gathering

During Phase 1, CMC started collecting quantitative and qualitative data to measure pilot program results and success for the selected sub-metered 80 apartment units across seven sites. The three primary sources of quantitative raw data were ComEd's advanced metering infrastructure (AMIs), ecobee smart thermostats, and eGauge submeters.

### 3.1.1 Datasets

The analysis is based on data monitored and collected via cellular modem or downloaded directly on site. The data types can be found in Table 5.

**Table 5. Interval Data Types**

| Dataset | Data Point | Symbol | Unit | Interval |
|---|---|---|---|---|
| **Electric Utility AMI** | Utility Electricity Use | WB | kWh | 30-minute |
| **Sub-meter** | Heat Pump Electricity Use<br>Electric Resistance (Strip) Heat Electricity Use | HP<br>STRIP | kWh<br>kWh | 15- minute |
| **Smart Thermostat** | Set points, mode and site conditions | EB | Varies | 15- minute |

AMI usage data and specific data points, collected by sub-metering equipment and smart thermostats, were used to form the basis of a variety of analyses. These data points can be found below in Table 6. Not all sub-metered and smart thermostat data points were necessary for all proposed types analyses, though they were collected to provide flexibility as the evaluation phase developed. The research team initially had difficulty in accessing data remotely, which was later remedied through labor-intensive on-site data pulls. This on-site effort was further stymied by tenant and property management/ownership turnover, though no site was omitted due to inaccessible sub-meter or thermostat data.

**Table 6. Sub-meter and Smart Thermostat Data Points**

| Heat Pump - Sub-metered Data | Smart Thermostat Data |
|---|---|
| L1 Voltage [Vs] | System Mode |
| L2 Voltage [Vs] | Program Mode |
| Heat Pump Amp - Input [As] | Cool/Heat Set Temp (F) |
| Resistance Amp - Input [As] | Indoor Current Temp (F) |
| Heat Pump Power [kWh] | Indoor Current Humidity (%RH) |
| Heat Pump Power* [kVAh] | Outdoor Current Temp (F) |
| Resistance Power [kWh] | Outdoor Current Humidity (%RH) |
| Resistance Power* [kVAh] | Cool Stage 1/2 (sec) |
| Heat Pump PF [s] | Heat Stage 1/2 (sec) |
| Resistance PF [s] | Fan (sec) |

## 3.1.2 Climate Data

CMC weather-normalized the study results to incorporate the variability in climate and weather conditions between the study and during the typical year. This weather-normalization requires additional external data. As shown in Table 7, data was collected from the National Oceanic and Atmospheric Administration (NOAA) and the weather station closest to the study sites.

**Table 7. Additional Data Types**

| Dataset | Data Point | Symbol | Unit | Interval |
|---|---|---|---|---|
| **NOAA Weather** | Daily average ambient temperature | TAO(d) | Deg. F | daily |
| **NOAA Degree Day** | Heating degree day<br>Cooling degree day | HDD(d)<br>CDD(d) | | daily |
| **TMY3**[2] | TMY daily average ambient temperature | TMY(d) | Deg. F | daily |

The weather for the 2019 evaluation period experienced a higher number of heating degree-days

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[2] Source: National Solar Radiation Data Base, 1991- 2005 Update: Typical Meteorological Year 3, Site Number: 725300, Site Location: Chicago O'Hare Intl AP, https://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html#I

(HDD) than 2018, though it also experienced fewer cooling degree-days (CDD). The weather data for the pilot study can be seen below in Table 8. January 2019 experienced a climate anomaly in a polar vortex sub-freezing event. This event is the subject of additional analysis later in this study.

**Table 8. Climate During the Pilot Study – HDD and CDD**

| 2018 | HDD | CDD | 2019 | HDD | CDD |
|---|---|---|---|---|---|
| **Jan-18** | 1231 | 0 | **Jan-19** | 1358[3] | 0 |
| **Feb-18** | 1002 | 0 | **Feb-19** | 1083 | 0 |
| **Mar-18** | 879 | 0 | **Mar-19** | 944 | 0 |
| **Apr-18** | 717 | 6 | **Apr-19** | 486 | 15 |
| **May-18** | 137 | 165 | **May-19** | 283 | 55 |
| **Jun-18** | 34 | 220 | **Jun-19** | 74 | 149 |
| **Jul-18** | 3 | 352 | **Jul-19** | 4 | 373 |
| **Aug-18** | 4 | 343 | **Aug-19** | 10 | 248 |
| **Sep-18** | 66 | 183 | **Sep-19** | 29 | 159 |
| **Oct-18** | 426 | 39 | **Oct-19** | 452 | 19 |
| **Nov-18** | 908 | 0 | **Nov-19** | 912 | 0 |
| **Dec-18** | 996 | 0 | **Dec-19** | 951 | 0 |
| **All CY** | **6403** | **1308** | **All CY** | **6586** | **1018** |

## 3.2 Performance Analysis

### 3.2.1 Heating Energy Impacts

There were 111 total housing units across seven sites, of which 80 (72 percent) were treated through the pilot program. 78 housing units were able to be included in the study analysis (98 percent). Two were removed from the data set due to missing pre-AMI usage data. 54 were analyzed using the primary energy impact methodology, while 24 were analyzed using alternative calculations described in the methodology section. Energy impacts were determined using site information and the calculations provided, and do not include generation or transmission losses. The impacts also do not examine quantitative financial impact on individual occupants, in part or in aggregate.

Heating energy impacts were found to be on the mid- to lower end of mean heating energy impacts for available studies, though fewer focused exclusively on multifamily applications. Impacts also were lower than the estimated first-year savings calculated through the Illinois TRM, which had a mean heating reduction for the sites in the study of 3,721 kWh. Multifamily housing units have, on average,

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[3] Polar vortex

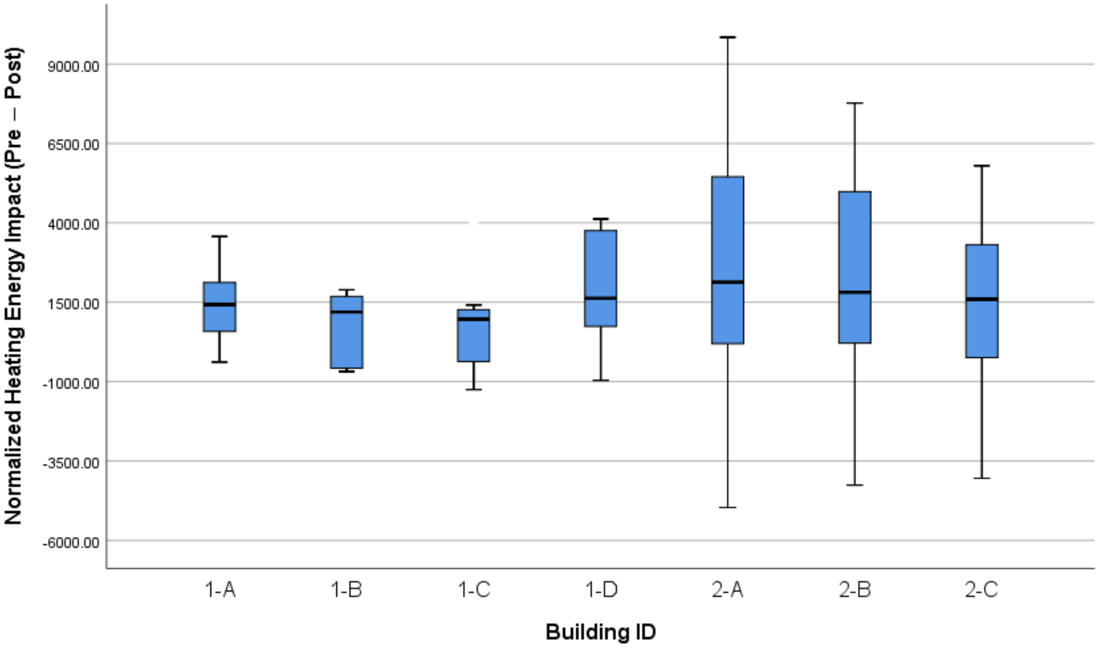
lower heating loads than single-family residential buildings, though not in every case. The results indicate a weather-normalized mean heating energy impact per unit for the pilot of 1,637 kWh +/- 547 with a precision of 33.4 percent at 90 percent confidence. This equates to a mean percentage reduction of 24.56 percent across all pilot participant sites. The results for all subsets can be found below in Table 9.

**Table 9. Heating Energy Impact Summary**

| Site | Units | % Treat of Total Units at Site | Mean Area (SQ FT) | Mean Normal Pre-heat (kWh) | % with Lock-out | % with Multi-head | % with Shell Treat | Mean Normal Heat Energy Impact (kWh) | % Mean Heating Red | Stand Error Mean (kWh) | Precision @90% Confidence |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Group 1** | **32** | **100%** | **514** | **5470** | **25%** | **38%** | **25%** | **1223** | **22%** | **437** | **(±35.72%)** |
| **1-A** | 8 | 100% | 507 | 7673 | 0% | 50% | 0% | 1429 | 19% | 716 | (±50.13%) |
| **1-B** | 8 | 100% | 600 | 3470 | 100% | 0% | 100% | 724 | 21% | 662 | (±91.38%) |
| **1-C** | 8 | 100% | 550 | 5706 | 0% | 100% | 0% | 814 | 14% | 956 | (±117.53%) |
| **1-D** | 8 | 100% | 400 | 5032 | 0% | 0% | 0% | 1925 | 38% | 1070 | (±55.62%) |
| **Group 2** | **46** | **58%** | **572** | **7495** | **26%** | **7%** | **0%** | **1925** | **26%** | **875** | **(±45.45%)** |
| **2-A** | 15 | 50% | 707 | 10399 | 53% | 20% | 0% | 2476 | 24% | 1748 | (±70.58%) |
| **2-B** | 15 | 100% | 622 | 8137 | 24% | 0% | 0% | 1812 | 22% | 1759 | (±97.05%) |
| **2-C** | 16 | 50% | 400 | 4171 | 0% | 0% | 0% | 1514 | 36% | 1067 | (±70.49%) |
| **All** | **78** | **72%** | **549** | **6664** | **25%** | **19%** | **10%** | **1637** | **25%** | **547** | **(±33.43%)** |

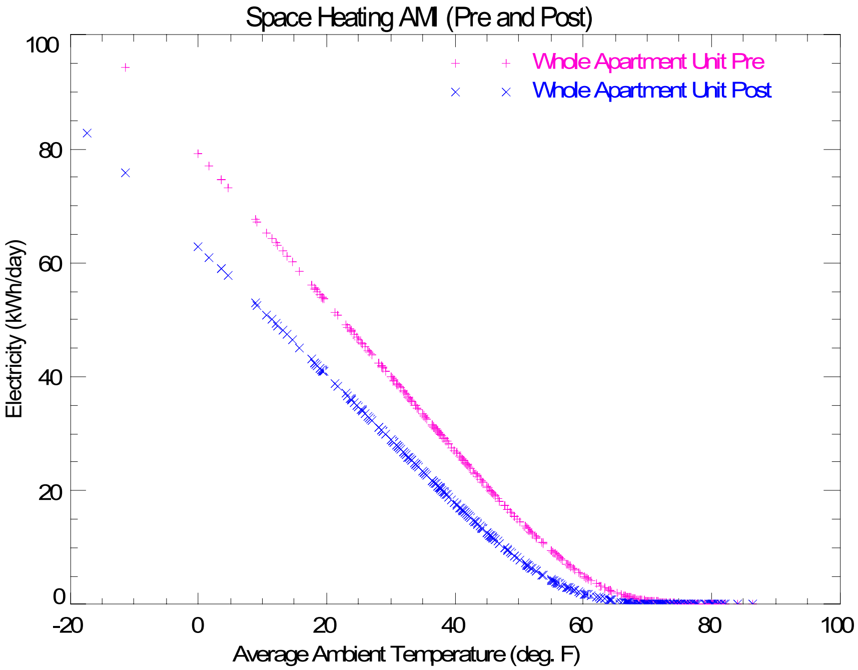
The evaluation team found a high level of variability between sites, including for energy impacts, hours of use, continued resistance baseboard use and settings, and finally on heating energy impacts, which may account for higher error (less precise) in the results. As noted in the methodology section, the use of static baseload, thereby not accounting for seasonal changes in non-heating plug load, may have a minor impact on heating energy results. Of the 78 sites analyzed, 58 had positive heating energy impacts, while 20 showed negative energy impacts. The stem and leaf plot of heating energy impacts is shown in Figure 3.

**Figure 3. Heating Energy Impact Variation Stem and Leaf Plot**



The apartment pre- and post-AMI versus temperature plot in Figure 4 shows the overall reduction of usage across all sites. In the plot below, for each ambient temperature degree during the heating season, the total consumption across all sites is shown.

**Figure 4. Pre and Post AMI and Temperature Plot**



A topical review of the results shows a complex picture with many variables to consider. Certain results, such as multi-head applications, appear to show a clearly less positive energy impact for these systems. This is evidenced by sites with the highest percentage of multi-head units demonstrating the least positive energy outcomes. An example is site 1-C, a site with moderate pre usage and 100 percent multi-head application, which demonstrated the least positive reduction percentage. A closer look at the comparison between single- and multi-head units, discussed later in the report, indicates a more nuanced result. This includes more positive energy impacts for multi-head systems in specific scenarios. Another initial observation would indicate that Site 1-B, with 100 percent lock-out and shell treatment, showed only moderate reduction at 21 percent. However, the site also had the least amount of pre-heat usage, which is a critical value in heating energy impacts.

### 3.2.2 Sites with Ideal DHP Operation

There were 20 units identified where CMC researchers identified a strong ccDHP heating trend with some or no supplemental electric resistance as temperatures decreased. These units were coded as ideal scenarios. While the mean AMI pre-heating usage was very similar to the overall pilot results, the overall percentage reduction was significantly higher at 48 percent with a mean heating energy impact of 2,728 kWh. The ratio of pilot variables, such as number of lock-outs, was also very similar to the wider sample. This indicates that occupant behavior is a key to a successful scaled program. The results of the comparison for this group can be found in Table 10 below.

**Table 10. Heating Energy Impact Summary – Ideal ccDHP Operation**

| Site | Units | Mean Area (SQ FT) | Mean Normal Pre- heat (kWh) | % with Lock-out | % with Multi-head | % with Shell Treat | Mean Normal Heat Energy Impact (kWh) | % Mean Heating Red |
|---|---|---|---|---|---|---|---|---|
| **Ideal DHP** | **20** | **546** | **5738** | **25%** | **15%** | **5%** | **2728** | **48%** |
| All | 78 | 549 | 6664 | 25% | 19% | 10% | 1637 | 25% |

### 3.2.3 Pre-heating Usage Impact

CMC did not have access to utility data during the study's recruitment phase, but rather requested utility approval for secure transfer of data once sites were selected, approved and installations complete. While a potential study limitation, CMC's assumption was that existing electric resistance heating would provide the necessary pre-heat usage for a viable study. The sites selected provided a wide range of pre-heat usage profiles that made for rich analysis, with all viable except for two apartment units. The primary finding around pre-treatment period heating energy usage is that it is generally correlated to the overall heating energy impacts.

A linear regression test with normalized heating energy impacts as the dependent variable, was tested against pre-heat usage as the independent variable. The results indicate a directional relationship with pre-heat usage, with significance at the .0005 level ($p<0.05$ is significant), which indicates the regression model significantly predicts the outcome variable and is a good fit for the data. An R value of .536 indicates that 28 percent of all variation in heating energy impact is dependent on pre-heating usage.

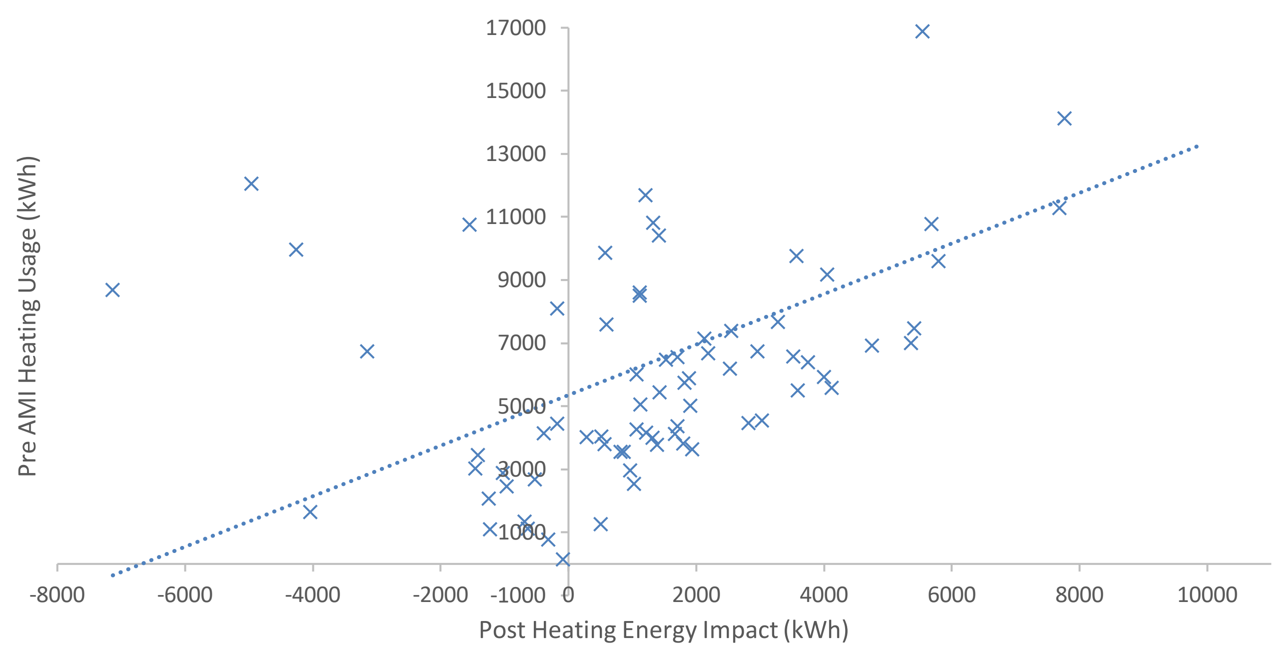
**Table 11. Linear Regression Output Tables – Pre Heat Usage**

| Model Summary | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Change Statistics | | | | |
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | R Square Change | F Change | df1 | df2 | Sig. F Change |
| 1 | .536[a] | .287 | .278 | 2497.18 | .287 | 30.61 | 1 | 76 | .000 |

*a. Predictors: (Constant), Normalized Pre Heat*

This relationship also can be seen visually in Figure 5 below.

**Figure 5. Pre-heating Usage and Heating Energy impact**



Where there were instances of high pre-heat with negative heating energy impacts, this may be attributed to various causes that are consistent with high resistance use in general:

- Pre-existing high temperature settings derived from specific perceived home comfort needs may have driven occupants to utilize resistance heat.

- Single-head installations where multi-head systems would be more appropriate, requiring the use of additional electric resistance heat. This is discussed in the multi-head systems analysis.
- The change in control devices, i.e. moving from numeric dial to web-enabled smart thermostat, may prompt customers to increase temperature past prior temperatures, as these were not previously quantified for the occupants.
- Efficient technology rebound effect, or the phenomenon of new technology can lead to increased energy usage.
- Lack of ambient lock-out technology that could have prevented premature use of electric resistance. This is discussed in the analysis on ambient air lock-out controls.
- The need for better education, educational materials and communication with occupants.

### *Pre-Heat Usage Recommendations*

Future program design should include pre-heat analysis or some form of minimum requirements. CMC recommends, for individually metered or whole building mean housing unit pre-heat electric resistance usage to be =>4,000 kWh to be considered for program treatment. The logic for this decision point can be found in Table 12 below. Sites with low pre-heat, beneath 4,000 kWh, had a negative mean normalized heating energy impact. As noted in the section on methodology, occupant turnover and unoccupied ranges were removed from the data set, accounting for those cases within this recommendation.

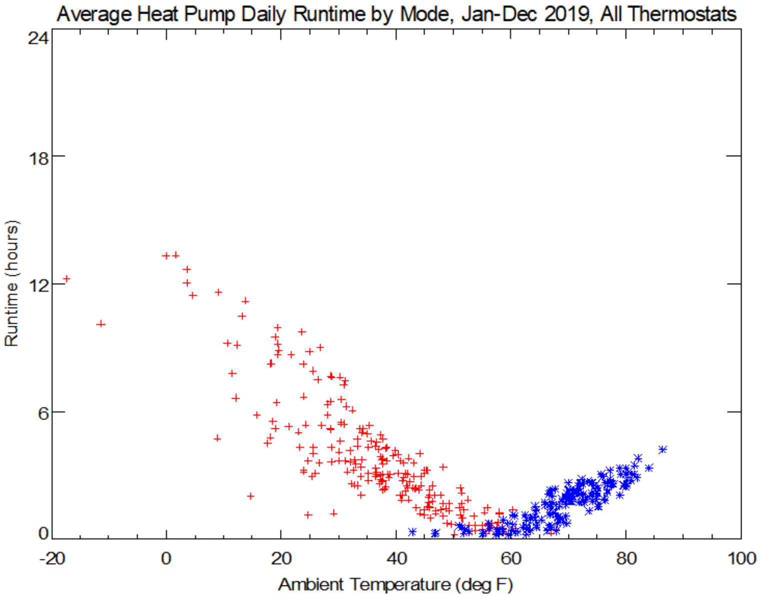
**Table 12. Pre-Heat Usage Recommendation**

| Pre-Heat Bin (kWh) | Units | Mean Pre-Heat (kWh) | Mean Normalized Heat Impact (kWh) |
|---|---|---|---|
| **< 4000 kWh Pre-Heating** | 21 | 2,458 | -181 |
| **> 4000 kWh Pre-Heating** | 57 | 8,214 | 2,306 |

### 3.2.4 Operational Hours

Operational hours for heating and cooling were derived from smart thermostat data capture for ccDHP systems. The mean runtime in the heating and cooling operating modes for all available thermostats was calculated for each day. A runtime between 0 zero to 24 hours was used to calculate the mean, with missing values for that day being excluded from the calculation. Average days with less operating time than 15 minutes were then excluded from the plot in Figure 6 and not used to calculate the results. This has very little impact on the results in total, changing the cooling runtime by seven hours and the heating runtime by two hours. The primary thermostat was used to determine operational hours for multi-head configurations.

**Figure 6. Average Heat Pump Daily Runtime by Mode**



Low amounts of cooling runtime can be observed over colder temperatures < 50 °F. There are approximately three days that all fall under 1-hour of total runtime, which are likely the result of thermostat misuse during the shoulder seasons when the occupant switches from cooling to heating. During the months of April, May and October, daily average temperatures range between running in heating and cooling modes depending on how close the residents set their heating and cooling setpoints to each other. Occupants likely were switching their thermostat modes back and forth causing cooling runtime over colder outdoor temperatures. Examples of this behavior can be seen at site 2-C in Figure 7 below.

**Figure 7. Average Heat Pump Daily Runtime by Mode -- Example Site 2-C**

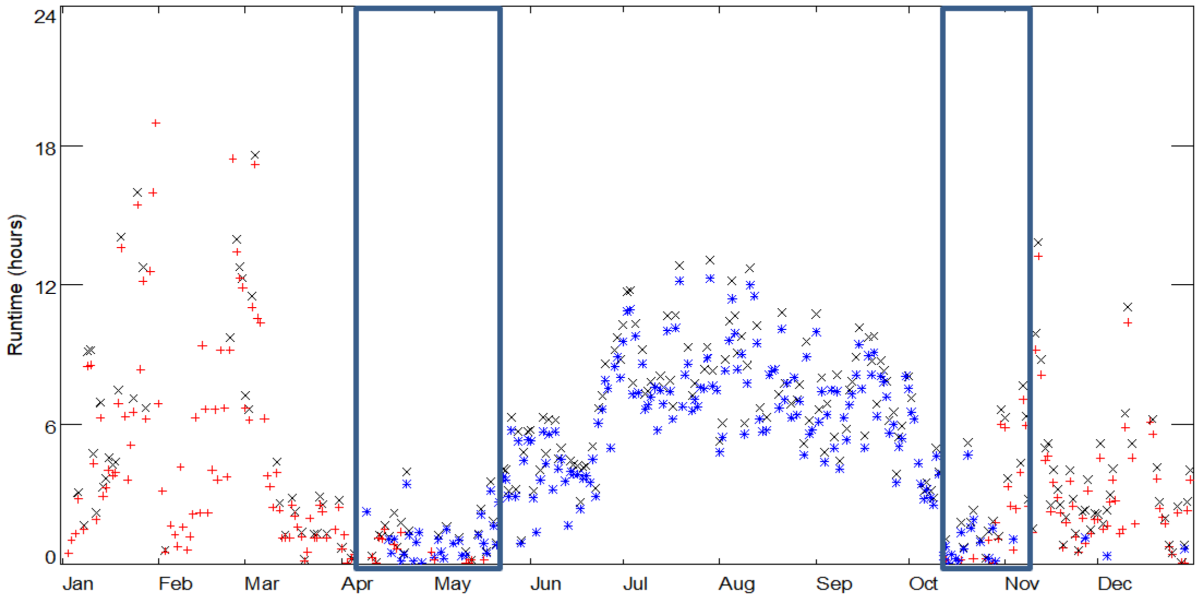


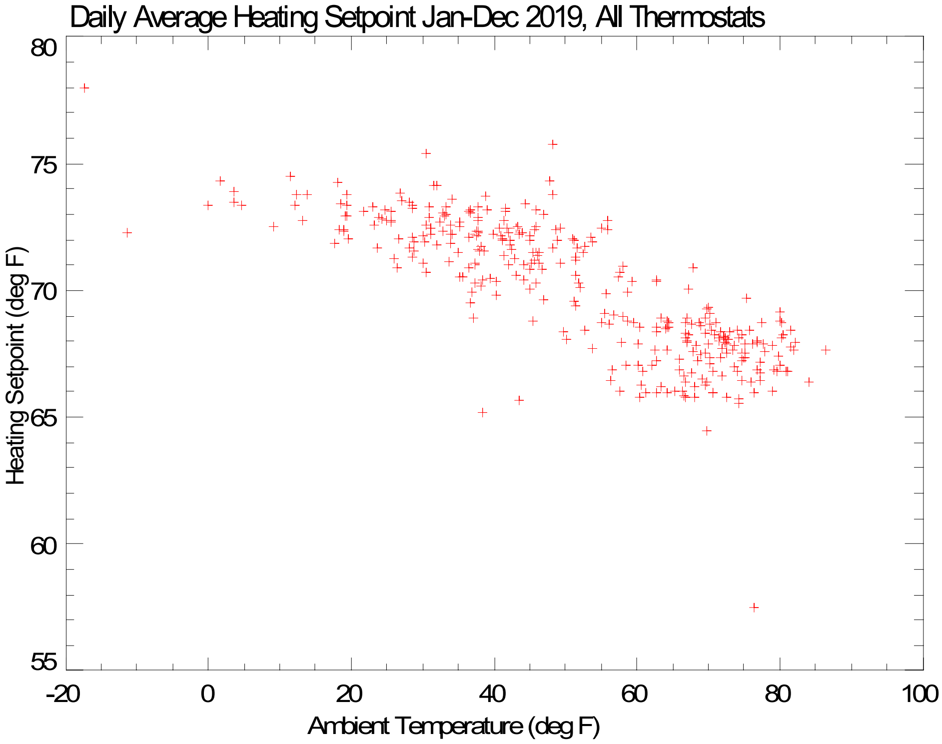
**Table 13. Observed Run Hours for Heating and Cooling Seasons**

| Season | Days | Hours | Mean % Runtime | Operational Hours | Mean EFLH – 78 Units @ 45°F | Mean EFLH – 78 Units @ 17°F | Mean EFLC – 78 Units |
|---|---|---|---|---|---|---|---|
| **Winter 2019** | 118 | 2832 | 27.3% | 774 | 636 | 996 | |
| **Summer 2019** | 92 | 2184 | 14.1% | 308 | | | 188 |

### *Thermostat Setpoints*

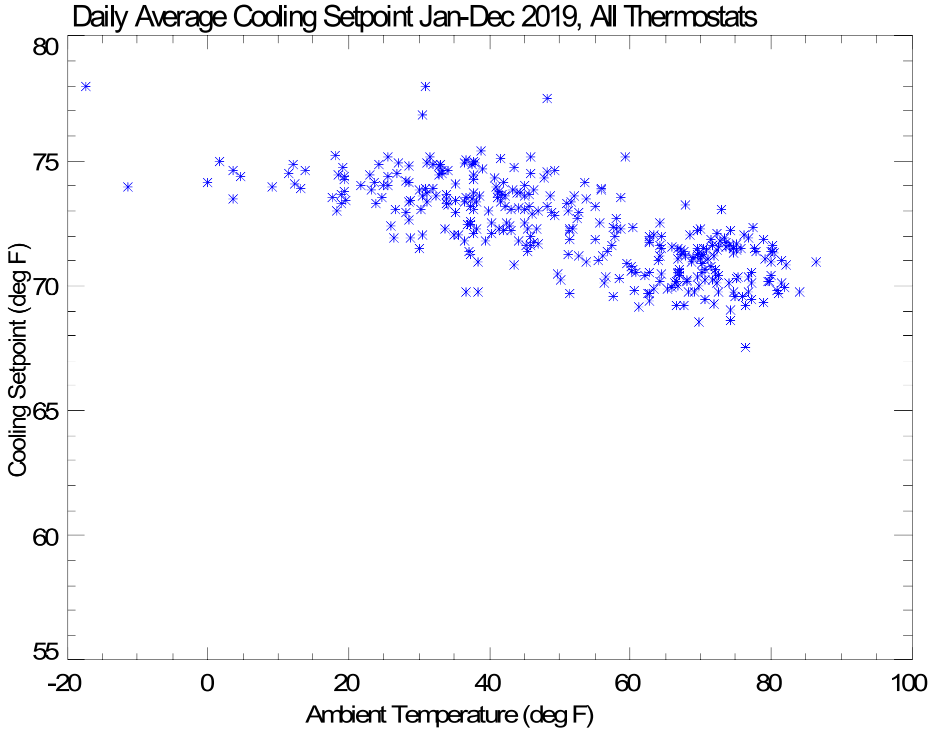
In heating mode, the smart thermostats have an increasing setpoint (65 °F - 75 °F ~Outer Range) that correlates with a decrease in ambient temperature. As ambient temperature drops, the setpoint increases to improve comfort. The thermostats were generally installed on an interior wall where it measures indoor temperatures. Rooms with exterior walls will be cooler than where the thermostat is located, so the setpoint is increased to heat those cooler rooms as outdoor temperature decreases. On days with ambient temperatures less than 15 °F, the setpoint on the thermostat appears to level out to approximately 73.5 °F. Any missing values were excluded from the daily average.

Figure 8. Average Thermostat Set Point -- Heating



In cooling, the setpoint follows a similar trend to heating but with less of a range (69 °F - 75 °F ~Outer Range). The cooling setpoint is very similar to the heating setpoint over colder temperatures since the cooling setpoint is programmed to be greater than the heating setpoint. The difference between the setpoints is seen over mild to warmer daily temperatures (60 °F - 80 °F) where the cooling setpoint is around 70 °F to 71 °F and the heating setpoint is around 67 °F to 68 °F.

**Figure 9. Average Thermostat Set Point -- Cooling**



## 3.2.5 Balance Point

The mean pre-heat balance point for all units was 59.73°F, while the mean balance point during the post evaluation period was 55.23°F. This is notable, as the balance point should have only shifted for the building treated with shell retrofits. The lower balance point is generally correlated with positive energy impacts—there is a statistically significant (p=0.001) directional relationship, as identified through linear regression, between balance point change and heating energy impacts.

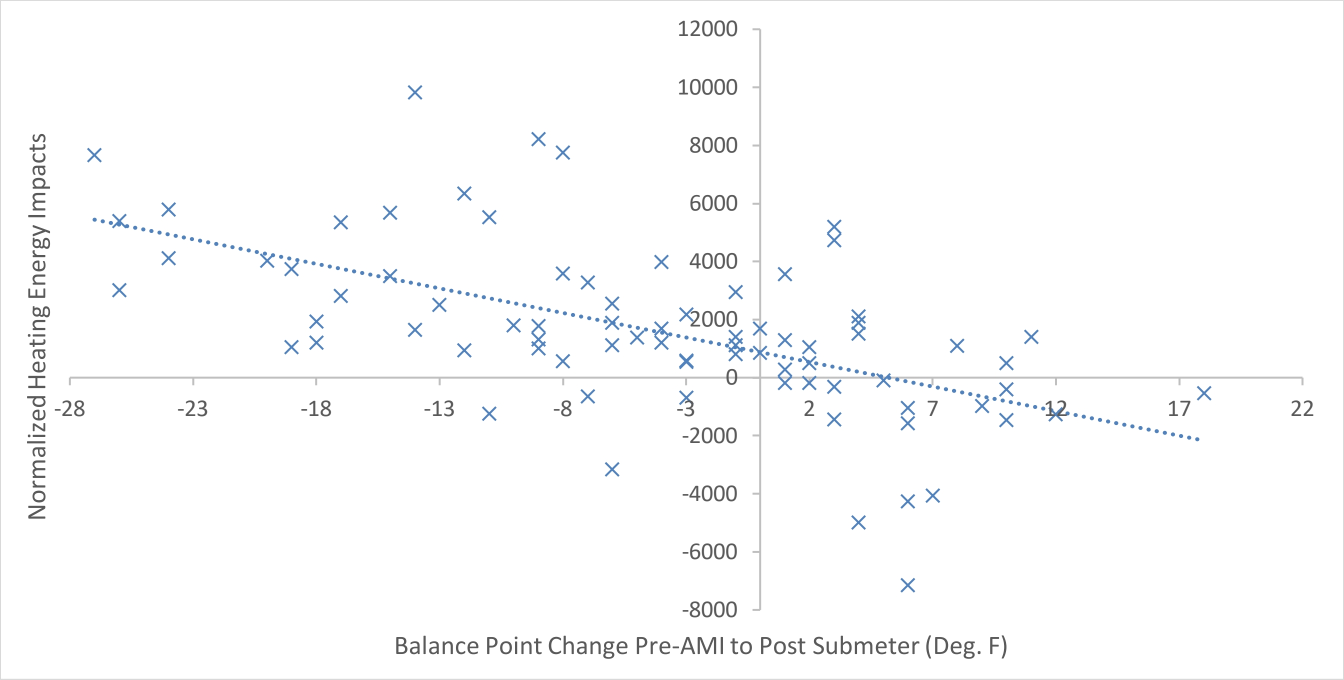
**Table 14. Heating Balance Point -- Regression Output**

| | | | | | Change Statistics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | R Square Change | F Change | df1 | df2 | Sig. F Change |
| 1 | . 582a | .339 | .330 | 2405 | .339 | 38.97 | 1 | 76 | . 000 |

*a. Predictors: (Constant), Balance Point Change*

This comparison can be seen visually in Figure 10.

Figure 10. Balance Point Change Pre-heating to Post Submeter



While the relationship between balance point and energy impacts is clear, what is less clear is the specific driving factor in lower balance points. This could be attributed to:

- Control Device Interactions – The pre-existing control systems could be set at a higher temperature intentionally temporarily, though not readjusted. With the more advanced thermostats used in the pilot, the thermostats would automatically revert to a schedule, preventing this behavior. This would provide a different result at each installation site, depending on the user's pre-period behavior. The change in thermostat could also lead to other behavioral change, such as a higher awareness of the actual temperature setting, creating more energy use awareness.
- Heat Distribution – The research team has considered the possibility that heat pump distribution has played a role in balance point shifts. DHPs have airflow embedded, meaning there may be fewer cold spots within the apartment, so the occupant may perceive that they are warmer throughout their residence with a lower heating set point.
- Shell Treatment – This would be, in many other scenarios, the most impactful change on balance point, but the research team, from the sample of 1-B, could not conclusively attribute this to shell treatment. Site 1-B had a lower starting balance point (56.1°F), which follows the lower pre-heating usage, though had a similar reduction overall of 8 percent (51.9°F).

## 3.2.6 Electric Resistance Heat Use and Ambient Lock-Outs

Existing resistance baseboard heat was not removed from any housing unit. This was a design element done to provide adequate heat in the event the ccDHPs were not capable of meeting customer need. There were also cost and cosmetic concerns with their removal. In addition, CMC anticipated future resistance by building owners at total removal of those systems in a scaled program. CMC used this opportunity to test existing ambient lock-out technology against education on electric resistance used as a backup heat source. It was important for CMC to understand if education was a viable path forward, as there would be some cost savings on equipment installation without the lock-out devices.

CMC employed digital two-stage temperature controls specifically designed for use with the selected ccDHPs. The devices were applied to the electric resistance baseboards in primary living spaces, such as living rooms, though were not applied to secondary rooms, such as additional bedrooms or bathrooms. Occupants could employ these additional electric resistance heaters as they saw fit. This configuration could impact the effectiveness of lock-outs.

20 apartments across three sites received ambient air lock-out devices as part of the ccDHP installation process. The remaining apartments were reliant on education from the CMC SEA to avoid using the resistance heat unless absolutely necessary. Housing units with ambient air lock-outs can be found in Table 15.

**Table 15. Housing Units with Ambient Air Lock-Out**

| Site ID | Address | Unit(s) |
|---|---|---|
| **2-B** | 1353 E 70th St | 1, 2, 3 |
| **2-B** | 1361 E 70th St | 3 |
| **1-B** | 3317 Lewis | 1, 2, 3, 4 |
| **1-B** | 3321 Lewis | 1, 2, 3, 4 |
| **2-A** | 7453 Bennett | 1, 2, 5, 6 |
| **2-A** | 7457 Bennett | 1, 2, 5, 6 |

The lock-out devices are designed to prevent use of the resistance baseboard heat until the outside ambient air falls below a specified temperature, using an externally mounted sensor. After discussions with Mitsubishi and review of system performance ratings, CMC selected 15°F ambient air temperature as the point at which electric resistance heaters could be energized. The energizing of electric resistance heat could then be manually operated by the occupant. These temperature-activated controls operate between -20°F and 140°F and have negligible power consumption.

### *Lock-out Correlation*

From a statistical perspective on lock-outs, CMC examined the Eta correlation between sites with lock-out and energy impacts. Eta is a non-linear correlation coefficient that examines the relationship between variables, lock-outs, versus a scale variable, heating energy impacts. An Eta of .219 indicates that there is a low, yet existing relationship or association within the entire sample group for ambient lock-outs as a categorical variable and heating energy impacts, with five percent of the variation in results stemming from ambient lock-outs.

## *Energy Impacts*

Sites with ambient lock-outs also demonstrated moderately higher mean savings and displaced resistance heating where the mean reduction for sites with lock-outs was 34 percent and 22 percent for sites without lock-outs. One site (1-B) that received 100 percent lock-outs had a similar reduction percentage as sites without lock-outs. 1-B had the lowest AMI pre-heat usage profile though still exhibited positive heating energy impacts. This may indicate that ambient lock-outs mitigate some of the impact of low pre-heat usage. The results of the comparison can be found in Table 16 below.

**Table 16. Ambient Air Lock-Out Heating Energy Impacts**

| | Site | Units | % of Total Units at Site | Mean Normalized Heat Energy Impact (kWh) | Mean Normalized Pre Heat AMI (kWh) | Mean % Heat Reduction | Mean Area (SQ FT) | % Multi-head Units | % Shell Treatment |
|---|---|---|---|---|---|---|---|---|---|
| Lock-out | 1-B | 8 | 100% | 724 | 3470 | 21% | 600 | 0% | 100% |
| | 2-A | 8 | 53% | 2576 | 7735 | 33% | 702 | 0% | 0% |
| | 2-B | 4 | 27% | 2663 | 5023 | 53% | 574 | 0% | 0% |
| | Lock-out | 15 | | 1853 | 5486 | 34% | 636 | 0% | 53% |
| Education Only | 1-A | 8 | 50% | 1429 | 7673 | 19% | 507 | 50% | 0% |
| | 1-C | 8 | 100% | 814 | 5706 | 14% | 550 | 100% | 0% |
| | 1-D | 8 | 100% | 1925 | 5032 | 38% | 400 | 0% | 0% |
| | 2-A | 7 | 80% | 2362 | 13445 | 18% | 713 | 20% | 0% |
| | 2-B | 11 | 100% | 1503 | 9269 | 16% | 639 | 0% | 0% |
| | 2-C | 16 | 100% | 1514 | 4171 | 36% | 400 | 0% | 0% |
| | Education | 63 | | 1563 | 7071 | 22% | 519 | 23% | 0% |
| | **All** | **78** | | **1637** | **6664** | **25%** | **549** | **19%** | **10%** |

Of particular interest is site 2-B, where 15 apartments were treated in total, though only four received lock-outs. Within site 2-B, with similar building characteristics, housing units with lock-outs had a 53 percent reduction, while housing units without lock-outs only had a 16 percent reduction in normalized heating usage. Overall, the housing units with lockouts had low pre-heat usage, which in most cases for study participants would be correlated with less positive energy impacts. However, the housing units with lock-outs had significantly greater relative reductions. This is an indication that lock-outs can be effective in preventing unnecessary electric resistance usage.

**Table 17. Ambient Air Lock-Out Analysis Site 2-B**

| Site 2-B | Mean Area (Sq Ft) | Shell Treatment | Indoor Head Configuration | Units | Mean Normalized Pre-Heat (kWh) | Mean Post Electric Resistance (kWh) | Mean Normalized Heating Energy Impact (kWh) | Mean % Heating Reduction |
|---|---|---|---|---|---|---|---|---|
| **Lock-Out** | 574 | No | Single | 4 | 5023 | 2343 | 2663 | 53.0% |
| **Education Only** | 639 | No | Single | 11 | 9269 | 4442 | 1503 | 16.2% |

### *Resulting Electric Resistance Usage*

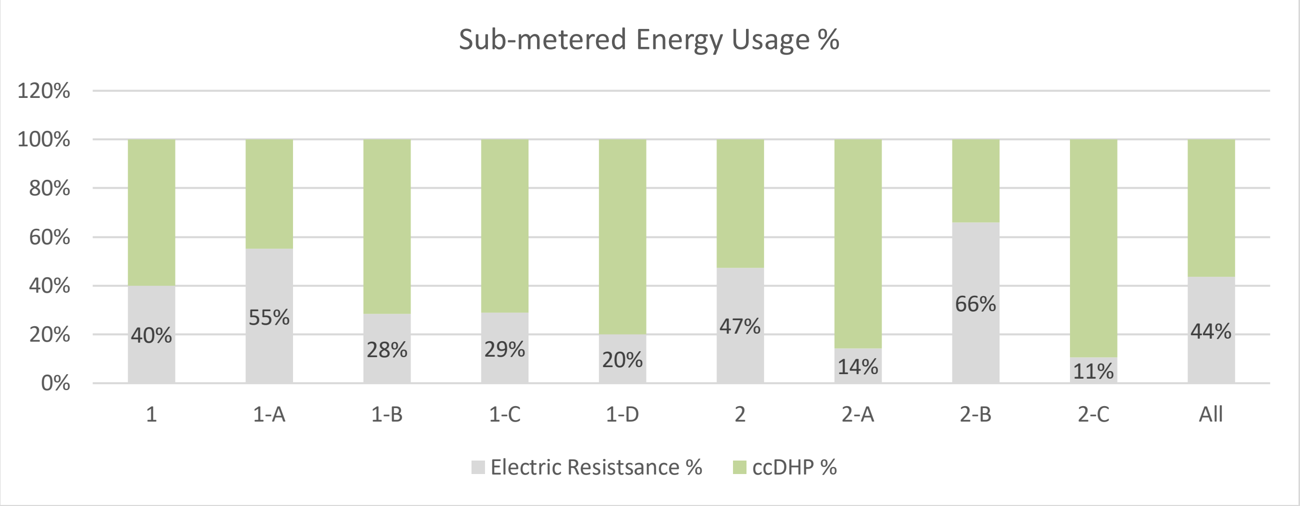
Due to missing heating loads for ccDHPs in the sub-metered data, as indicated in the alternative methodology section, 54 sites are included in the electric resistance usage comparison. The results therefore cannot provide a complete picture of electric resistance heating at each building. Post sub-metering data for electric resistance and DHPs indicate the percentage of overall sub-metered energy usage for electric resistance was 44 percent. Sample group one had 40 percent electric resistance heat usage, as compared to a 47 percent for sample group two. While group two had a higher overall electric resistance usage as a percentage of total sub-metered energy usage, there are many factors influencing mean savings reductions, including higher pre-heating usage for those sites as indicated by historical AMI data, fewer multi-head systems and variability in occupant behavior, even at the same site.

**Table 18. Electric Resistance Usage by Group**

| Site | Total Units | Electric Resistance as % of Sub-meter | Mean Normal Pre Heat (kWh) | % with Lock-out | % with Multi-head | % with Shell Treat | Mean Normal Heat Energy Impact (kWh) | % Mean Heating Reduction |
|---|---|---|---|---|---|---|---|---|
| **Group 1** | 27 | 40.0% | 5470 | 25% | 38% | 25% | 1223 | 22% |
| **Group 2** | 27 | 47.4% | 7495 | 26% | 7% | 0% | 1925 | 26% |
| **All** | **54** | **43.5%** | **6664** | **25%** | **19%** | **10%** | **1637** | **25%** |

The site-by-site comparison of utilization can be found in Figure 11. Sites with ambient air lock-out technology were generally successful in displacing resistance heat, such as site 1-B, Concerning sites with high resistance heat usage percentage, 1-A had no lockouts and likely did not follow education. 2-B only had four sites with lock-outs, those had lower electric resistance usage and significantly more positive energy impacts. The remaining high use apartments at 2-B drove up overall electric resistance percentage at the site. It should be noted that ambient lock-out technology was only applied to electric resistance heat in the main living space and not supplemental rooms, making 100 percent displacement by this means impossible. This indicates that education and technology in this configuration can be effective to encourage electric resistance displacement, though should be used in tandem.

**Figure 11. Electric Resistance as a Percentage of Total Sub-metered Usage – 54 Sites**



When examining the 54 cases with full sub-metered data through linear regression, there was a statistically significant relationship between post electric resistance usage, regardless of lock-outs, and heating energy impacts where p is .003, (<0.05 indicates significance). This relationship, as indicated by the R-square value, accounts for 16 percent of the variation in heating energy impacts for these units.

**Table 19. Linear Regression Output Tables – Post Electric Resistance**

| | | | | | Change Statistics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | R Square Change | F Change | df1 | df2 | Sig. F Change |
| 1 | . 401a | .161 | .145 | 2462 | .161 | 9.964 | 1 | 52 | . 003 |

## *Electric Resistance Education*

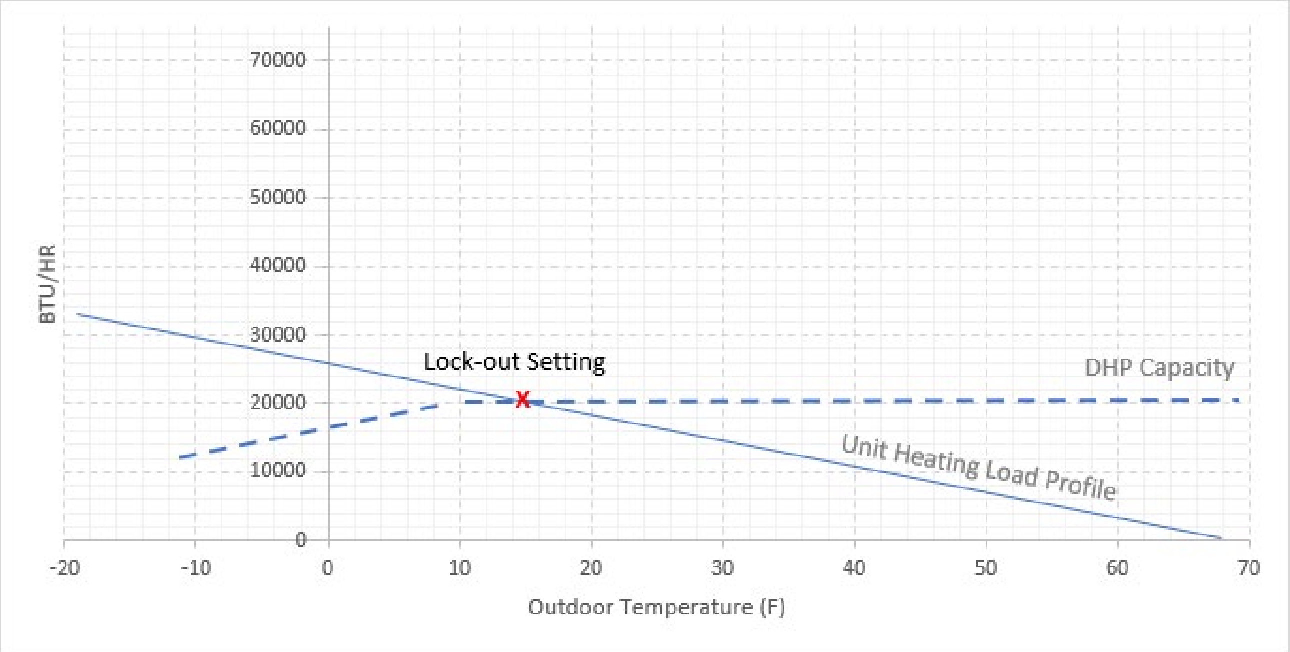
For the apartments not receiving lock-out controls, the SEA provided additional education to occupants on the use of electric resistance heat as a backup heating source only as necessary. Survey results of occupants indicate that 23 percent do not recall receiving any education during the installation of their unit, though 91 percent indicated they were present during the installation and CMC can confirm that education was provided (see section 4 for details). Site 1-D did not receive ambient lock-outs, though also had the highest mean energy reduction (38 percent) for any site. Five housing units out of eight were 100 percent dependent on the installed ccDHPs, indicated a high level of education effectiveness at those sites. Savings may have been even higher at 1-D, though one apartment had a 93 percent electric resistance utilization rate. Site 2-C also received no lock-out controls, though also had the second highest mean heating energy reductions at 36 percent.

For sites with high electric resistance utilization and/or negative energy impacts, the tenants may not have absorbed beneficial information, including how and when to use the supplemental electric resistance heat, especially if they did not receive an ambient lock-out system.

### *Recommendations*

In the case of a scaled program, ambient lock-out technology can be a cost-effective addition to ensure the appropriate level of electric resistance displacement. CMC recommends calculating load profiles and plotting de-rated ccDHP capacity to determine the outdoor temperature at which the electric resistance can be energized. This would be in place of the pilot approach, which was to use a static ambient temperature (15°F) lock-out for all control devices. This approach may have the two-fold benefit of assured occupant comfort and safety, along with encouraging the least amount of electric resistance usage. For similar sized or configured apartment units, the additional analysis time would be worth the additional positive impact potential. Figure 12 illustrates the impact of each approach.

**Figure 12. Lock-out Configuration**



In addition, CMC recommends bolstering education efforts for all tenants around supplemental heating and non-standard supplemental heating such as electric ovens and plug-in space heaters, regardless of lock-out application. Education proved effective at two sites without lock-out technology and the combination of education and lock-outs should provide the best savings potential. Education should include the use of laminated equipment placards, education booklets, quick tips on magnets or coasters and a comprehensive post-treatment period.

### 3.2.7 Single-Head vs. Multi-Head

The applicability of multi-head system DHPs has been the target of prior studies, with many finding lower COP and less positive energy impacts. The heating needs of multifamily housing units are different than that of residential single-family buildings, though multi-head configurations may offer some benefit, especially in larger or more complex unit layouts. With this in mind, this study sought to test the application of multi-head systems across a variety of contexts within the sample set. This includes 100 percent of an entire building site, as well as partial application across two other sites, at 50 percent and 20 percent. A total of 15 housing units across three sites received multi-head ccDHP systems, as shown in Table 20.

**Table 20. Units with Multi-head Systems**

| Site ID | Address | Units |
|---|---|---|
| **1-A** | 709 Grand Avenue | 1, 3 |
| **1-A** | 711 Grand Avenue | 1, 3 |
| **1-C** | 4311 Centennial Court | 1 - 8 |
| **2-A** | 7451 Bennett | 1 |
| **2-A** | 7459 Bennett | 2, 6 |

Applications for either system, single- or multi-head, were designed to heat entire apartments and no single zones within a larger space. Therefore, boundary discussions were not discussed with occupants. Temperature equalization strategies were put in place by the CMC team. Single-head installations were also provided air transfer grills, when deemed necessary, between the primary heated space and additional spaces, such as a bedroom. This approach promotes air flow and allows the ccDHP to heat or cool as much of the space as is possible, without the need for supplemental electric resistance heating.

#### *Multi-head Correlation*

The Eta correlation for all multi-head systems as the independent variable against the dependent variables of heating energy impacts was .011, indicating no statistical correlation. A second test, multinomial logistic regression, used to compare categorical variables against scale or other categorical variables, with consideration to covariate variables that are not impact factors, was applied to the binned categories. The binned categories, by usage reduction, were Negative, Low-Positive, Positive and High-Positive heating energy impacts. The factors of the model were the number of indoor heads. No statistical significance was discovered among the variables, as shown in Table 21. Significance is assumed when p <= 0.05. The model performed with less significance when living area was considered.

**Table 21. Multi-head Logistic Regression Output Table**

| Parameter Estimates | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Wald | df | Sig. | Exp(B) | 95% Confidence Interval for Exp(B) | |
| | | | | | | | | Lower Bound | Upper Bound |
| **High Positive Energy Impact** | Intercept | -0.405 | 0.913 | 0.197 | 1.000 | 0.657 | | | |
| | [No. of Indoor Heads=1.00] | -0.054 | 0.985 | 0.003 | 1.000 | 0.956 | 0.947 | 0.138 | 6.525 |
| | [No. of Indoor Heads=2.00] | 0b | | | 0.000 | | | | |
| **Low Positive Heating Impact** | Intercept | 0.847 | 0.690 | 1.508 | 1.000 | 0.220 | | | |
| | [No. of Indoor Heads=1.00] | -1.084 | 0.772 | 1.972 | 1.000 | 0.160 | 0.338 | 0.075 | 1.535 |
| | [No. of Indoor Heads=2.00] | 0b | | | 0.000 | | | | |
| **Negative Heating Impact** | Intercept | 0.000 | 0.816 | 0.000 | 1.000 | 1.000 | | | |
| | [No. of Indoor Heads=1.00] | -0.111 | 0.882 | 0.016 | 1.000 | 0.900 | 0.895 | 0.159 | 5.041 |
| | [No. of Indoor Heads=2.00] | 0b | | | 0.000 | | | | |

### *Heating Energy Impacts*

The lack of statistical significance does not mean an analysis of the results are not useful, although less general inference can be made about the overall population. There is rich information in analysis of the heating energy impacts and CMC has provided separate sub-population metrics for installations with a single indoor head and those with multiple indoor heads. Table 22 shows this analysis between systems, although other study factors, including lock-out and weatherization treatment, are shown to make a site-by-site evaluation more helpful when trying to understand the implications of multi-head systems. No housing unit receiving a multi-head system received an ambient lock-out or shell treatment, though site 1-C did previously receive light air sealing measures before the pilot.

CMC generally found more positive impacts overall than previous studies, although overall percentage reduction against single-head systems was lower – 22 percent reduction for multi-head systems versus a 25 percent overall reduction for single head systems. It should be noted that site 1-C was the only site to receive 100 percent multi-head application and that site had the smallest reduction for any site in the study at 14 percent. This is a notable finding. As discussed in the system efficiency section, multi-head unit installation had a mean season COP of 1.47 versus 2.63 for single-head installations.

**Table 22. Single- Versus Multi-head Analysis**

|  | Site | Units in Group | Mean Normalized Pre-Heat (kWh) | Mean Normalized Heating Energy Impact (kWh) | Mean % Heating Reduction | Mean Area (SQ FT) | % with Lock-out | % Shell Treatment |
|---|---|---|---|---|---|---|---|---|
| **Multi-head** | 1-A | 4 | 8073 | 2047 | 25% | 507 | 0% | 0% |
|  | 1-C | 8 | 5706 | 814 | 14% | 550 | 0% | 0%[4] |
|  | 2-A | 3 | 12298 | 3624 | 29% | 727 | 0% | 0% |
|  | **All** | **15** | **7656** | **1705** | **22%** | **574** | **0%** | **0%** |
| **Single Head** | 1-A | 4 | 7273 | 811 | 11% | 507 | 0% | 0% |
|  | 1-B | 8 | 3470 | 724 | 21% | 600 | 100% | 100% |
|  | 1-D | 8 | 5032 | 1925 | 38% | 400 | 0% | 0% |
|  | 2-A | 12 | 9925 | 2190 | 22% | 702 | 67% | 0% |
|  | 2-B | 15 | 8137 | 1812 | 22% | 622 | 27% | 0% |
|  | 2-C | 16 | 4171 | 1514 | 36% | 400 | 0% | 0% |
|  | **All** | **63** | **6428** | **1621** | **25%** | **542** | **32%** | **13%** |

Overall, pre-heat usage for multi-head sites was 19 percent higher than single-head sites. The research team suspected that his may have contributed to the slightly more positive energy impacts than expected for multi-head units. This was confirmed through using the coefficients from the linear regression model based on pre heat and post energy heating impacts. These were used to predict savings based on pre-heating values, the results of which can be found in Table 23 below. The results indicate that multi-head installations, when considering pre-heating usage, underperformed against predicted usage by 14 percent, where single-head installations were generally where expected.

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[4] Site 1-C previously received light air sealing treatment, prior to the commencement of the pilot study

Table 23. Single- Versus Multi-head Predicted Savings – Pre Heat Normalized

| Site | Constant Unstnd Coeff - B | Normalized Pre-Heat Coeff - B | Mean Normalized Pre-Heat (kWh) | Predicted Value | Actual | Variance |
|---|---|---|---|---|---|---|
| **Multi-head** | -750.562 | 0.358 | 7656 | 1990 | 1705 | **-14.33%** |
| **Single Head** | -750.562 | 0.358 | 6428 | 1551 | 1621 | 4.54% |

Considering the statistically significant relationship between the higher pre-heat usage and heating energy impacts, multi-head units energy savings were not entirely surprising.

### *Multi-head and Electric Resistance*

A deeper look at the sample sites offers additional perspective on the heating energy impacts shown in Table 20. Site 2-A had the highest mean area at more than 700 square feet as well as the highest mean pre heat usage of any site, with a mean over 12,000 kWh. Of the 15 housing units treated at the site, three received multi-head systems. The study found that the apartments at site 2-A that received a single-head system had less positive energy impacts than the multi-head systems at the same site – 29 percent reduction for multi-head and 22 percent for single-head.

The same scenario was found to be true at site 1-A, where housing units with single-head installations had higher post electric resistance heating and less positive energy impacts, 25 percent reduction for multi-head and 11 percent for single-head. The variation in single-head reduction may be explained by the lock-outs installed on the single head systems (67 percent) at 2-A. The more positive energy impact for the multi-head systems in these scenarios may be due to a higher heating load requirement.

### *Recommendations*

CMC recommends the limited application of multi-head units for a scaled program, based on heating load calculations, unit size and pre-heat usage requirements. It should be stressed that single-head systems generally deliver higher efficiencies and lower costs, and this study has shown that the mean heating energy impacts for single-head units are more positive. With that assumption, the study also suggests that housing units where multi-head applications were likely necessary, though not utilized, may have required additional heating capacity or experienced distribution issues. High mean post electric resistance heat resulted, creating less positive heating energy impacts. Future studies should consider specific survey questions around this point for more qualitative, customer-focused context.

In addition to and in concert with recommendations found elsewhere in this recommendation, CMC recommends the use of ambient air lock-out controls for any multi-head application, which would likely mitigate some of the issue as well.

### 3.2.8 Shell Treatment/Weatherization

Many programs look to make homes and buildings what is considered “heat pump ready.” This approach often includes air sealing treatments and insulation that may lower the structure’s balance point, increase occupant comfort and maximize energy impacts. As a general rule based on decades of energy efficiency work, CMC advocates for shell treatment with ccDHP installations, whenever cost-effective and feasible as it is a proven method of positive heating energy impacts.

A building’s design plays an important role in the feasibility of multifamily shell retrofits and CMC found practical limitations in determining viability of fully comprehensive shell retrofits in multifamily buildings, especially given the limited time for recruitment and installation for the pilot study. This includes assessment of wall cavity insulation and/or airflow diagnostic studies. Even with these limitations, CMC was able to assess each building for prescriptive air sealing retrofits and viability of ceiling cavity insulation, determining one site, 1-B, an ideal candidate due to low-R values of ceiling cavity insulation and opportunity for air sealing throughout the building.

**Table 24. Housing Units with Shell Treatment Performed During the Pilot**

| Site ID | Address | Unit(s) |
|---|---|---|
| **1-B** | 3317 Lewis | 1 - 4 |
| **1-B** | 3321 Lewis | 1 - 4 |

Site 1-B was treated comprehensively with air sealing and insulation through a partner program. These building performance retrofits were installed in conjunction with the installation of the ccDHP systems on site. This building is considered heat pump ready. Site 1-C previously had light air sealing performed, though no additional insulation.

#### *Shell Treatment Correlation*

An Eta test was performed with shell treatment the independent variable and heating energy impacts the dependent variable. The test found a very low, but existing, directional relationship between the variables, with an Eta of .106. The inclusion of site 1-C, with previous minor air sealing, improved the Eta to .151. Even at this level, the results indicate that variation in the model cannot be predicted with shell treatment, as shell treatment only accounts for 2 percent of the variation. This does not indicate the shell treatment is ineffective or should not be pursued, rather that a relationship between energy impacts and shell treatment were not found in this study.

Another separate test was performed between the categorical variable of shell treatment and balance point variation between the pre- and the post-period. The Eta was .171 indicating a directional relationship between shell treatment and balance point, though still low, with approximately 3 percent of the variation in balance point variation explained by shell treatment.

Living area by square footage, as an independent variable in multinomial logistic regression, was not shown to have statistical significance within the sample groups.

### *Energy Impacts*

The primary site with shell performance completed during the pilot showed less positive energy impacts than sites not treated with shell retrofits. 1-B had a mean heating reduction of 21 percent, as compared with non-treated sites that showed a 25 percent reduction.

**Table 25. Units with Shell Treatment Energy Impact Summary**

| Site | Units in Group | Mean Area (SQ FT) | Mean Normalized Heat Energy Impact (kWh) | Mean Normalized Pre Heat (kWh) | Mean % Heating Reduction | % Multi-head Units | % with Lock-outs |
|---|---|---|---|---|---|---|---|
| **1-B** | 8 | 600 | 724 | 3470 | 21% | 0% | 100% |
| **Shell Treatment** | **8** | **600** | **724** | **3470** | **21%** | **0%** | **100%** |
| **1-A** | 8 | 507 | 1429 | 7673 | 19% | 50% | 0% |
| **1-C** | 8 | 550 | 814 | 5706 | 14 % | 100% | 0% |
| **1-D** | 8 | 400 | 1925 | 5032 | 38 % | 0% | 0% |
| **2-A** | 15 | 707 | 2476 | 10399 | 24% | 20% | 53% |
| **2-B** | 15 | 622 | 1812 | 8137 | 22% | 0% | 27% |
| **2-C** | 16 | 400 | 1514 | 4171 | 36% | 0% | 0% |
| **No Shell Treatment** | **70** | **543** | **1741** | **7030** | **25%** | **21%** | **17%** |
| **All** | **78** | **549** | **1637** | **6664** | **25%** | **19%** | **26%** |

The research team attributes some of this less positive impact with the low pre-heat usage number. Using the coefficients from the linear regression, CMC predicted the energy impact for the study for both groups, based solely on pre-heat usage. The linear regression, based on the sample set, allowed CMC to confirm that site 1-B overperformed against its predicted heating energy impact.

**Table 26. Housing Units with Shell Treatment Predicted Heating Energy Impact**

| Site | Constant Unstnd Coeff – B | Normalized Pre Heat Coeff - B | Mean Normalized Pre Heat (kWh) | Predicted Value | Actual | Variance |
|---|---|---|---|---|---|---|
| **No Shell Treatment** | -750.562 | 0.358 | 7030 | 1766 | 1740 | -1.48% |
| **Shell Treatment** | -750.562 | 0.358 | 3470 | 492 | 742 | **50.91%** |

Site 1-B, based on the low pre-heat number, should have only realized 492 kWh of savings, however, there was a staggering 51 percent increase over predicted values. The findings suggest that the application of shell measures may negate the negative energy penalties of low pre-heat usage. This site also had ambient lock-outs, which needs to be considered, though this is an important finding.

#### *Recommendations*

Based on the findings at site 1-B, shell treatment has a mitigating effect on low pre-heat usage penalties. In addition, the mean cooling energy impact at the site was net positive. For these reasons, CMC recommends shell retrofits to make ccDHP installation sites heat pump ready. This should include insulation whenever possible. While shell treatment is an important aspect in a scaled program, CMC does not recommend omission of potential ccDHP installation candidates due to lack of shell retrofit opportunities. In addition, CMC recommends a lower pre-heat mean usage threshold of 3,500 kWh per apartment for buildings receiving building shell treatments before or immediately after the installation of ccDHP systems.

### 3.2.9 Cooling Energy Impacts

Heating climate DHP applications have historically been oversized[5] for cooling, as the systems are most often sized for heating loads. Prior studies found that while some sites experience negative cooling impacts, the overall impact for savings is net positive[6]. The mean cooling energy impact was negative for all sites in this study, with a mean energy impact of -349 kWh. As indicated elsewhere in the document, the static baseload may not capture some variance due to seasonality, though CMC anticipates this impact to be low. The IL TRM calculations for this sample groups indicated a mean deemed first-year savings value of 340 kWh. 78 percent of sites showed no change based on no pre- or post-cooling usage or negative savings.

For this study, CMC recorded the nameplate capacities of existing zonal air conditioning systems, where available, though the usage patterns and working condition were not recorded or tested. The results indicate an increase in capacity against existing systems which may have contributed to the negative energy impacts. The ccDHP installations provided an increase in cooling capacity by 50 percent. It should be noted that the TRM uses the capacity of the replacement system, not the existing, when determining calculations. CMC had previously identified this as a savings inflation factor to the third-party evaluator and the utility, with the results of the study confirming the initial concern. The capacity variation percentages, as well as the cooling energy impacts are shown in Table 27.

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[5] NEEP Ductless Heat Pump Meta Study, 2014

[6] CADMUS Evaluation of Cold Climate Heat Pumps in Vermont, 2017

Table 27. Cooling Energy Impact Summary

| Site | Estimated SEER | Existing AC Capacity (K-BTU) | Provided Capacity (K-BTU) | % Capacity Increase | % with Multi-head | % with Shell Treat | Mean Normal Pre-cool (kWh) | Mean Normal Cool Energy Impact (kWh) |
|---|---|---|---|---|---|---|---|---|
| **Group 1** | 16.7 | **296** | **444** | **50%** | **38%** | **25%** | **267** | **-162** |
| **1-A** | 13.2 | 40 | 132 | 230% | 50% | 0% | 57 | -223 |
| **1-B** | 14.0 | 96 | 96 | 0% | 0% | 100% | 399 | 71 |
| **1-C** | 17.1 | 96 | 144 | 50% | 100% | 0% | 427 | -372 |
| **1-D** | 20.3 | 64 | 72 | 13% | 0% | 0% | 186 | -122 |
| **Group 2** | 16.5 | **408** | **615** | **51%** | **7%** | **0%** | **156** | **-479** |
| **2-A** | 15.8 | 180 | 264 | 47% | 20% | 0% | 158 | -737 |
| **2-B** | 20.2 | 100 | 207 | 107% | 0% | 0% | 164 | -60 |
| **2-C** | 13.8 | 128 | 144 | 13% | 0% | 0% | 146 | -630 |
| **All** | 16.6 | **704** | **1059** | **50%** | **19%** | **10%** | **201** | **-349** |

It is notable that the only site with a mean positive cooling energy impact is site 1-B, which did not experience a capacity increase. While the site also had the second highest pre-cooling usage, the energy impacts were still low compared to prior studies as well as the TRM deemed values, though some prior studies were examining cooling only and are not heating focused, as is the case with this study.

### *Pre-cooling Usage Impacts*

The low to zero pre-cooling usage was a direct cause of negative energy impacts, compounded by cooling capacity increases. Housing units participating in the study often had little to no pre-cooling usage. Analysis of AMI data indicates that 64 percent of housing units had very low pre-cooling usage profiles. The mean cooling energy impacts for sites beneath 500 kWh pre-cooling were negative. The binned pre-cooling usage is shown in Table 28.

Table 28. Pre-cooling Usage Profiles

| Pre-cooling Bin Category | Units | Mean Normalized Pre-cooling (kWh) | Mean Normalized Cooling Impacts (kWh) |
|---|---|---|---|
| **No Usage - 0 -20 kWh** | 36 | 12 | -498 |
| **20 - 120 kWh** | 16 | 75 | -566 |
| **121 - 500 kWh** | 14 | 299 | -101 |
| **> 500 kWh** | 12 | 837 | 61 |
| **All** | **78** | **201** | **-349** |

A linear regression test with normalized cooling energy impacts as the dependent variable, was tested against pre-cooling usage. When outliers were not removed, the results indicate no directional relationship between pre-cooling usage and cooling energy impacts, with significance at the .057 level (p<0.05 is significant), which indicates the regression model does not predict the outcome variable. When removing instances where there is no pre-cooling or post-cooling, leaving 59 cases, the model is significant at the .015 level. An R value of .316 indicates that 10 percent of all variation in cooling energy impact is dependent on pre-cooling usage within the sample group. Low r-squared results are often expected where human behavior creates wider variations than other phenomenon and, in this case, does not diminish the significance.

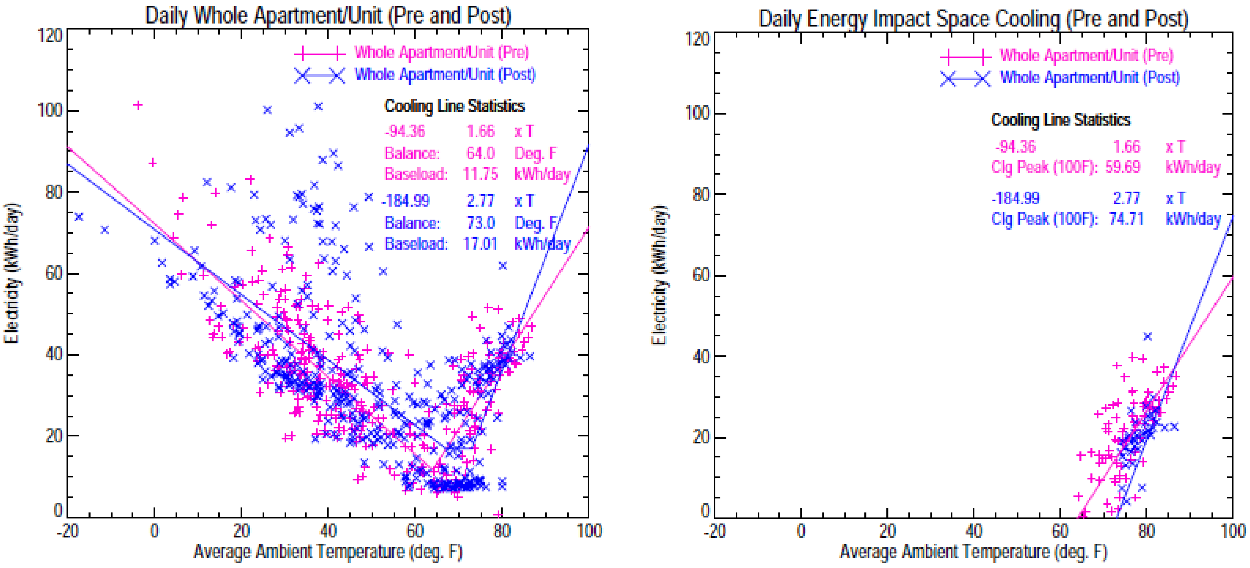
**Table 29. Linear Regression Output Tables – Pre-cooling Usage**

| Model Summary | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Change Statistics | | | | |
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | R Square Change | F Change | df1 | df2 | Sig. F Change |
| 1 | . 316a | .10 | .084 | 1060 | 1.0 | 6.344 | 1 | 57 | .015 |
| *a. Predictors: (Constant), Normalized Pre-cooling* | | | | | | | | | |

### *Positive Energy Impact Example - Cooling*

There were instances where positive cooling energy impacts were observed. The plot below in Figure 13 shows an example from site 1-B of a 12,000 BTU capacity, single-head unit application in a 600-square-foot apartment with a normalized pre-cooling usage of 1,703 kWh. This represents the highest pre-cooling usage for the sample set. The results show a cooling balance point increase of 4°F (64°F to 68°F), likely due to shell treatment at the site. There was a positive energy impact of 955 kWh. The site has a calculated SEER of 18.2.

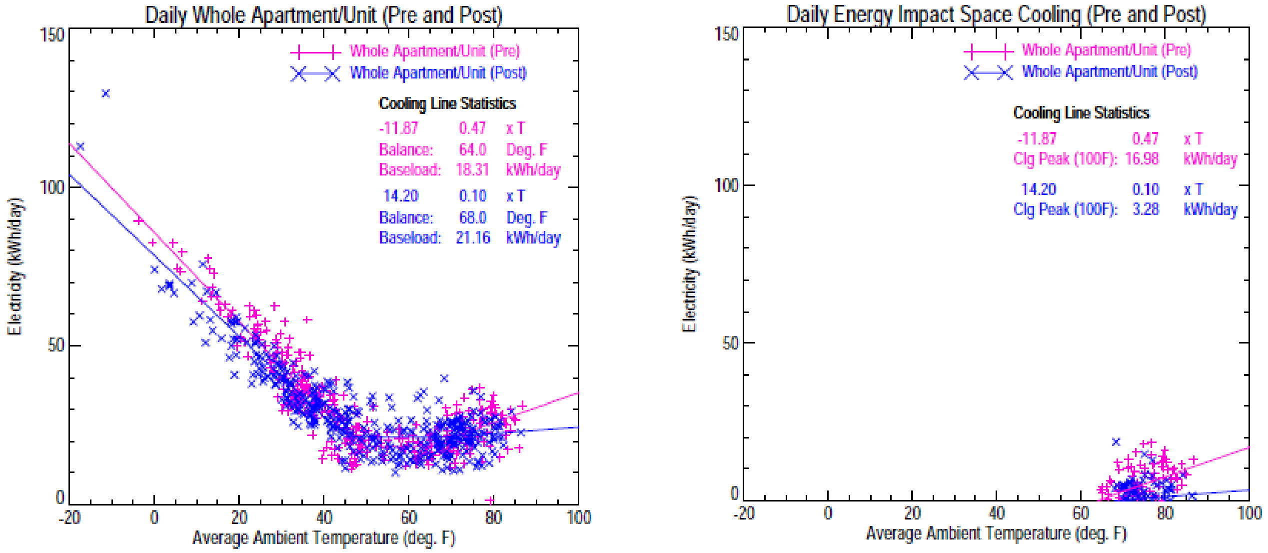
**Figure 13. Example of Positive Cooling Energy Impact – Site 1-B**



### *Negative Energy Impact Example - Cooling*

Alternatively, the plot below in Figure 14 shows an example from site 1-C, an 18,000 BTU multi-head system in a 550-square-foot apartment with a lower pre-cooling usage of 485 kWh. The results show a cooling balance point increase of 1°F (64°F to 65°F). The energy impact at the site was -364 kWh, likely due to a 50 percent capacity increase over the existing system. The site had a calculated SEER of 21.5.

**Figure 14. Example of Positive Cooling Energy Impact – Site 1-C**



### *Seasonal Energy Efficiency Ratio*

In many cases, there was no cooling captured by the sub-meter and as such, a SEER rating could not be calculated. As SEER is a calculation of the delivered cooling divided by the electricity consumed to provide the cooling, the analysis was then limited. The calculated SEER for all systems where this value could be calculated was 16.6.

Table 30. SEER Energy Efficiency Ratio

| System Type | Mean Estimated SEER | Mean Pre Cooling Usage (kWh) | Mean Normalized Cooling Energy Impact (kWh) |
|---|---|---|---|
| **MUZ-FH09NA** | 16.2 | 159 | -461 |
| **MUZ-FH12NA** | 13.9 | 261 | 15 |
| **MUZ-FH15NA** | 16.8 | 135 | -323 |
| **MUZ-FH18NA** | 21.7 | 144 | -244 |
| **MXZ-2C20NAHZ** | 14.2 | 179 | -981 |
| **MXZ-2C20NAHZ2** | 17.1 | 427 | -372 |
| **All** | **16.6** | **201** | **-349** |

#### *Cooling Recommendations*

The lack of pre-cooling usage should be a consideration for scaled programs, as LMI customers may not have existing or working air conditioning at the time of retrofit. Enhanced education may provide a meaningful pathway toward more positive energy outcomes for cooling, though for those housing units with little to no pre-cooling usage, the impact will be to minimize negative impacts. A program guideline requirement for pre-cooling usage is not recommended, as it will omit valuable potential participants from future programs. CMC recommends prioritization of high pre-cooling, though not disqualification based on low pre-cooling usage. Housing units with existing package terminal air conditioners (PTAC) and electric strip heat are excellent candidates for replacement, as are non-multifamily applications where a central air conditioner may be in use.

While cooling capacity created a mean savings penalty, thoughtful consideration should be given to the health and comfort of LMI occupants. Heating only installations may be possible, though CMC does not recommend this pathway due to technology access and equity concerns, coupled with the health of elderly occupants, which make up a higher percentage of LMI apartment units, as compared to non-LMI apartment units.

### 3.2.10 Coefficient of Performance (COP)

The COP of a DHP system generally describes the ability of the DHP to efficiently extract heat from outdoor ambient air and deliver it as useful heat to a conditioned space. The higher the COP, stated or as tested, the greater the final output of useful heating as relative to the required input. As indicated in the section on Data Methodology, the heating seasonal COP was calculated using a HP energy ratio and calculated total system COP, which includes electric resistance heat. Incomplete heating load capture from sub-meters required a separate alternate energy impact calculation for 24 installation sites and, as such, the COP could not be calculated. Sites with negative heating energy impacts (12) are not represented in the results for COP.

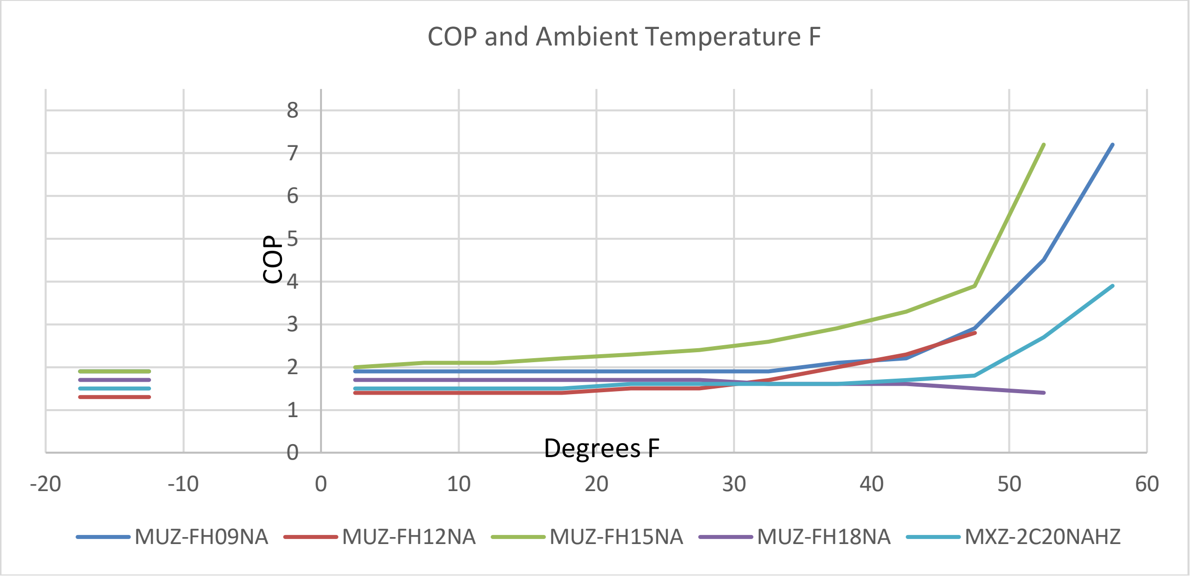
For the sites where COP could be calculated, the mean heating seasonal COP for all sites was 2.36 There was a large variance in performance between single- and multi-head systems. Single-head mean heating seasonal COP was 2.63, while multi-head systems had a mean seasonal COP of 1.47. The results indicate that the performance variation between single- and multi-head units was greater than typically stated.

**Table 31. Seasonal COP by DHP Model**

| System Configuration | Mean DHP System Capacity (kBTU) | Calculated HSPF | Mean Seasonal DHP COP | Mean Stated COP @ 5F | Mean Stated COP @ 17F | Mean Stated COP @ 47F |
|---|---|---|---|---|---|---|
| **Single Head** | **12** | **8.98** | **2.63** | **2.0** | **2.3** | **4.2** |
| MSZ-FH09NA | 9 | 8.59 | 2.52 | 2.2 | 2.5 | 4.5 |
| MSZ-FH12NA | 12 | 6.72 | 1.97 | 2.1 | 2.1 | 4.2 |
| MSZ-FH15NA | 15 | 11.83 | 3.47 | 1.7 | 2.1 | 4.1 |
| MSZ-FH18NA | 18 | 5.48 | 1.61 | 1.9 | 2.1 | 3.5 |
| **Multi-head** | **19** | **5.01** | **1.47** | **2.0** | **2.2** | **4.0** |
| MSZ-FH12NA/MSZ-FH06NA | 18 | 5.28 | 1.55 | 2.0 | 2.1 | 4.0 |
| MSZ-FH15NA/MSZ-FH06NA | 21 | 4.82 | 1.41 | 1.9 | 2.1 | 4.0 |
| **All** | **14** | **8.06** | **2.36** | **2.0** | **2.2** | **4.2** |

The impact on COP from temperature can be seen in Figure 15. Temperature during the evaluation period was binned in 5-degree increments and plotted against calculated COP by system. There is a faster degradation of efficiency with colder temperatures than what is stated by the manufacturer for several units. Both MSZ-FH09NA and FH15NA single-head units most closely hewing to stated efficiency curves.

**Figure 15. COP and Ambient Temperature**



For those units, Figure 16 and Figure 17 show the number of days in each temperature bin, with the COP for each bin. This weighted day view is useful in understanding the length of time that the unit performed at varying efficiency levels throughout the pilot study. It is worth noting that both of these systems performed at a relatively high COP level during the polar vortex's worst days, staying at 1.9 COP on average, for all systems in those categories.

**Figure 16. COP and Ambient Temperature – Weighted by Days at Temperature Bin – MUZ-FH09NA**

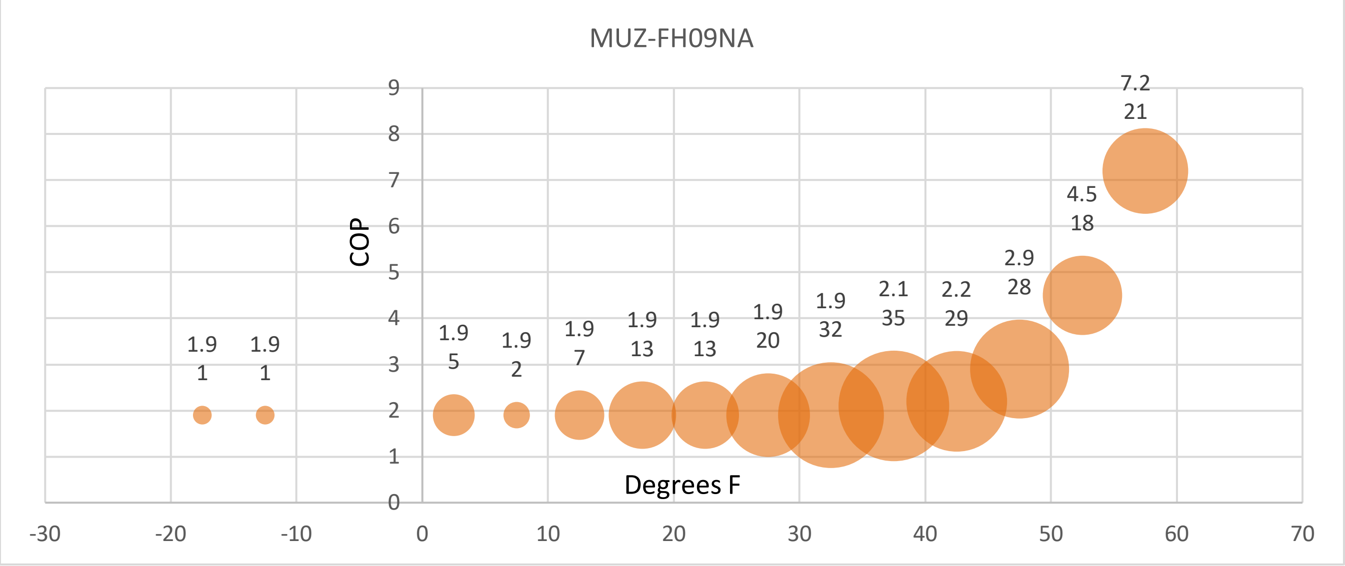
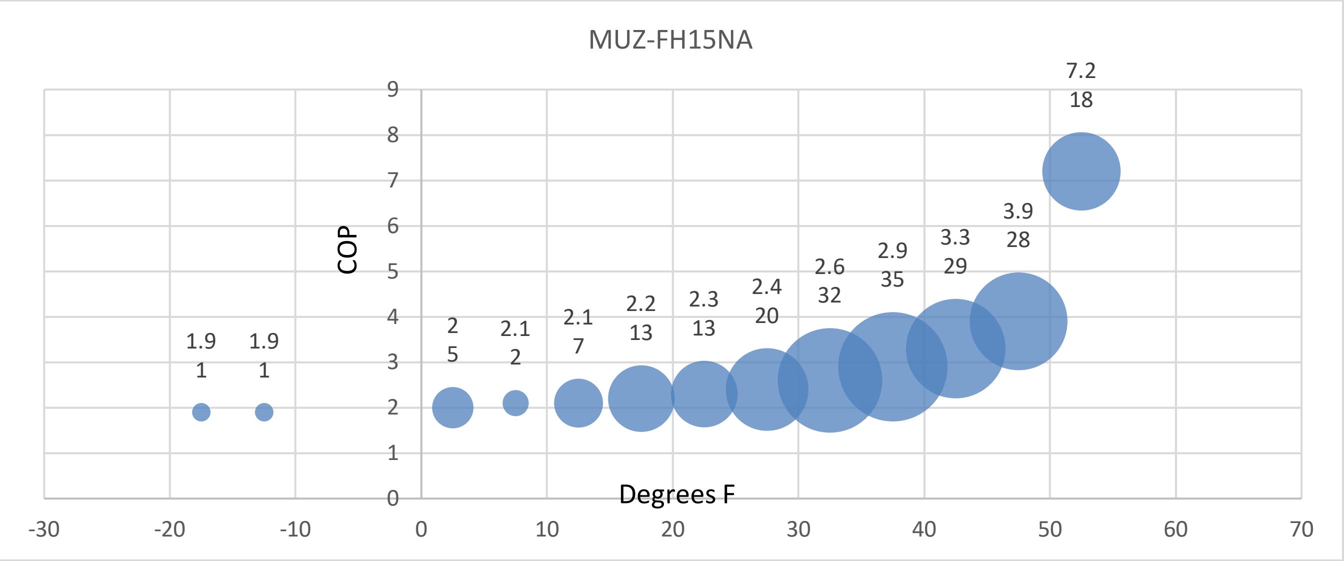


**Figure 17. COP and Ambient Temperature – Weighted by Days at Temperature Bin – MUZ-FH15NA**



The daily electricity consumption against ambient temperature by all DHP model types is shown in Figure 18. Consumption by temperature rose most quickly, starting around 48°F, for multi-head systems, though single head configuration 18K BTU DHPs (two units in the COP analysis) had the lowest COP of any single-head system and the highest daily energy consumption versus temperature.

**Figure 18. Pre and Post AMI and Temperature Plot**

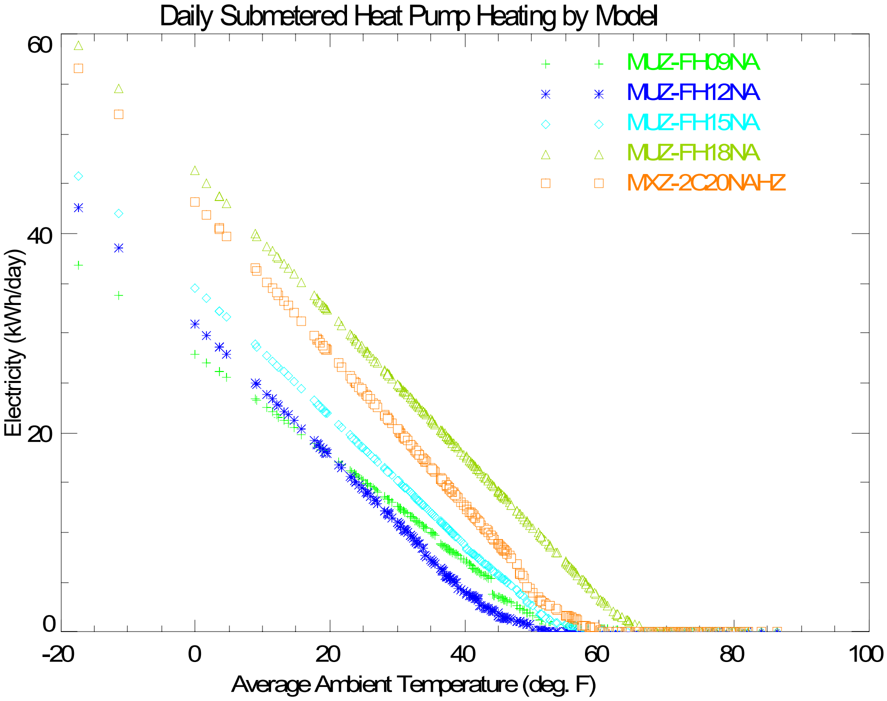


Figure 19 through Figure 23 show the relationship between ambient temperature and sub-metered electric resistance and DHP systems by system type. This is an important relationship for the implied COP calculation for the systems.

**Figure 19. Sub-metered Results by Unit Type MUZ-FH09NA**

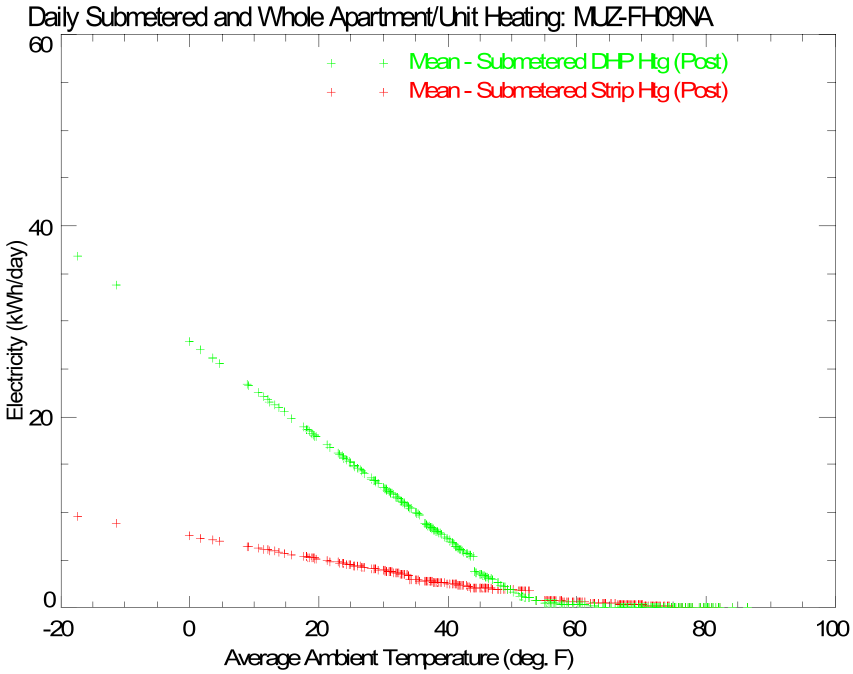


Figure 20. Sub-metered Results by Unit Type MUZ-FH12NA

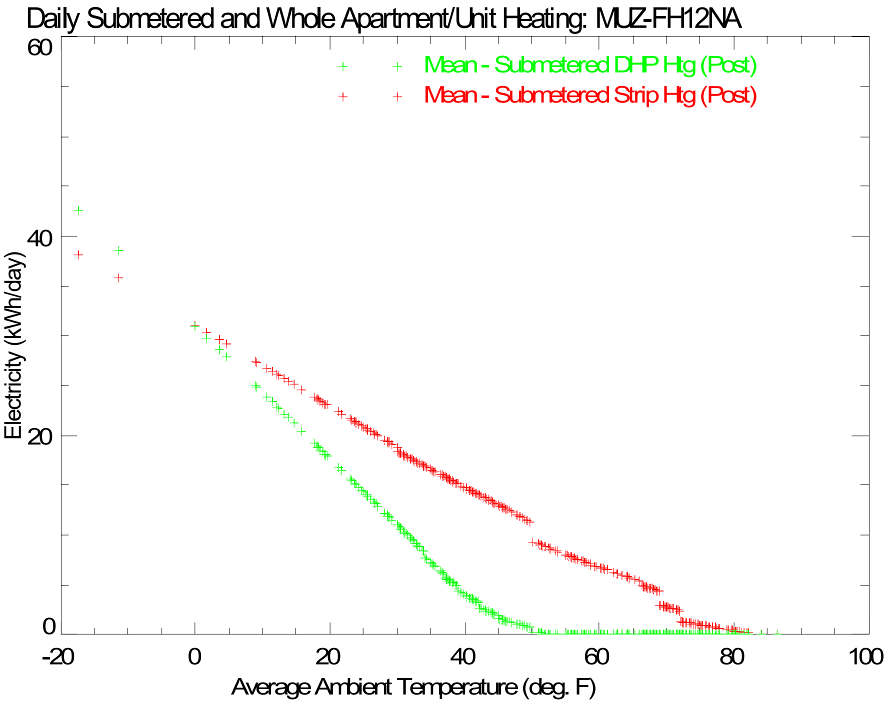
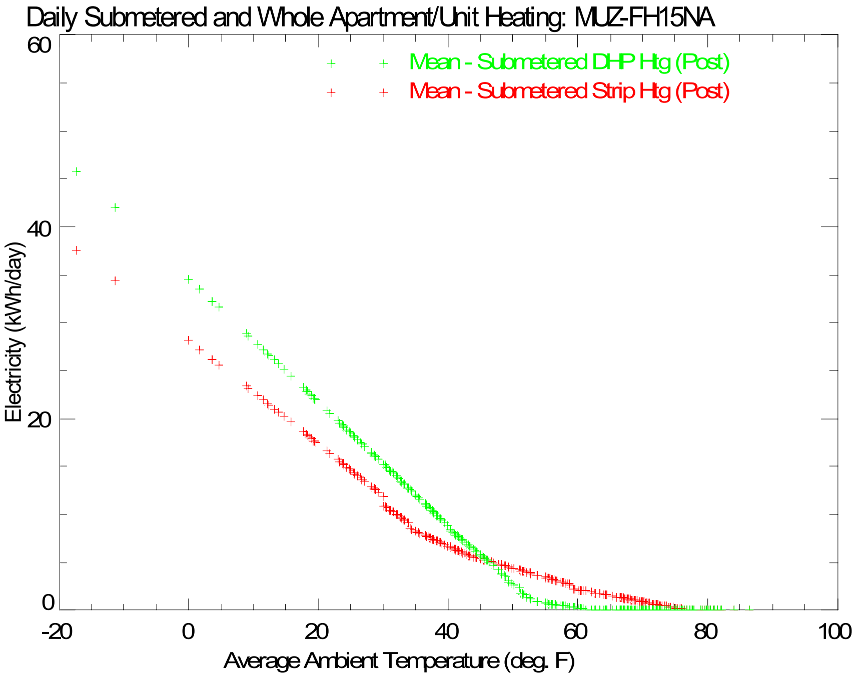


Figure 21. Sub-metered Results by Unit Type MUZ-FH15NA



It should be noted that the 18K single-head systems shown in Figure 22 below also had the lowest electric resistance space heater use, with zero use overall – both of these systems also had an ambient air lock-out control. The low resistance heat and high DHP consumption created a scenario where the system and DHP COP were equal, though very low.  As the relationship for this system to temperature does not follow similar ratios as other systems, other factors may be impacting the COP, including heating temperature and heating load.

**Figure 22. Sub-metered Results by Unit Type MUZ-FH18NA**

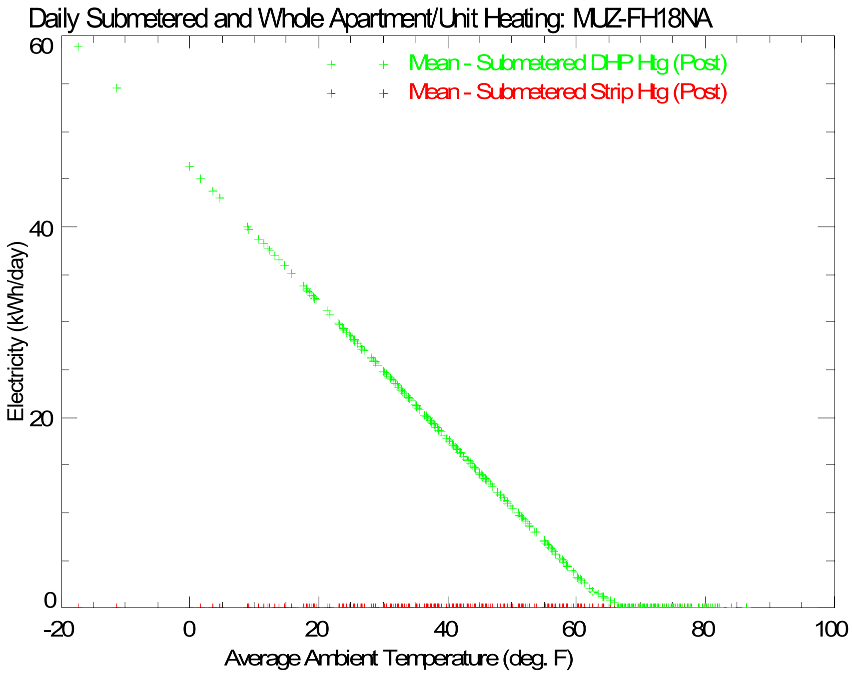
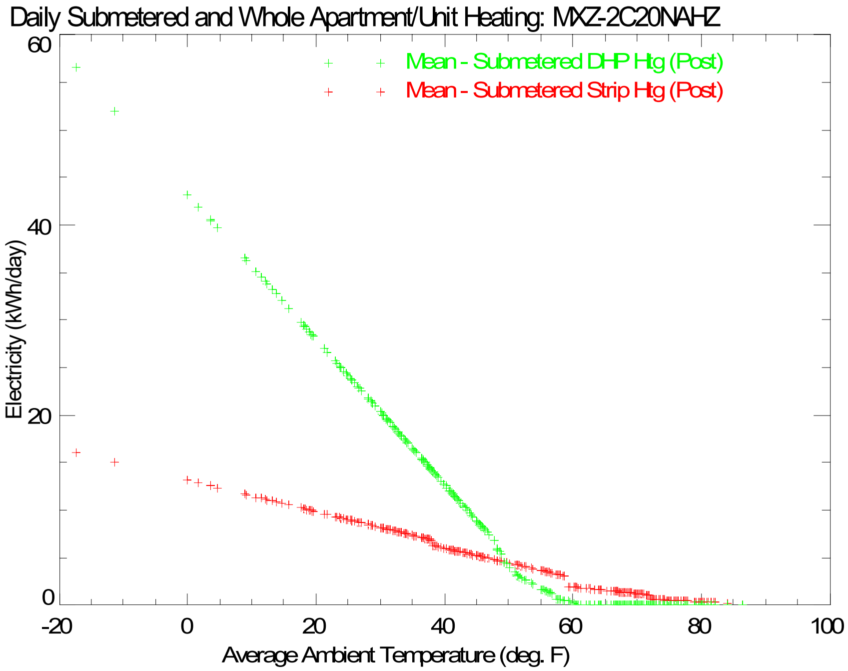
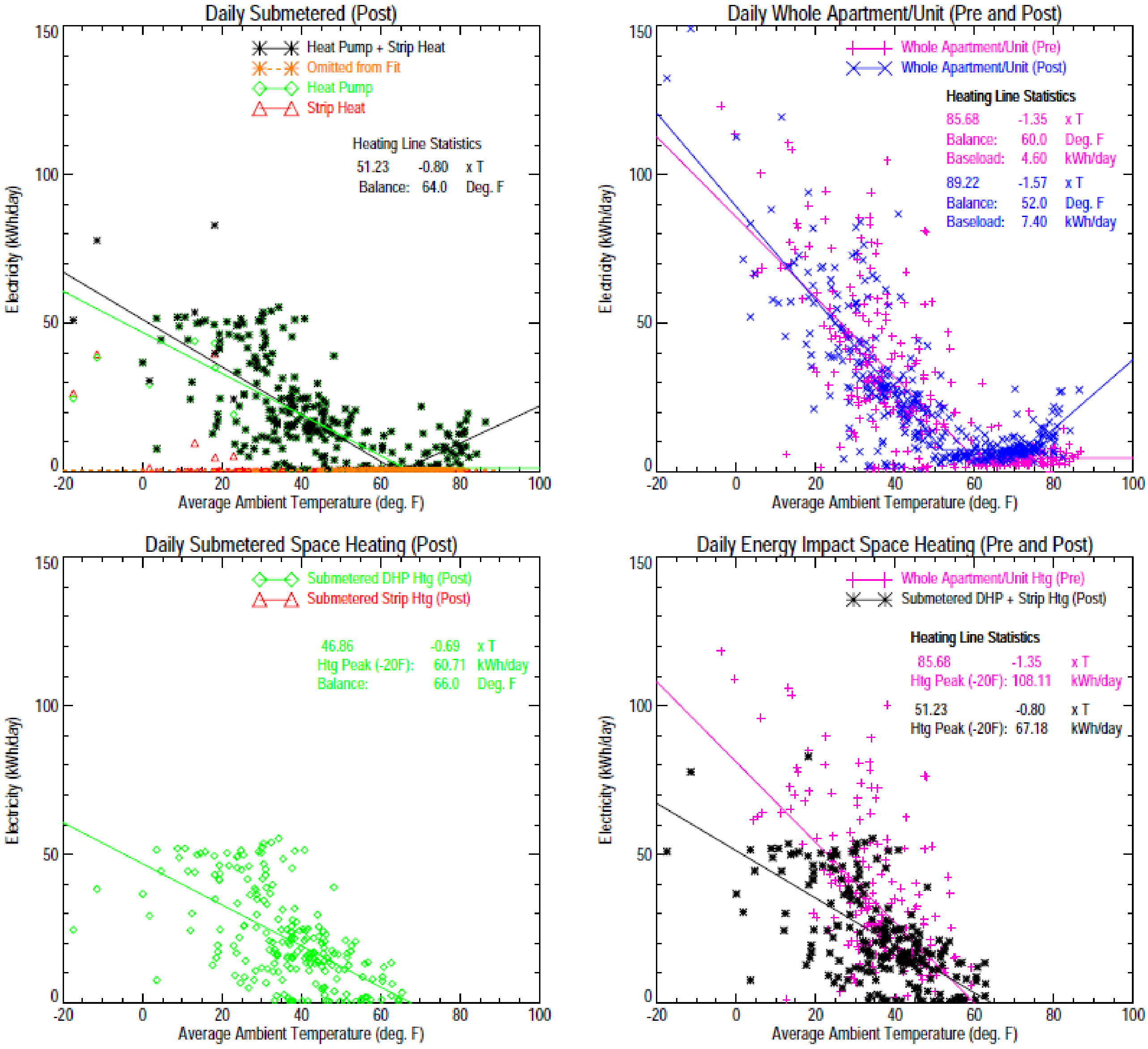


**Figure 23. Sub-metered Results by Unit Type MXZ-2C20NAHZ**



Further analysis of an example from site 2-A with a single-head 18K further highlights this relationship. Utilizing a COP bin analysis on mean heating load trends may not necessarily represent the performance of each system type. There are many factors that impact performance at each individual site such as balance points, behavioral pre and post period operation, and owner comfort level. When averaged together, these may not be totally representative, though the overall implied COP is appropriate for generalized performance of the systems.

**Figure 24. Site 2-A 18K Single-Head Example**



It is useful to note that while greater COP values indicate lesser electricity consumption for the unit, there are other factors influencing heating energy impacts, such as pre-heating usage, building shell treatment, etc. That is, the savings associated with each DHP installation will be proportional to the apartment's heating requirements.

A summary of calculated seasonal system efficiencies by site and group and can be found below in Table 32. The table shows that sites with a higher percentage of multi-head systems have lower mean COP as a result. This includes site 1-C, which features 100 percent multi-head units and the lowest mean COP as 1.4.

**Table 32. Seasonal System Efficiency Summary**

| Site | Mean Seasonal COP | Mean Normal Heat Energy Impact (kWh) | % Mean Heating Reduction | % with Lock-out | % with Multi-head | % with Shell Treat |
|---|---|---|---|---|---|---|
| **Group 1** | **1.91** | **1223** | **22%** | **25%** | **38%** | **25%** |
| **1-A** | 1.73 | 1429 | 19% | 0% | 50% | 0% |
| **1-B** | 2.24 | 724 | 21% | 100% | 0% | 100% |
| **1-C** | 1.41 | 814 | 14% | 0% | 100% | 0% |
| **1-D** | 2.57 | 1925 | 38% | 0% | 0% | 0% |
| **Group 2** | **2.79** | **1925** | **26%** | **26%** | **7%** | **0%** |
| **2-A** | 2.36 | 2476 | 24% | 53% | 20% | 0% |
| **2-B** | 3.29 | 1812 | 22% | 24% | 0% | 0% |
| **2-C** | 2.49 | 1514 | 36% | 0% | 0% | 0% |
| **All** | **2.36** | **1637** | **25%** | **25%** | **19%** | **10%** |

### 3.2.11 Polar Vortex

In January and early February 2019, a wave of brutally cold air from the Arctic polar vortex caused sub-zero temperatures across Canada and the north-central United States. The impact on the Midwest, and in particular Illinois, was extreme. For example, the temperature plunged to -17°F, with a windchill of -52°F, at Chicago O'Hare International Airport. The average daily temperatures at NOAA weather station at O'Hare International Airport, from January 24, 2019 to February 1, 2019, was 2.5°F. The daily temperature of the event, as well as the proceeding and following days, is shown in Table 33.

**Table 33. NOAA - Chicago O'Hare International Airport, IL - Weather Data**

| NOAA – Chicago O'Hara International Airport, IL | |
|---|---|
| Date | Daily Temperature |
| 21-Jan-2019 | 10.0°F |
| 22-Jan-2019 | 23.0°F |
| 23-Jan-2019 | 26.5°F |
| **24-Jan-2019** | **12.0°F** |
| **25-Jan-2019** | **-0.5°F** |
| **26-Jan-2019** | **2.5°F** |
| **27-Jan-2019** | **3.0°F** |
| **28-Jan-2019** | **21.0°F** |

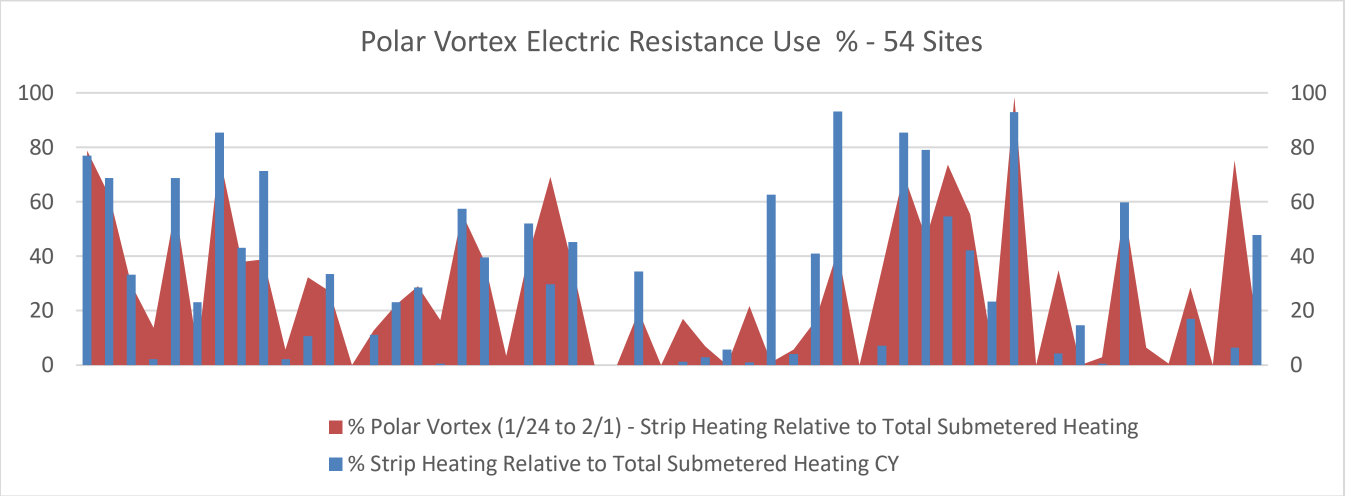
| NOAA – Chicago O'Hara International Airport, IL | |
|---|---|
| **29-Jan-2019** | **0.0°F** |
| **30-Jan-2019** | **-16.5°F** |
| **31-Jan-2019** | **-10.0°F** |
| **1-Feb-2019** | **11.0°F** |
| 2-Feb-2019 | 28.0°F |
| 3-Feb-2019 | 43.5°F |
| 4-Feb-2019 | 40.5°F |
| 5-Feb-2019 | 28.5 |

The influx of air from the North Pole created intense winds with several areas experiencing large snowfall; multiple people died as a result. While extremely unfortunate, these conditions created a testing scenario for cold climate heat pump technology, as well as utilization of electric resistance systems, as the period was significantly outside design temperature ranges.

### *Polar Vortex Electric Resistance Use as Percentage of Overall Sub-metered Heating*

The drop in temperature allowed almost unfettered access to electric resistance heating in all housing units, as the temperature dropped below 15°F on 89 percent of the days during the polar vortex event. In many cases, this resulted in higher electric resistance heating use and impacts the heating load trend during the post period, though other surprising behavior also resulted. This included the non-use of electric resistance heating during the event as well as increased ccDHP use for those not previously utilizing the ccDHPs. While the decision to leave the electric resistance heating in place as a supplemental heating source was buttressed by this event, not all occupants utilized the electric resistance heat in the same way. The variation in electric resistance utilization is shown in Figure 25.

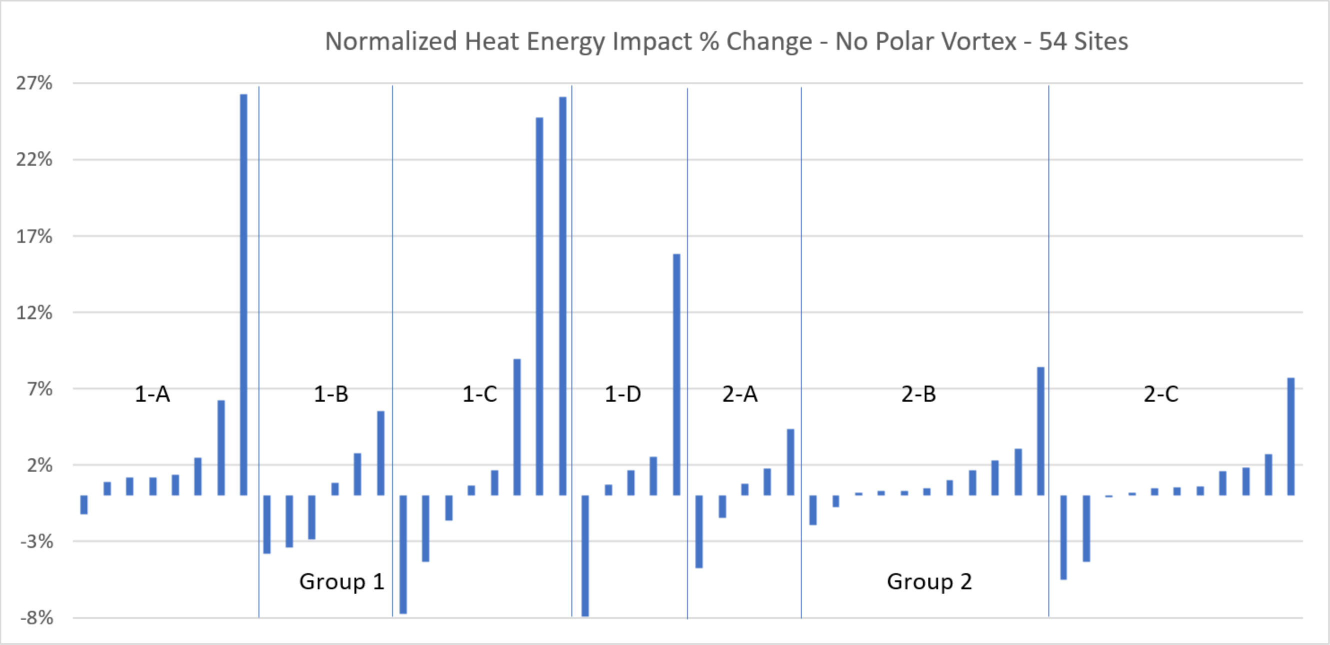
Figure 25. Electric Resistance % - Polar Vortex



## *Polar Vortex – Heating Energy Impact*

The total mean heating energy impact for all sites was 2.19 percent more negative due to the polar vortex. Of the 54 sites where sub-metered data was available, 39 sites demonstrate a more positive normalized heating energy impact with the removal of the polar vortex event from the data set. Fifteen sites would have a more negative energy impact. This can be seen in Figure 26.

Figure 26. Percent Change Normalized Heat Energy Impact – No Polar Vortex, 54 Sites

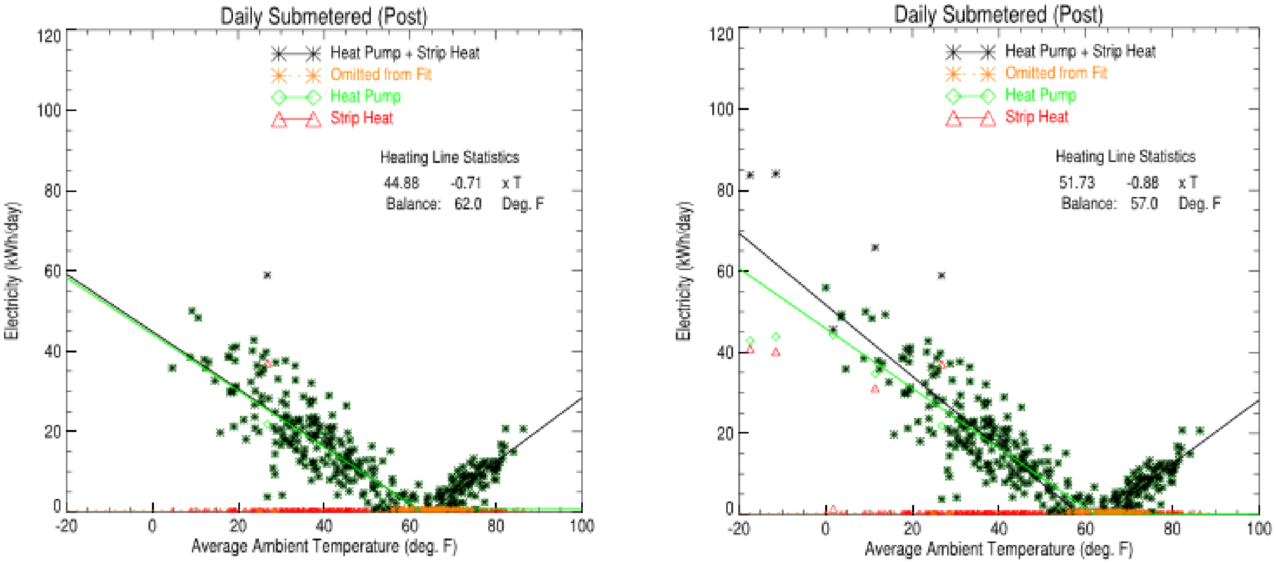


## *Polar Vortex – Resistance Heat Negative Impact*

An example of this negative energy impact based on increased electric resistance use can be seen in

Figure 27. The plot on the left shows the heating load trend without the polar vortex period and indicates a high reliance on the ccDHP and a lower load trend. The right plot includes the nine days designated as the polar vortex and it shows that the occupant decided to use the strip heating in conjunction with the heat pump.

**Figure 27. Example Plots of Polar Vortex Impact- Site 2-A – R – Polar Vortex, L – Rest of Heating Season**



The difference results in a 4.34 percent increase in savings (149 kWh) **without** the polar vortex event.

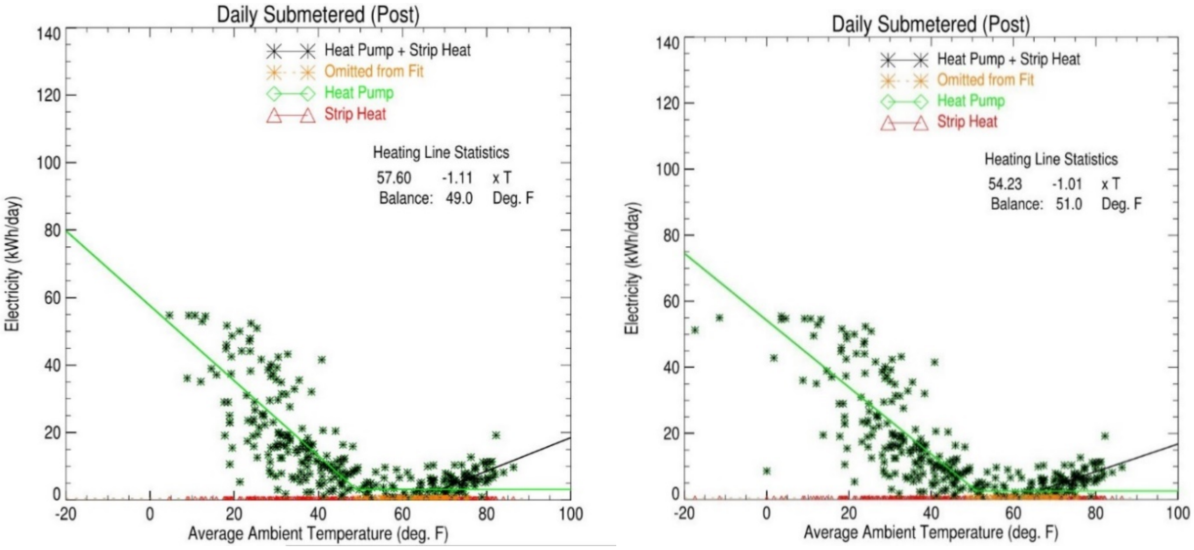
**Table 34. Example of Polar Vortex Impact- Unit at Site 2-A**

| Analyzed Time Period | HP Energy as % Total Heat | Electric Resistance Energy as % Total Heat | Mean Energy Savings (kWh) |
|---|---|---|---|
| **Jan 24th – Feb 1st Only** | 78.2 | 21.8 | - |
| **Jan – Dec 2019 Excluding Jan 24th – Feb 1st** | 99.0 | 0.1 | 3,422 |
| **Jan – Dec 2019** | - | - | 3,279 |

### *Polar Vortex – Non-energized Electric Resistance*

Not all housing units increased electric resistance usage during the event. Sixteen total sites relied on the ccDHP at a rate of 100 percent during the polar vortex. This includes the majority of apartments at site 1-D, which also had the highest overall mean savings of any site at 38 percent. This was a surprising discovery. An example is a housing unit at site 2-B as shown in Figure 28. The plot on the right represents the nine days of the polar vortex event. The plots indicate that the resident does not use strip heating even during the coldest periods. The heat pump levels out below approximately 5°F, so it is likely that the heat pump was at capacity resulting in colder temperatures inside the apartment.

Figure 28. Example Plots of Polar Vortex Impact- Site 2-B – R – Polar Vortex, L – Rest of Heating Season



The load trend decreases on the bottom plot since there are points over colder days that do not follow the expected trend. The result is a 0.76 percent decrease in savings (-14 kWh).

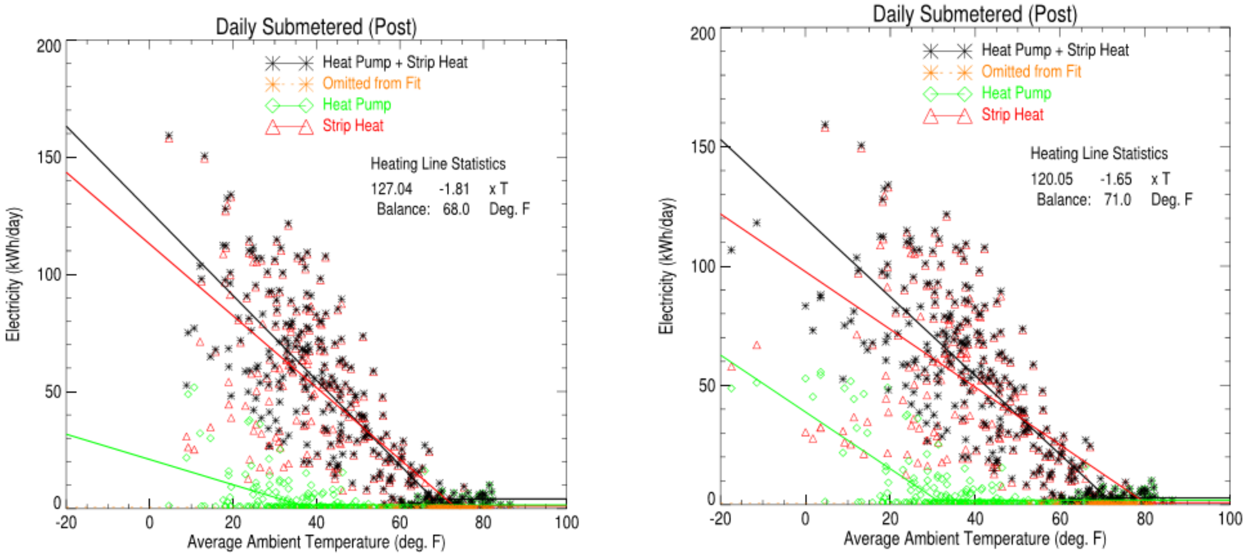
Table 35. Example of Polar Vortex Impact- Unit at Site 2-B

| Analyzed Time Period | HP Energy as % Total Heat | Electric Resistance Energy as % Total Heat | Mean Energy Savings (kWh) |
|---|---|---|---|
| **Jan 24th – Feb 1st Only** | 100 | 0 | - |
| **Jan – Dec 2019 Excluding Jan 24th – Feb 1st** | 100 | 0 | 1,800 |
| **Jan – Dec 2019** | - | - | 1,813 |

### *Polar Vortex – Increased Heat Pump Utilization*

Another interesting behavior characteristic was witnessed in housing units that generally only used electric resistance heat leading to overall negative energy impacts. There were six apartments that demonstrated a 20 percent or more increase in ccDHP usage as percentage of total heating as a result of the polar vortex. An example housing unit, also from site 2-B, where the occupant generally uses electric resistance heating over the ccDHP but begins to use the ccDHP in conjunction with strip heating when daily temperatures are below ~35F. See Figure 29 below. The left plot shows the heating load trend without the colder period, resulting in less heat pump heating.

**Figure 29. Example Plots of Polar Vortex Increased DHP- Site 2-B – R – Polar Vortex, L – Rest of Heating Season**



The difference results in a 0.3 percent decrease in savings (13 kWh) without the vortex event. The load trend decreases on the right plot, which is due to the more efficient heat pump contributing more to the total heating load. The savings are in result of a balance point shift from 71°F when including the colder period to 68°F when not including the colder period.

**Table 36. Example of Polar Vortex Impact- Unit at Site 2-B**

| Analyzed Time Period | HP Energy as % Total Heat | Electric Resistance Energy as % Total Heat | Mean Energy Savings (kWh) |
|---|---|---|---|
| **Jan 24th – Feb 1st Only** | 57.8 | 42.2 | - |
| **Jan – Dec 2019 Excluding Jan 24th – Feb 1st** | 6.7 | 93.2 | -4,273 |
| **Jan – Dec 2019** | - | - | -4,261 |

## 3.3 Calculation Methodology

### 3.3.1 Pre-Processing and Data Quality

Data output from the sub-metered devices and smart thermostats varied in formats and/or different incremental time ranges. Prior to the commencement of data analysis, CMC processed the raw data daily into a database with a consistent format. We defined a valid daily data point as one that has been created from a full day of interval data. This means that the 15-minute sub-metered interval dataset must have data available for all 96 data intervals in the day (4 intervals/hour x 24 hours/day) for it to be given a daily value.

The daily heat pump power *HP(d)* is the sum over all intervals *i* in the day, where *ni* is the total number of intervals in the day:

$$HP(d) = \begin{cases} \sum_{i=1}^{ni} HP(i), & ni = 96 \\ nodata & ni \neq 96 \end{cases}$$

The sub-metered data for each unit contains up to four electric resistance strip heat measurement channels. We sum all four strip heat channels to generate a single value for whole apartment electric resistance strip heat electricity use per day *STRIP(d)*:

$$STRIP(d) = \begin{cases} \sum_{i=1}^{ni} STRIP1(i) + STRIP2(i) + STRIP3(i) + STRIP4(i) & ni = 96 \\ nodata & ni \neq 96 \end{cases}$$

This creates a small analytical limitation, in that specific electric resistance sources, i.e. bedroom locations, cannot be identified for heavier usage. The ease of analysis for the compiled electric resistance heating sources made this a preferable choice. It also provided an adequate look at supplemental heating.

For some of the sub-metered data loggers, the electrical energy interval data is negative from the first record until a point in time, after which it is all positive. A negative value for electrical energy heat pump or resistance heat is not the result of the physical environment, and the absolute value of the data during the initial period follows the same trend against ambient temperature once it changes to all positive values. We therefore assume that the direction of the current transducer (CT) readings were manually switched at that time and take the absolute value of all sub-metered readings prior to converting the interval data to daily values.

### 3.3.2 Energy Impacts

A critical area of focus for this study is the energy impacts of ccDHPs in LMI multifamily settings. The pilot design will apply these findings to the expected impacts for a scaled program, existing and future acquisition costs and program optimization recommendations for the most positive energy impacts. With these goals in mind, energy impacts are calculated here by comparing space heating and cooling energy use extracted from whole building electric energy usage for the baseline period with the sub-metered ccDHP cooling and heating energy usage and electrical resistance strip heat energy usage for the post-installation period.

For this analysis, the baseline period *b* is defined as January 1, 2018, to December 31, 2018, and the post period *p* is defined as January 1, 2019, to December 31, 2019. These corresponding months allow for comparison of similar weather patterns and reduces differences from seasonal changes in occupant behavior. The utility meter data is available for almost all sites from the start of 2018. All ccDHPs were installed in between these two periods and began providing data before the start of 2019, except for four apartments where the heat pump was installed on January 4, 2019. The methodology described below applies to the final analysis.

### 3.3.3 Space Heating and Cooling

We quantify the baseload *Base* (the electrical usage that is not associated with heating or cooling) in kWh/day and heating and cooling balance points *HBAL / CBAL* in degrees Fahrenheit for each apartment unit from the whole building electricity use. It should be noted that baseload electricity use is highly driven by inter-day occupant choices, causing a reasonable amount of scatter in the 1 – 3 kWh band. While time of year has an influence on parameters such as amount of daylight available, when compared to occupant behavior this influence is small.  Additionally, the load shape determined by the regression analysis can have either a “U” or “L” shape with a flat baseload, or “V” shaped where the baseload value occurs only for single period.  Only one of the three load shapes, the “U” shape, would be suitable for a variable baseline analysis, and this would not be consistent with the methodologies used for the other load shapes.  The average, temperature independent baseline method was preferred to simplify the analysis and provide consistency.

CMC used the baseload values to isolate the space heating and cooling electric usage during the baseline period. To do this, CMC used a two-changepoint method using EEmeter python library[7] thorough python version 2.7. A data array of daily power data was populated and output into a file and was used in conjunction with an hourly ambient temperature file. The energy and temperature data were imported and prepared by the library into a daily design matrix to generate daily temperature values by aggregating the hourly data. The design matrix was then used by the library to generate a model according to CALTRACK[8] specifications. The parameters for the heating, cooling and baseload lines were then obtained from the model and output to a file. The model parameters from the updated file are returned to use for the final analysis.

The result is a three-line model that optimizes the change point between the heating, cooling and baseload. This model was applied on each of the baseline and post AMI periods, with an assumption that the baseload is constant outside of heating and cooling days, i.e., it is not correlated with temperature. The model provides a single baseload for baseline (*Basepre*) and post AMI (*Basepost*) periods and heating and cooling balance points for the baseline (*PRE*) and post AMI (*POST)* periods.

An example of heating and cooling is depicted in Figure 30.

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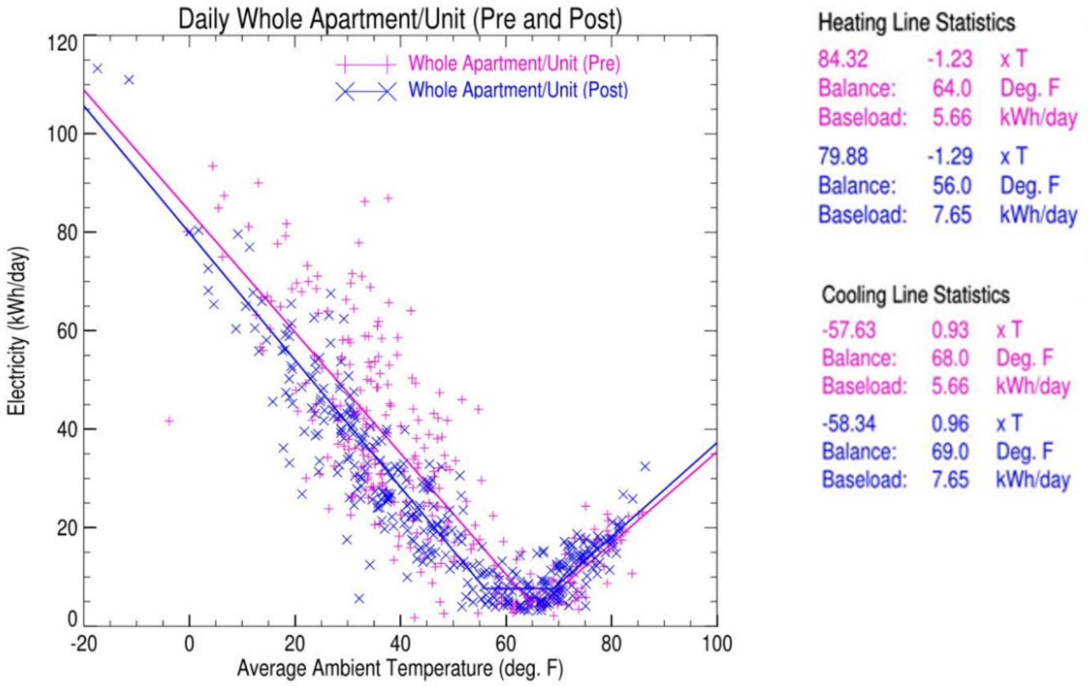
[7] http://eemeter.openee.io/

[8] https://www.caltrack.org/

**Figure 30. Example AMI Utility Analysis with Two-Changepoint Method – Heating and Cooling**



The heating and cooling balance point was taken to be the baseline and post balance point *(CBALPRE / HBALPRE & CBALPOST_AMI / HBALPOST_AMI*).

### Heating

The daily space heating electrical usage in the baseline period (*HEPRE*) was then taken to be the whole building electrical usage *WB* minus the baseload (*Basepre*):

$$HE_{PRE}(d) = \begin{cases} WB(d) - Base_{PRE}(d) & T \leq HBAL_{PRE} \\ 0 & T > HBAL_{PRE} \end{cases}$$

The daily space heating electrical usage in the post period (*HEPOST_AMI*) was then taken to be the whole building electrical usage *WB* minus the baseload (*Basepost*):

$$HE_{POST\_AMI}(d) = \begin{cases} WB(d) - Base_{POST}(d) & T \leq HBAL_{POST\_AMI} \\ 0 & T > HBAL_{POST\_AMI} \end{cases}$$

### Cooling

The daily space cooling electrical usage in the baseline period (*CEPRE*) was then taken to be the whole building electrical usage *WB* minus the baseload (*Basepre*):

$$CE_{PRE}(d) = \begin{cases} WB(d) - Base_{PRE}(d) & T > CBAL_{PRE} \\ 0 & T \leq CBAL_{PRE} \end{cases}$$

The daily space cooling electrical usage in the post period (*CEPOST_AMI*) was then taken to be the whole building electrical usage *WB* minus the baseload (*Basepost*):

$$CE_{POST\_AMI}(d) = \begin{cases} WB(d) - Base_{POST}(d) & T > CBAL_{POST\_AMI} \\ 0 & T \leq CBAL_{POST\_AMI} \end{cases}$$

### *kWh from January through June 2019*

To normalize space heating and cooling electrical usage in the pre and post period, CMC used the line from the two-changepoint model on the daily baseline and post AMI values *HEPRE(d)* and *HEPOST_AMI(d) and CEPRE(d)* and *CEPOST_AMI(d)* to identify a normalized heating and cooling load line for each period,

$$HE_{pre\_norm}(d) = c0 + c1 \times T_{post}$$

$$CE_{pre\_norm}(d) = c0 + c1 \times T_{post}$$

where *HEpre_norm* is the normalized electric usage for space heating and *CEpre_norm* is the normalized electric usage for space cooling in the pre period, *TPost* is the ambient temperature in the post period, and *c0* and *c1* are the coefficients of the fitted line provided by the two-changepoint model.

$$HE_{post\_AMI\_norm}(d) = c0 + c1 \times T_{post}$$

$$CE_{post\_AMI\_norm}(d) = c0 + c1 \times T_{post}$$

where *HEpost_AMI_norm* is the normalized electric usage for space heating and *CEpost_AMI_norm* is the normalized electric usage for space cooling in the post period, and *c0* and *c1* are the coefficients of the fitted line provided by the two-changepoint model.

The baseline space heating and cooling electrical usage is the sum of the normalized space heating and cooling over all baseline days, i.e.,

$$HE_{pre\_norm} = \sum_{d=1}^{nd} HE_{pre\_norm}(d)$$

$$CE_{pre\_norm} = \sum_{d=1}^{nd} CE_{pre\_norm}(d)$$

Similarly, the post AMI normalized space heating and cooling electrical usage is:

$$HE_{post\_AMI\_norm} = \sum_{d=1}^{nd} HE_{post\_AMI\_norm}(d)$$

$$CE_{post\_AMI\_norm} = \sum_{d=1}^{nd} CE_{post\_AMI\_norm}(d)$$

The energy impact in kWh is the difference between the normalized baseline and post AMI periods:

$$HEI_{norm} = HE_{post\_AMI\_norm} - HE_{pre\_norm}$$

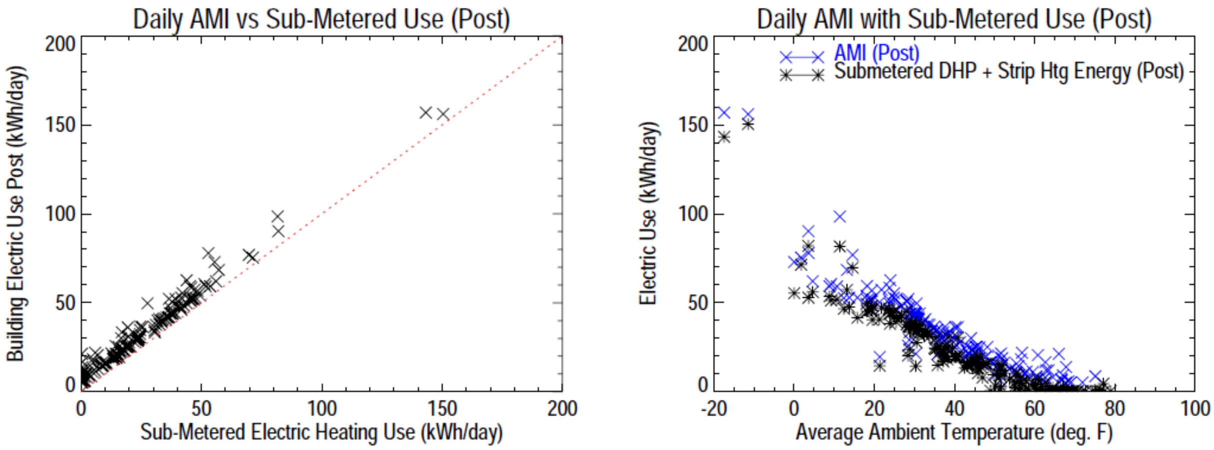
$$CEI_{norm} = CE_{post\_AMI\_norm} - CE_{pre\_norm}$$

These values have been presented both as kWh and kWh per square foot. The metrics were calculated for each apartment unit, allowing CMC to report the minimum, maximum and mean over all apartments and to use the results for cross-tabulation, analysis and visualization. No adjustment was made to subtract non-heating energy such as defrost cycles or standby power.

### 3.3.4 Alternative Energy Impact Analysis – Post AMI Readings vs. Sub-Metered Measurements

To ensure that each utility AMI meter is associated with the correct sub-metered meter, CMC analyzed the total space heating load from the sub-meters in the post-installation period alongside the whole housing unit electricity usage for the same period. This also can indicate if sub-metered loads have been captured correctly. Figure 31 below shows an apartment with a high correlation between the utility AMI and the sub-metered data.

**Figure 31. AMI and Sub-Meter Correlation Example**



Sites with suspected missing sub-metered heating loads were previously flagged and removed from the data analysis.

CMC conducted an additional analysis to make all sites valid by using the post AMI readings as a substitute for the sub-metered data. Through this additional analysis, CMC is able to provide system

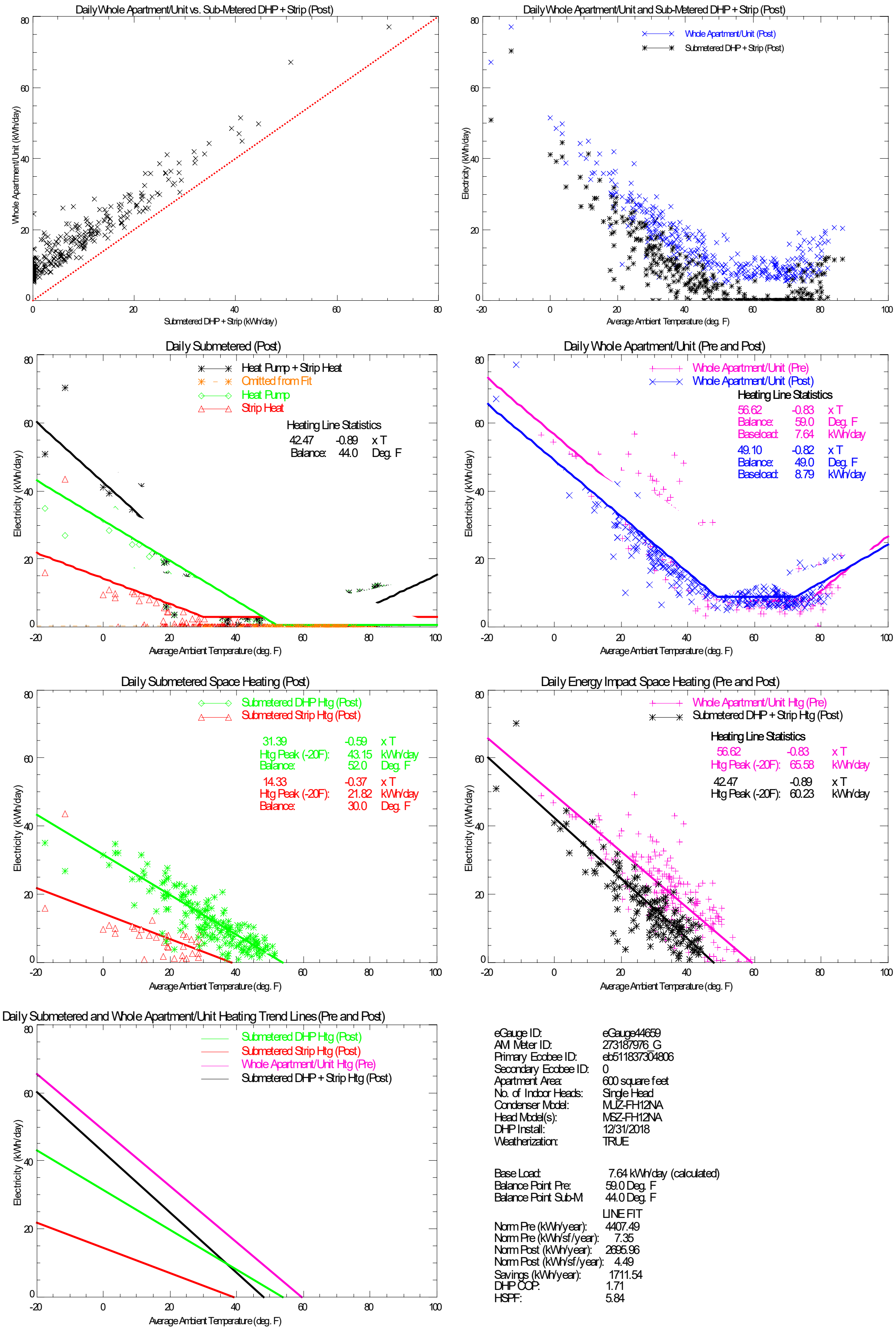
COP (strip and heat pump heating performance combined) and an energy impact, though HP COP could not be identified separately. The overall impact on mean savings for sites using the alternative methodology was a reduction in savings, as the replacement for missing sub-metered heating loads with AMI data will cause a correction more in line with actual usage. This provides a more accurate analysis and prevents inflated savings estimates. Two sites were removed from the analysis due to no pre-heating AMI data; the lack of missing AMI data is undetermined, though may be related to occupancy or meter issues. Inclusion of these housing units would have created unconfirmed negative heating and cooling impacts, compromising the results of the study. The number of sites that utilized the alternative analysis methodology can be seen below in Table 37.

**Table 37. Application of Methodology Count**

| Site | Total Units at Site | Units Treated | % of Units Treated | Units Included in Analysis | % of Units Treated Included in Analysis | Primary Analysis | Secondary Analysis |
|---|---|---|---|---|---|---|---|
| **1-A** | 8 | 8 | 100% | 8 | 100% | 8 | 0 |
| **1-B** | 8 | 8 | 100% | 8 | 100% | 6 | 2 |
| **1-C** | 8 | 8 | 100% | 8 | 100% | 8 | 0 |
| **1-D** | 8 | 8 | 100% | 8 | 100% | 5 | 3 |
| **2-A** | 30 | 15 | 50% | 15 | 100% | 5 | 10 |
| **2-B** | 17 | 17 | 100% | 15 | 88% | 11 | 4 |
| **2-C** | 32 | 16 | 50% | 16 | 100% | 11 | 5 |
| **All** | **111** | **80** | **72%** | **78** | **98%** | **54** | **24** |

Providing this secondary analysis also allowed CMC to compare results for non-flagged sites. It is important to note that the two analyses look at completely different sets of data, though the overall mean energy impact was similar. In many cases, the combined sub-metered heating measurements had a close correlation to the post AMI readings, making for similar results when calculating energy impact and system COP, with the heating sub-metered and post AMI load lines appearing very similar. An example can be found below in Figure 32. Combined sub-metered heating measurements for this example had a close correlation to the post AMI readings, making for similar results when calculating energy impact and system COP. If the 8.79 kWh/day baseload was subtracted from the blue post AMI readings (Figure 31 above), the heating sub-metered and post AMI load lines would be very similar.

## Figure 32. Alternative Methodology Correlation Example



Daily Whole Apartment/Unit vs. Sub-Metered DHP + Strip (Post)

Daily Whole Apartment/Unit and Sub-Metered DHP + Strip (Post)

Daily Submetered (Post)

Daily Whole Apartment/Unit (Pre and Post)

Daily Submetered Space Heating (Post)

Daily Energy Impact Space Heating (Pre and Post)

Daily Submetered and Whole Apartment/Unit Heating Trend Lines (Pre and Post)

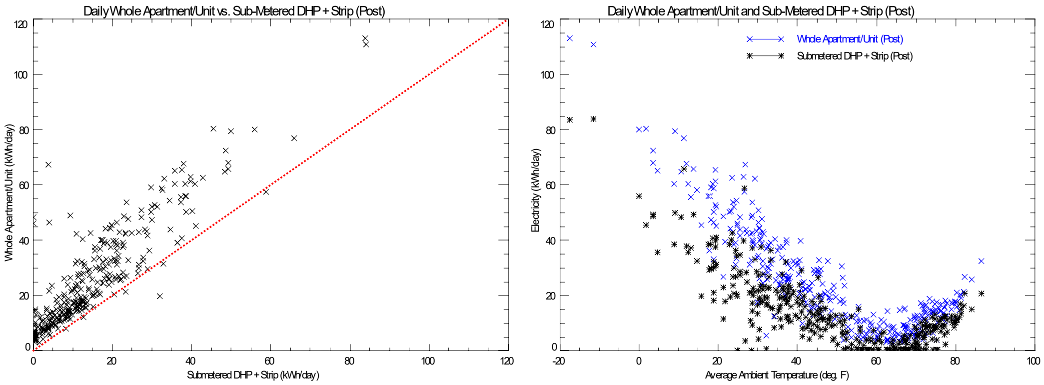
eGauge ID: eGauge44659
AM Meter ID: 273187976_G
Primary Ecobee ID: eb511837304806
Secondary Ecobee ID: 0
Apartment Area: 600 square feet
No. of Indoor Heads: Single Head
Condenser Model: MUZ-FH12NA
Head Model(s): MSZ-FH12NA
DHP Install: 12/31/2018
Weatherization: TRUE

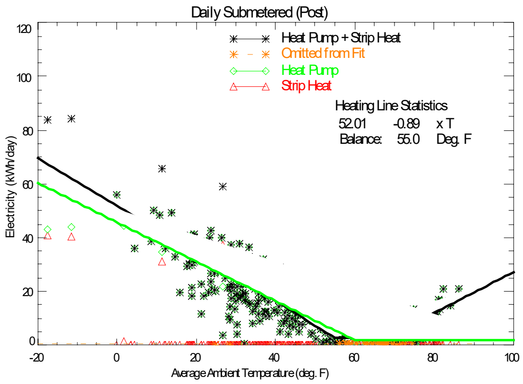
Base Load: 7.64 kWh/day (calculated)
Balance Point Pre: 59.0 Deg. F
Balance Point Sub-M: 44.0 Deg. F

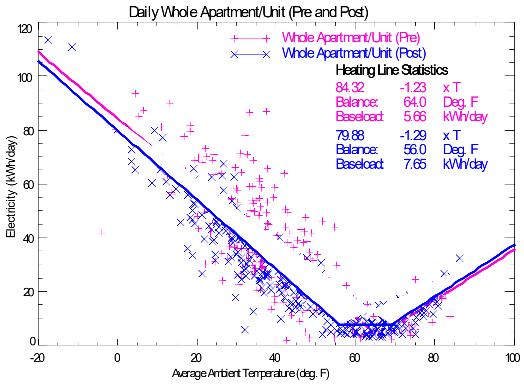
LINE FIT
Norm Pre (kWh/year): 4407.49
Norm Pre (kWh/sf/year): 7.35
Norm Post (kWh/year): 2695.96
Norm Post (kWh/sf/year): 4.49
Savings (kWh/year): 1711.54
DHP COP: 1.71
HSPF: 5.84

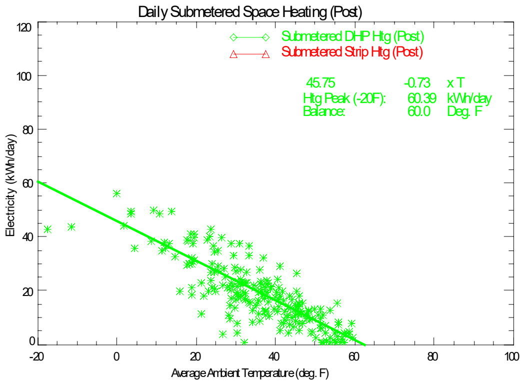
When sub-metered heating measurements were less or zero during the heating season and the post AMI data continued to show operation, this changed the location of the heating trend line and balance point between post AMI and sub-metered data. The system COP and energy impact is based on very different trends and is greatly impacted. An example can be found below in Figure 33. Sub-metered heating measurements in this example were lower than the post AMI data, which can be seen in the comparison plot. The sub-metered measurements peak at 69.86 kWh/day while the post AMI readings peak just under 100 kWh/day once the baseload is removed. This changes where the heating trend line is located between post AMI and sub-metered data.

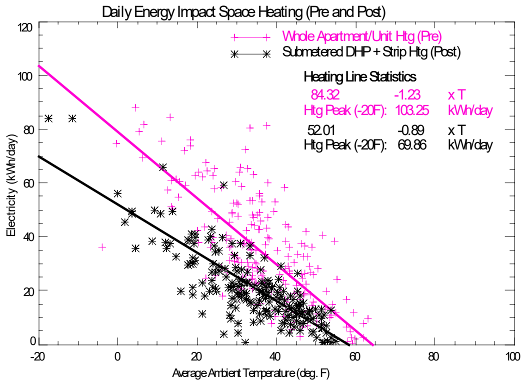
**Figure 33. Alternative Methodology Non-Correlation Example**

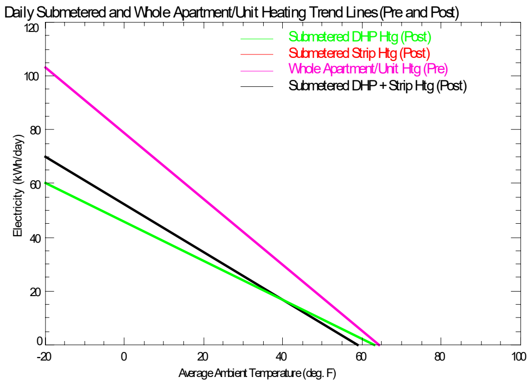












| | |
|---|---|
| eGauge ID: | eGauge44636 |
| AM Meter ID: | 270453852_G |
| Primary Ecobee ID: | eb511898885229 |
| Secondary Ecobee ID: | 0 |
| Apartment Area: | 702 square feet |
| No. of Indoor Heads: | Single |
| Condenser Model: | MUZ-FH18NA |
| Head Model(s): | MSZ-FH18NA |
| DHP Install: | 11/2/2018 |
| Weatherization: | FALSE |

| | |
|---|---|
| Base Load: | 5.66 kWh/day (calculated) |
| Balance Point Pre: | 64.0 Deg. F |
| Balance Point Sub-M | 55.0 Deg. F |
| | LINE FIT |
| Norm Pre (kWh/year): | 7984.22 |
| Norm Pre (kWh/sf/year): | 11.37 |
| Norm Post (kWh/year): | 4594.45 |
| Norm Post (kWh/sf/year): | 6.54 |
| Savings (kWh/year): | 3389.77 |
| DHP COP: | 1.74 |
| HSPF: | 5.93 |

## 3.3.5 Additional Statistical Analysis

Where possible and applicable, CMC has completed statistical testing on the sample set to look for correlated or directionally related study factors. This additional analysis was completed in IBM SPSS Standard 26 and includes linear regression on scale or interval variables such as pre heat and pre-cooling on energy impacts and multinomial logistic regressions for comparison of multiple nominal (categorical) variables and/or scale or interval data sets. The purpose of these tests is to identify statistically significant relationships that may solidify study findings and provide rationale for future program recommendations.

### 3.3.6 Efficiency Methodology

Efficiency ratings that often come as a result of standardized industry performance testing are not based on field studies. For heat pumps, Heating Seasonal Performance Factors (HSPF) is the common measure of heating efficiency, while Seasonal Energy Efficiency Ratio (SEER) is the equivalent for cooling. TRM calculations, including those for the Illinois TRM, use stated efficiency values based on Air Conditioning, Heating and Refrigeration Institute (AHRI) rated values to create deemed savings results. The mean rated efficiencies, including for COP, for the ccDHP systems used in this study vary depending on the capacity of the system and indoor head configuration. Rate capacities for all systems can be found in Table 38 below.

**Table 38. Rated System Performance**

| | Unit | Rated Capacity @47 | Rated Capacity @32 | Rated Capacity @17 | Cooling Capacity | Rated SEER | Rated EER | Rated HSPF | COP @47 | COP @17 | COP @5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **MSZ-FH06NA2** | 8700 | 7300 | 5900 | | 6000 | 33.1 | 19.1 | 12.5 | 4.68 | 3.14 | 2.45 |
| **MSZ-FH09NA2** | 10900 | 8800 | 6700 | | 12000 | 30.5 | 16.1 | 12.5 | 4.5 | 2.48 | 2.16 |
| **MSZ-FH12NA2** | 13600 | 10800 | 8000 | | 13600 | 26.1 | 13.8 | 11.5 | 4.2 | 2.1 | 2.07 |
| **MSZ-FH15NA2** | 18000 | 14500 | 11000 | | 15000 | 22 | 12.5 | 11 | 4.06 | 2.13 | 1.72 |
| **MSZ-FH18NA2** | 20300 | 17000 | 13700 | | 17200 | 21 | 12.5 | 11 | 3.46 | 2.12 | 1.93 |

These savings estimates may not reflect operation of systems in actual conditions, especially high-intensity weather events. This study looks to examine the operational efficiency ratings as applied to LMI multifamily units, which takes into consideration the retention of electrical resistance space heating. This supplemental heat may create scenarios in which the “system” includes the heat pump, as well as the resistance heat, in tandem. As such, CMC has opted to calculate both a system and heat pump only COP, as well as estimated HSPF and SEER.

### 3.3.7 Implied Coefficient of Performance

Coefficient of performance (COP) is generally defined as energy delivered to a space for heating purposes, divided by the actual electric usage required to operate the delivery technology. From this perspective, electric resistance heat has a COP of 1.0, as all electricity consumed by the delivery technology is converted into usable heat.

Some prior studies, where field testing of COP was attempted, found difficulty in obtaining consistent or accurate results. Standardized laboratory testing of COP is difficult in an uncontrolled environment, such as an apartment unit. The heat pumps selected for this study have the ability to modulate compressor and fan speeds, creating challenges in assessing the amount of heat delivered to a particular housing unit. Because of this, CMC used an implied COP built upon the results of the sub-metered and AMI datasets.

To normalize space heating and cooling electrical usage in the pre and post period, CMC used the line from the two-changepoint model on the daily baseline and post-installation values *HEPRE(d)* and *HEPOST(d) and CEPRE(d)* and *CEPOST(d)* to identify a normalized heating and cooling load line for each period,

$$HE_{pre\_norm}(d) = c0 + c1 \times T_{post}$$

$$CE_{pre\_norm}(d) = c0 + c1 \times T_{post}$$

where *HEpre_norm* is the normalized electric usage for space heating and *CEpre_norm* is the normalized electric usage for space cooling in the pre period, *TPost* is the ambient temperature in the post period, and *c0* and *c1* are the coefficients of the fitted line provided by the two-changepoint model.

$$HE_{post\_norm}(d) = c0 + c1 \times T_{post}$$

$$CE_{post\_norm}(d) = c0 + c1 \times T_{post}$$

where *HEpost_norm* is the normalized electric usage for space heating and *CEpost_norm* is the normalized electric usage for space cooling sub-metered in the post period, and *c0* and *c1* are the coefficients of the fitted line provided by the two-changepoint model.

$$HE_{post\_AMI\_norm}(d) = c0 + c1 \times T_{post}$$

$$CE_{post\_AMI\_norm}(d) = c0 + c1 \times T_{post}$$

where *HEpost_AMI_norm* is the normalized electric usage for space heating and *CEpost_AMI_norm* is the normalized electric usage for space cooling in the post AMI period, and *c0* and *c1* are the coefficients of the fitted line provided by the two-changepoint model.

### System COP

The implied system COP is calculated from normalized heating energy usage in the baseline and post-installation periods from either sub-metered *(COPsys*) data or post AMI (*COPsys_AMI*) measurements:

$$COP_{sys} = \frac{HE_{pre\_norm}}{HE_{post\_norm}}$$

$$COP_{sys_{AMI}} = \frac{HE_{pre_{norm}}}{HE_{post_{AMI_{norm}}}}$$

The system COP is the efficiency of the post period as a whole (Heat Pump and Strip).

### *Heat Pump COP*

The two-changepoint model is performed on the daily strip resistance (existing) space heating electric usage in the post-installation period. *STRIPPOST* is the sum of the resistance strip electrical usage below the strip heating balance point *HBALstrip*,

$$STRIP_{POST}(d) = \begin{cases} STRIP(d) & T \leq HBAL_{strip} \\ 0 & T > HBAL_{strip} \end{cases}$$

The two-changepoint model is performed on the daily heat pump space heating electric usage in the post-installation period. *HPPOST* is the sum of the heat pump electrical usage below the heat pump heating balance point *HBALHP*,

$$HP_{POST}(d) = \begin{cases} HP(d) & T \leq HBAL_{hp} \\ 0 & T > HBAL_{hp} \end{cases}$$

A HP energy ratio (RHP) is calculated by using *HPPOST and STRIPPOST*,

$$R_{HP} = \frac{HP_{POST}}{(HP_{POST} + \ STRIP_{POST})}$$

The implied COP of the heat pump (*COPHP)* is then calculated using the ratio and system COP,

$$COP_{HP} = \frac{(COP_{sys} + R_{HP} - 1)}{(R_{HP})}$$

### *Heat Pump HSPF from Jan through Dec 2019*

The implied HSPF of the heat pump (*HSPFHP*) is then calculated using the heat pump COP,

$$HSPF_{HP} = \ COP_{HP} * 3.412$$

### *Limitations*

These values represent implied heat pump and system COP and HSPF, rather than actual efficiencies since differences between the baseline and post-installation periods can impact this calculation. For example, occupancy, weatherization and behavioral changes such as different heating setpoints and comfort preferences can all have an effect.

### *Heat Pump SEER*

Temperature data was organized into bins (*Temp_Bin*) that increment at 2.5°F above the cooling balance point *CBALPOST*. A total number of days was recorded for each of the bins in the cooling season, and then the sum was taken to get the total number of days for the cooling season (*Tot_Days*).

$$Days_{Bin}(d) = \begin{cases} Days(d) & T \geq Temp\_Bin_{\ x} \\ 0 & T < Temp\_Bin_{\ x+1} \end{cases}$$

To normalize cooling runtime in the post period, CMC used the line from the two-changepoint model on the thermostat runtime (*CLG_Runtime*) to identify a normalized cooling runtime load line,

$$CLG\_Runtime_{norm}(d) = c0 + c1 \times T_{post}$$

Normalized thermostat cooling runtime (*CLG_Runtimenorm_Bin*) was then totaled for each temperature bin,

$$CLG\_Runtime_{norm\_Bin}(d) = \begin{cases} CLG\_Runtime_{norm}(d) & T \geq Temp\_Bin_{\,x} \\ 0 & T < Temp\_Bin_{\,x+1} \end{cases}$$

To determine space cooling delivered *(Delivered_CLGBin)*, we multiplied the rated daily cooling capacity9 *(CAP)* of the heat pump by the total normalized system cooling runtime (*CLG_Runtimenorm_Bin*) in each temperature bin. This was then divided by the total number of days in the cooling season (*Tot_Days*).

$$Delivered\_CLG_{Bin} = \frac{(CAP * CLG\_Runtime_{norm\_Bin})}{Tot\_Days}$$

To determine space cooling electrical energy consumed (*Consumed_CLGBin*), we summed the normalized electrical energy usage (*CEpost_norm*) to calculate the total energy consumed (*Consumed_CLGBin*) in each temperature bin. This was then divided by the total number of days in the cooling season (*Tot_Days*).

$$Consumed\_CLG_{Bin}(d) = \begin{cases} CE_{post\_norm}(d) & T \geq Temp\_Bin_{\,x} \\ 0 & T < Temp\_Bin_{\,x+1} \end{cases}$$

$$Consumed\_CLG_{Bin} = \frac{(Consumed\_CLG_{Bin})}{Tot\_Days}$$

All space cooling delivered bins (*Delivered_CLGBin*) were summed to calculate total space cooling delivered (*Delivered_CLGtotal*). Similarly, all space cooling electrical energy consumed bins (*Consumed_CLGBin*) were summed to calculate total space cooling delivered (*Consumed_CLGtotal*). SEER is then calculated by dividing energy delivered by energy consumed.

$$SEER = \frac{Delivered\_CLG_{total}}{Consumed\_CLG_{total}}$$

### *Occupancy Variation Adjustment*

Twenty-eight out of 80 housing units (35 percent) had some level of tenant turnover during either the pre-AMI or post-AMI period. The full list of accounts can be found in Appendix C – Tenant Turnover

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[9] https://www.mitsubishicomfort.com/tools/operations-manuals

Table. These periods were identified as periods where the accounts fluctuated at some point between a status of Final, Written Off or Active. Issues with tenant turnover most often affected pre-AMI data; 57.2 percent of terminated active accounts existing in 2018 AMI data. Table 39 outlines all unoccupied periods that have been excluded from the analysis. Note that behavioral changes due to changes in tenant, while possible to separate, have not been removed to provide the most information available for the results.

Table 39. **Unoccupied Periods Excluded from Analysis**

| AMI Meter Number | Unoccupied Start Date 1 | Unoccupied End Date 1 | Unoccupied Start Date 2 | Unoccupied End Date 2 | Unoccupied Start Date 3 | Unoccupied End Date 3 |
|---|---|---|---|---|---|---|
| **272169052_G** | 5/23/2018 | 8/24/2018 | 1/1/2018 | 5/23/2018 | | |
| **274029876_G** | 1/1/2018 | 3/12/2019 | | | | |
| **272164233_G** | 2/22/2018 | 5/23/2018 | | | | |
| **271115370_G** | 1/1/2018 | 5/23/2018 | | | | |
| **272994060_G** | 9/3/2019 | 12/31/2019 | | | | |
| **270422002_G** | 1/1/2018 | 6/23/2018 | 8/22/2018 | 8/27/2018 | | |
| **272998399_G** | 1/1/2018 | 1/11/2018 | | | | |
| **273187978_G** | 6/11/2018 | 9/23/2018 | | | | |
| **270449785_G** | 7/24/2019 | 12/31/2019 | | | | |
| **272232868_G** | 1/1/2018 | 8/13/2018 | 8/13/2018 | 8/28/2018 | | |
| **270453855_G** | 4/27/2018 | 8/8/2018 | | | | |
| **270453853_G** | 1/11/2019 | 1/25/2019 | | | | |
| **273143556_G** | 6/19/2018 | 7/10/2018 | | | | |
| **273143558_G** | 9/4/2018 | 11/9/2018 | 8/17/2018 | 9/4/2018 | 10/4/2019 | 10/7/2019 |
| **270556835_G** | 1/1/2018 | 1/29/2018 | 11/28/2018 | 12/15/2018 | 6/25/2019 | 7/9/2019 |
| **272176720_G** | 2/26/2018 | 3/2/2018 | | | | |
| **270453747_G** | 7/17/2018 | 10/30/2018 | 1/17/2019 | 7/9/2019 | | |
| **270264539_G** | 1/1/2018 | 5/23/2018 | | | | |
| **273890288_G** | 1/1/2018 | 10/10/2018 | | | | |
| **271906284_G** | 8/28/2018 | 8/30/2018 | | | | |
| **270264587_G** | 7/26/2018 | 11/10/2018 | | | | |
| **271906286_G** | 10/26/2019 | 12/31/2019 | | | | |
| **270450866_G** | 4/2/2019 | 6/7/2019 | | | | |
| **273769129_G** | 1/1/2018 | 9/18/2018 | 1/29/2019 | 2/21/2019 | | |
| **273188000_G** | 2/12/2019 | 11/1/2019 | | | | |

| AMI Meter Number | Unoccupied Start Date 1 | Unoccupied End Date 1 | Unoccupied Start Date 2 | Unoccupied End Date 2 | Unoccupied Start Date 3 | Unoccupied End Date 3 |
|---|---|---|---|---|---|---|
| **273187977_G** | 1/1/2018 | 3/14/2018 | | | | |
| **272296766_G** | 7/23/2019 | 9/30/2019 | | | | |
| **272008802_G** | 1/1/2018 | 4/30/2018 | | | | |

General historical patterns indicate that for unoccupied periods between tenants, thermostats are set lower than when the apartments are occupied. This may cause two separate trend lines on data visualization plots: higher electricity use during occupied periods and lower electricity use during unoccupied periods.

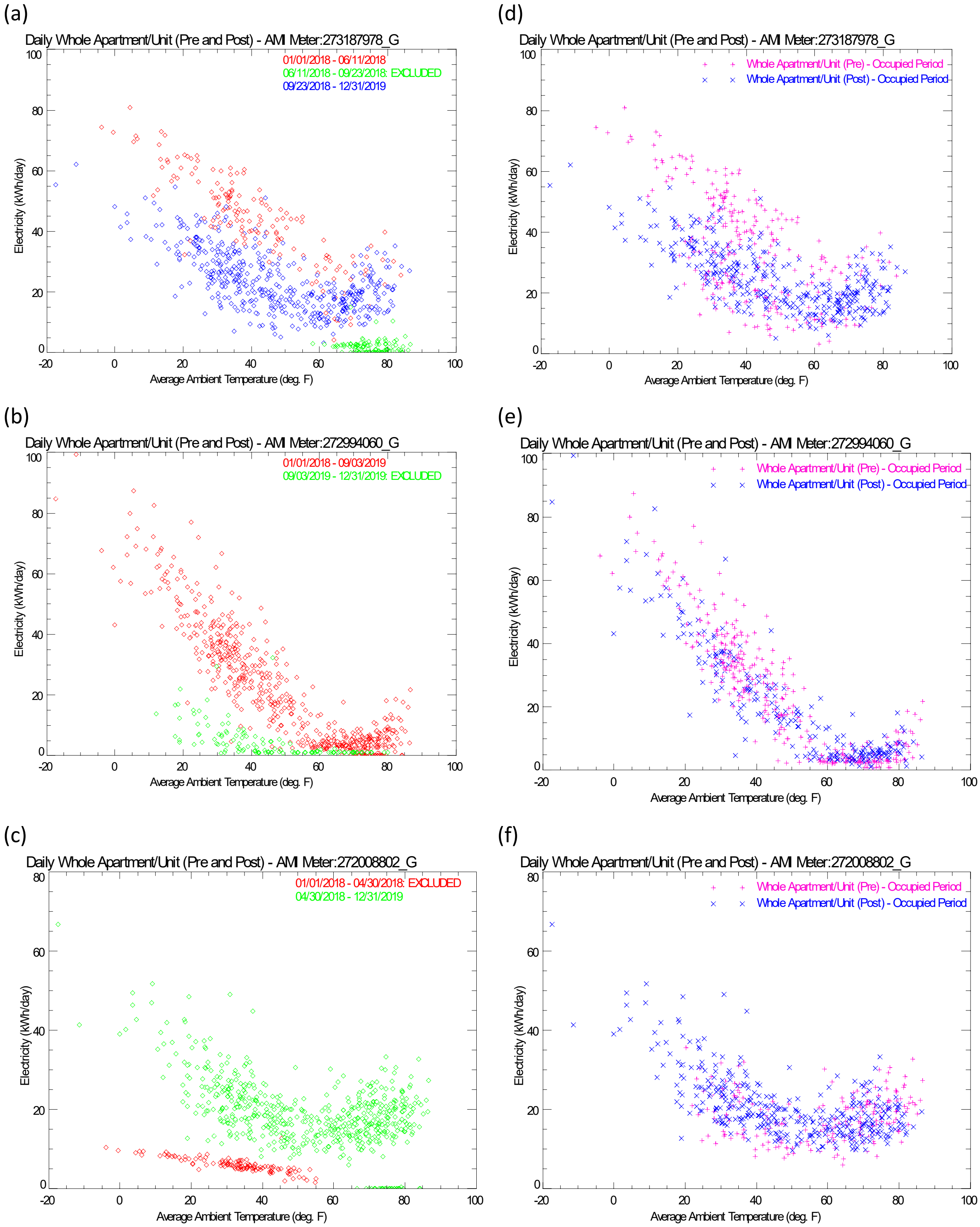
When analyzed against ambient outdoor temperature, this can often be seen as a flat line above 50 degrees Fahrenheit that is lower than the baseload during occupied periods. This line rises as temperatures drop below 50 degrees but at a much more gradual slope and below the load during occupied periods. This is consistent with a set point of approximately 50 degrees Fahrenheit, which may indicate attempts to maintain a temperature that will prevent freezing of waterlines during vacancy.

Figure 34(a-c) shows an example of variance of whole apartment electricity use against time for both occupied and unoccupied periods. These periods are separated based on an account turnover list provided by ComEd.

The account data was cleaned to limit the date range to the study period (1/1/2018 to 12/31/2019). Where an end date for one billing account overlaps with the start date for the subsequent billing account, the account activation date is used as the start date for the subsequent occupancy. CMC manually reviewed each data visualization plot and flagged unoccupied periods removal from the dataset. This allowed for more accurate trendlines that represent fully occupied apartments. Figure 34(a-c) below shows an example of variance of whole apartment electricity use against time for both occupied and unoccupied periods. These periods are separated based on an account turnover list provided by ComEd. Figure 34(d-f) below shows the same example data, but with the unoccupied periods removed.

**Figure 34. Examples of exclusion of date ranges from analysis based on account start/end dates.**

*Left (a- c): All date ranges in study period, with each date range indicated by a different color.*
*Right (d-f): Remaining data after exclusions.*



# 4 CUSTOMER SURVEYS & CHECK-INS

As part of the ComEd ccDHP Pilot Program, CMC prepared and conducted two ComEd-approved surveys to the participant population, consisting of 80 tenants and six property managers. The pilot was conducted over the course of a year from January 2019 to December 2019. Each survey was conducted by phone with an average total number of 22 tenants and two property managers participating across the two surveys. To incentivize participants, we distributed $25 gift cards after each completed survey.

In preparing to survey the population, we were advised that over the course of the pilot there was some turnover in tenants (35 percent) and property manager (29 percent). We also identified that 55 percent (12) of the tenants who did participate were the same tenants for both surveys.

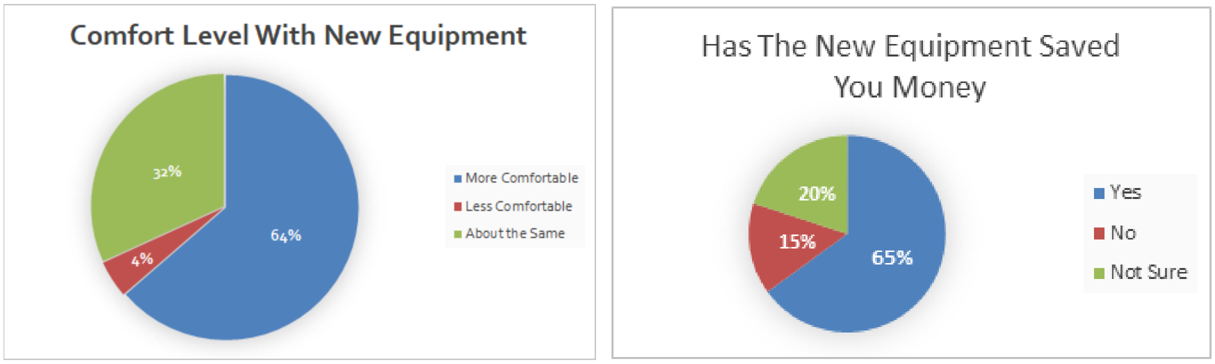
Also, it is important to note that many tenants in the pilot program participate in utility payment assistance programs such as the Low-Income Home Energy Assistance Program (LIHEAP), Community and Economic Development (CEDA) or other residential hardship programs offered by ComEd. In some cases, the participants had limited interest in reducing their energy usage, since utility costs were fully or partially subsidized.

The sections below provide an overview and summary of our survey research. We identified key points such as the performance of the equipment installed, energy savings, technology interaction, customer education and customer satisfaction. The first survey was administered six months post installation and the second 13 months post-installation.

## 4.1 Performance and Energy Use

A large majority (64 percent) of tenant participants felt the newly installed equipment made their homes feel more comfortable, and 32 percent felt that the comfort level was the same. We asked the same tenants if they felt the new equipment was saving them money, and 65 percent said they believe it is saving them money, while 20 percent were not sure.

**Figure 35. Customer Survey Responses: Comfort and Savings**



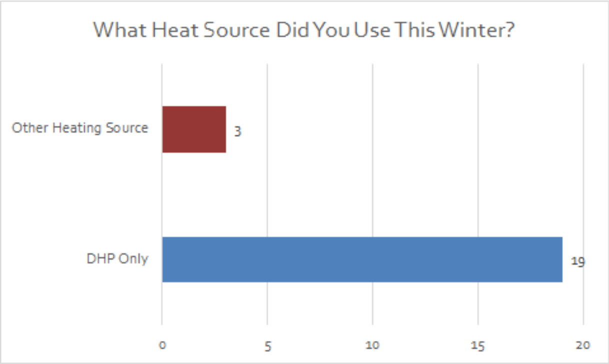
In addition to tenant comfort levels and realized savings, we assessed whether property managers needed to service the equipment during the pilot period. Of the two property managers who participated, one had to service or perform maintenance on the equipment and the other did not.

## 4.2 Technology Interaction

Since the pilot ran the course of two seasons, we wanted to assess what heating and cooling source tenants used—the ccDHP exclusively or an additional source. Our survey showed that almost all the tenants (19 of the 22 survey participants) used the ccDHP equipment only during the winter season. See Figure 36.

During the summer season, of the 20 tenants who participated, 12 used another cooling source other than the ccDHP only. See Figure 37.

**Figure 36. Customer Survey Responses: Winter Heat**



When tenants were asked in which season, they believed the ccDHP performed most efficiently, seven each stated either the winter season or the same for both summer and winter, while six tenants believed the summer season was the most efficient season. See Figure 38.

**Figure 37. Customer Survey Responses: Summary**

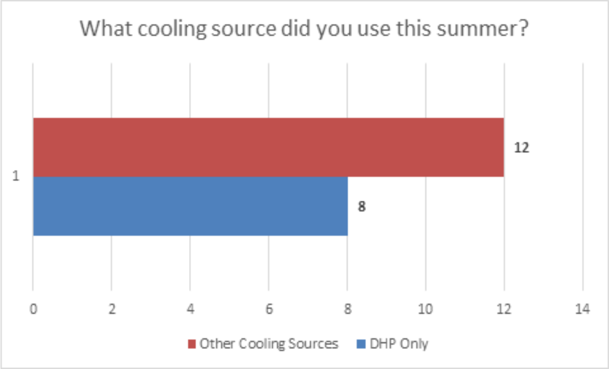
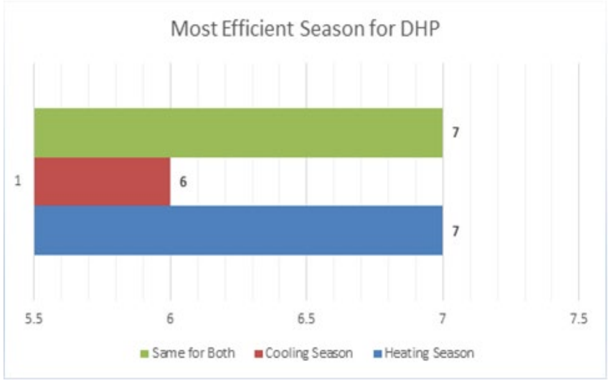


**Figure 38. Customer Survey Responses: Most Efficient Season for ccDHP**



## 4.3 System Maintenance

The Mitsubishi Hyper Heat ccDHP systems selected for this pilot were, in part, selected for the minimal maintenance required and reputation for reliability. The ccDHP units have easily accessible, washable filters made from natural materials. During the education process, tenants and property managers were taught how to remove, clean, and replace filters in accordance with manufacturer's recommended timeframes. Tenants were also alerted to the system's normal defrost cycle operation in the heating mode.

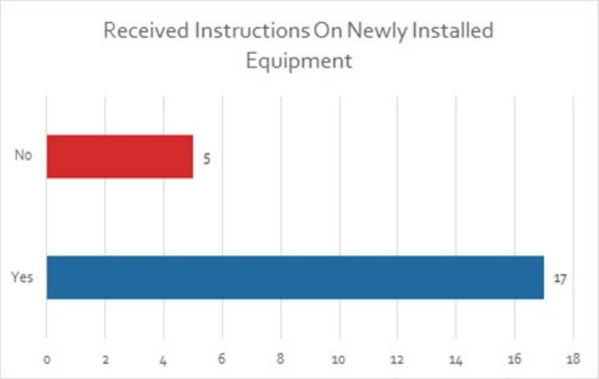
During the pilot, CMC worked closely with Four Seasons HVAC to respond to and resolve any installation and/or service-related issues (post installation) that occurred. The ccDHPs were exceptionally reliable and we received less than five service calls over the 15-month pilot period.

## 4.4 Education

CMC coordinated installation efforts with tenants and property managers. In some instances, tenants were not home during installation. We surveyed the tenants and found that 91 percent said they were home and nine percent were not.

Upon completion of every installation, each tenant should have received instructions on how to use their newly installed ccDHP, ecobee smart thermostats and ccDHP maintenance tips. We surveyed tenants to confirm that they received their instructions: 17 tenants said they did receive instructions and five said they did not receive instructions. See Figure 39.

**Figure 39. Customer Survey Responses: Received Equipment Instructions**



## 4.5 Satisfaction

We concluded our survey research by asking tenants if they planned on using the ccDHP moving forward and 90 percent said they would, five percent said no, and five percent were unsure.

It was important to assess the overall level of satisfaction tenants had with the entire pilot process, what we found was that most of the tenants were very satisfied with the equipment but a few tenants were not very satisfied with the explanation of the program, the installation process or the instructions to operate the equipment. Table 40 presents a summary of their responses.

**Table 40. Customer Survey Responses: Satisfaction**

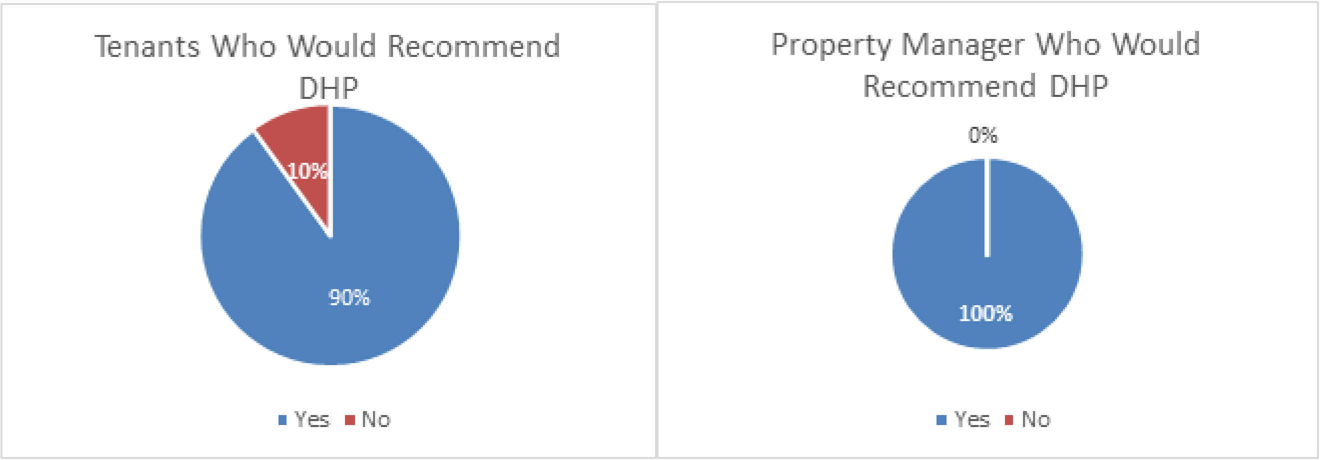
| | Very Dissatisfied | Somewhat Dissatisfied | Neutral | Somewhat Satisfied | Very Satisfied | Total |
|---|---|---|---|---|---|---|
| **Explanation of what to expect from the program** | 3 | 2 | 1 | 1 | 15 | 22 |

| | Very Dissatisfied | Somewhat Dissatisfied | Neutral | Somewhat Satisfied | Very Satisfied | Total |
|---|---|---|---|---|---|---|
| **The installation process** | 3 | 2 | 3 | 3 | 11 | 22 |
| **Instructions on how to use the equipment** | 3 | 2 | 2 | 1 | 14 | 22 |
| **The ductless heat pump** | 1 | 1 | 3 | 2 | 15 | 22 |
| **The smart thermostat** | 1 | 1 | 3 | 2 | 15 | 22 |

Equally important was the overall experience and satisfaction of the property managers. Overall, they were happy with the communication between the SEA and contractors. They also were pleased with the quality of the work but felt we could have done slightly better with equipment instructions and the installation process.

Our survey indicated that tenants and property managers alike were pleased with the newly installed equipment. Tenants found they were either more comfortable or about the same in their homes and most realized energy savings. The tenants seemed to find the equipment performed better during the winter than it did during the summer. Both tenants and property managers overwhelmingly said they would recommend the ccDHP. See Figure 40.

**Figure 40. Customer Survey Responses: DHP Recommendation**



Of the tenants who stated they would not recommend the newly installed equipment, they explained that opinion for these reasons:

- One tenant said the contractor did not fully explain how to use the equipment
- Two tenants stated that it made their utility bills higher
- Two tenants had mechanical issues with the equipment, one was a loose wire and the other was a faulty pump and reservoir door. Both issues were swiftly resolved with service calls.

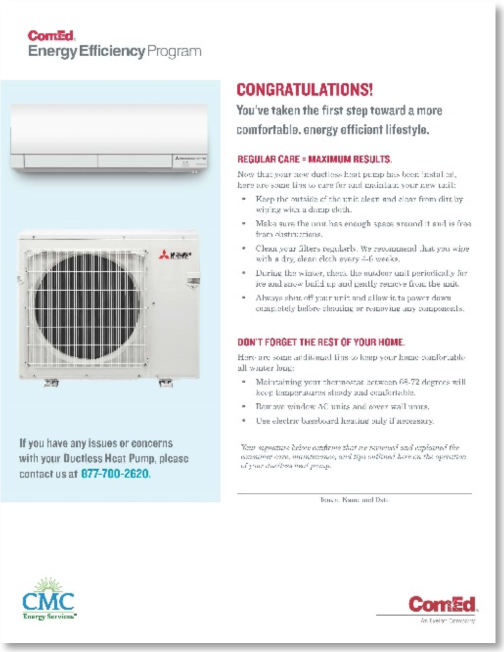
## 4.6 Suggestions for Improvements

Based on our survey results, we recommend that any future program incorporate additional on-site instruction and that education materials be left with the tenants and property managers. Many of the tenants' issues were behavioral. For example, some housing units had existing equipment that was still operational, so the tenants reverted to that equipment. During the pilot there we experienced a high rate of turnover in both tenants and property managers; providing education to the new tenants and new property managers would be helpful. Also, the pilot installation period began during the heating season, we think providing some additional instruction to tenants and property managers when switching to cooling season would be beneficial.

We have some education recommendations that would benefit customers and enhance their overall experience. These suggestions should be provided in addition to in-person instructions after installation: marketing collateral for tips and maintenance, instructional video on regular and extended care, and handy product tags for quick reference on how to operate the ccDHP unit. Below we have provided a sample of each for reference.

- Marketing collateral, energy tips, and equipment maintenance – A one-page information sheet (see the sample in Figure 41) that incorporates education about the ccDHP units is a great leave behind to the end user. It can provide tips to maintain the equipment, temperature control and other things the customer can do to increase the efficiency of their new ccDHP unit.
- Manufacturer Instructional video, link to be included on sell sheet and on hanging product tags [MITSUBISHI Electric Cooling & Heating - Homeowner Help: Filter Cleaning]
- Hanging product tags – A hanging product tag is a quick reference guide for parts and cleaning care attached to the ccDHP. See sample in Figure 42.

**Figure 41. Sample Marketing Collateral**



ComEd Energy Efficiency Program

**CONGRATULATIONS!**

You've taken the first step toward a more comfortable. energy efficient lifestyle.

**REGULAR CARE = MAXIMUM RESULTS.**

Now that your new ductless heat pump has been installed, here are some tips to care for and maintain your new unit:

- Keep the outside of the unit clean and clear from dirt by wiping with a damp cloth.
- Make sure the unit has enough space around it and is free from obstructions.
- Clean your filters regularly. We recommend that you wipe with a dry, clean cloth every 4-6 weeks.
- During the winter, check the outdoor unit periodically for ice and snow build up and gently remove from the unit.
- Always shut off your unit and allow it to power down completely before cleaning or removing any components.

**DON'T FORGET THE REST OF YOUR HOME.**

Here are some additional tips to keep your home comfortable all winter long:

- Maintaining your thermostat between 68-72 degrees will keep temperatures steady and comfortable.
- Remove window AC units and cover wall units.
- Use electric baseboard heating only if necessary.

*Your signature below confirms that we reviewed and explained the customer care, maintenance, and tips outlined here on the operation of your ductless heat pump.*

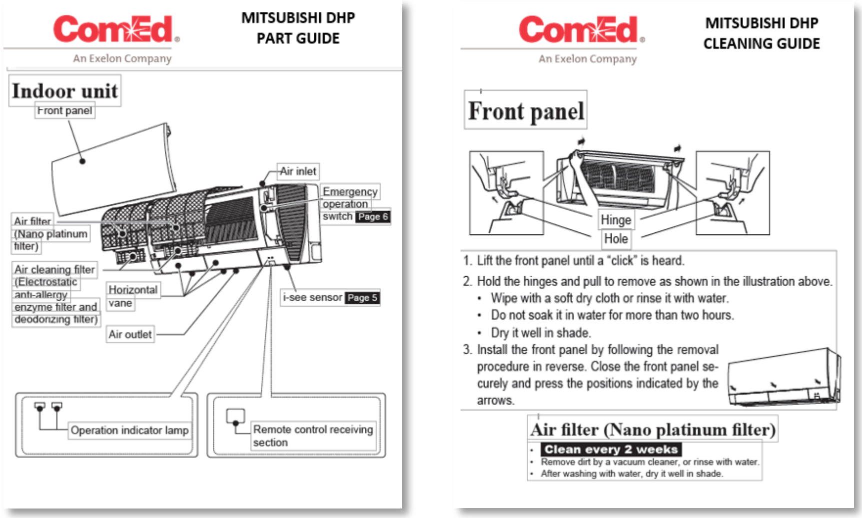
Tenant Name and Date

If you have any issues or concerns with your Ductless Heat Pump, please contact us at 877-700-2620.

CMC Energy Services

ComEd
An Exelon Company

**Figure 42. Hanging Product Tags**



MITSUBISHI DHP
CLEANING GUIDE

Front panel

1. Lift the front panel until a "click" is heard.
2. Hold the hinges and pull to remove as shown in the illustration above.
   - Wipe with a soft dry cloth or rinse it with water.
   - Do not soak it in water for more than two hours.
   - Dry it well in shade.
3. Install the front panel by following the removal procedure in reverse. Close the front panel securely and press the positions indicated by the arrows.

Air filter (Nano platinum filter)

- **Clean every 2 weeks**
- Remove dirt by a vacuum cleaner, or rinse with water.
- After washing with water, dry it well in shade.

# 5 CONTRACTOR INTERVIEWS

CMC Energy conducted in-depth interviews with each of the pilot partners, Franklin Energy, Mitsubishi Electric, Four Seasons HVAC and Mad Dash. The interviews focused on their experience participating in the pilot, as well as site and customer characteristics. Key findings include:

- Partners were complimentary of the overall quality and collaboration of the project team. For example, partners praised CMC's "on the ground" Senior Energy Advisor, Four Seasons' Diamond Dealer status, and the team's collective desire to put the customer first. All partners expressed interest in participating in a full ccDHP program for income-eligible customers.
- Several elements made partner participation challenging, such as the pilot's compressed timeframe and time spent at buildings that did not qualify. These correlate to each other, as the team had to select sites that were not fully vetted due to the pilot's time constraints (installation of all ccDHP units in a three-month period during the height of the Chicago heating season).
- Partners reported a desire to be more involved in the project to help maximize savings opportunities. For example, Mitsubishi would like to more participation in technical- or product-related conversations and Four Seasons HVAC suggests that contractors be more involved in site selection and site assessments.

The following sections summarize the feedback received from these partners.

## 5.1 Franklin Energy

Franklin provided marketing intelligence for pilot site selection based on their experience in the territory and working with ComEd on other initiatives in the Chicago market. Table 41 summarizes the feedback provided by Franklin Energy. The Franklin team's knowledge of the landscape, professional approach and insights into likely pilot candidates were key in meeting the tight installation timeline.

**Table 41. Franklin Energy Feedback**

| Observations | Opportunities |
|---|---|
| • CMC provided great project management<br>• Good communication, especially at the beginning of the project<br>• Small, owner-operated properties were the most responsive participants<br>• Positive response to the selection of Four Seasons as a premier HVAC contractor to meet aggressive goal | • There was a surprisingly high volume of tenant turnover<br>• Compressed timeline was difficult and caused some confusion<br>• Installation logistics were sometimes challenging<br>• Communication was better at the beginning of the project than in final phases |

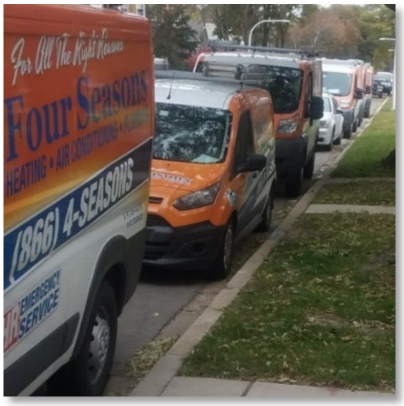
## 5.2 Mitsubishi Electric

Mitsubishi is the manufacturer of the ccDHP units used in this pilot. In addition to development of HyperHeat and other ccDHP technologies that enable cold-climate application, Mitsubishi has a distribution network throughout the Midwest that enables access to the equipment. Table 42 summarizes the feedback provided by Mitsubishi.

**Table 42. Mitsubishi Electric Feedback**

| Observations | Opportunities |
|---|---|
| • Trust and confidence established beyond just the product<br>• Contribution by all parties to collectively succeed<br>• Selection of Four Seasons as a premier HVAC contractor to meet aggressive goal | • Timeframe was unrealistic<br>• Did not fully understand project scope details<br>• No voice at the table for technical- or product-related conversations<br>• Sites not properly vetted |

## 5.3 Four Seasons HVAC



Four Seasons HVAC is a Diamond Dealer, which indicates the highest level of training and experience in the Mitsubishi product line. Four Seasons has technicians dedicated to ccDHP installation and had ready access to equipment through warehousing and distributor relationships. Four Seasons' technicians supported the site survey process and performed the heat lost/heat gain calculations to assure proper equipment sizing. Table 43 summarizes the feedback provided by Four Seasons.

**Table 43. Four Seasons HVAC Feedback**

| Observations | Opportunities |
|---|---|
| • Communication between contractors and CMC<br>• High quality team – "Dream Team"<br>• All team members willing to put the customer first<br>• Reliable team<br>• Service calls were minimal (Waukegan and Gurnee stand out) | • Travel time/site time wasted on buildings that did not qualify<br>• Lack of full pre-qualification system<br>• Ideally, more involvement in site selection or site assessment<br>• Minimum sales process to overcome owner skepticism |

## 5.4 Mad Dash

Mad Dash was responsible for the installation of the eGauge (sub-meter), cellular modem and ecobee smart thermostat. They also assisted with data retrieval and, ultimately, removed the eGauge and cellular modems from housing units upon pilot completion. Table 44 summarizes key observations from Mad Dash field staff as they interacted the most with tenants and property managers due to the complexity of the sub-metering and equipment controls.

**Table 44. Mad Dash Feedback**

| | S Bennett | 70th St | Grand Ave | N Lewis | Centennial | Zion | 147th St |
|---|---|---|---|---|---|---|---|
| Tenant Turnover | Significant | Significant | Minimal | Minimal | Minimal | Not reported | None |
| Property Management/ Tenant Relationship | Friction; lack of trust of ComEd | New property management company | Not reported | Not reported | Ownership changed | Not reported | Not reported |

| | S Bennett | 70th St | Grand Ave | N Lewis | Centennial | Zion | 147th St |
|---|---|---|---|---|---|---|---|
| Building/ Location Characteristics | Common to find power off for periods of time | Not reported | Not reported | Limited building access; poor cell signal; good insulation and structure | Newer building; well-insulated | Low income area; near condemned; poor insulation; studio apartments | Low income area; near condemned; poor insulation |
| Heating/ Cooling Mechanism | Occasional use of ovens for heat | Occasional use of ovens for heat | Had window units for AC prior to DHP | Not reported | Not reported | Common use of ovens for heat; space heaters likely; many heat strips did not work | Heat strips worked |
| Tenant Attitude/ Behavior | Not concerned about utility bill; initially not receptive to training; perceived savings with use of DHP | Perceived savings with use of DHP | Initial resistance to DHP | More aware of savings and utility bill; tenants generally happy | Tenants generally happy; DHP worked well | | Tenants did not use DHPs much; close interaction between tenants |

## 5.5 Suggestions for Improvements

Based on feedback received from partners, as well as the experience of CMC SEA, who was the point of coordination among partners and responsible for tenant/property management education and service concerns, we recommend the following to improve program results and savings:

- Implement a full pre-qualification system using tools like Google Earth to grade sites (e.g., target specific suburbs, garden apartments, etc.). This will streamline the process and result in more qualified sites. In addition, including trade partners in the selection process will result in a more accurate qualification.
- Allow for time to correct/adjust building conditions prior to participation. For example, electrical panel upgrades, pre-existing code violations.
- Include all trade partners in the onsite assessment so that they are fully aware of the project scope details. Specifically, the methods of data collection, operational temperature cutouts planned/executed, and data feedback.
- Develop a full sales process and collateral to overcome owner skepticism and deliver a clear value proposition to the property owner. In the pilot, half of the assessments converted to sales. We expect the close rate will be less in a full-scale program.

- Consider implementation during shoulder months to provide more favorable weather conditions. Also, consider including all apartments in a complex.
- Build a clear line-of-sight into the buildings in ComEd territory that have electric resistance heat. Franklin Energy has been capturing this data (and on electric water heating) over the last several years of multifamily work.

# 6 EVALUATION OF TECHNOLOGY COSTS

## 6.1 Average Equipment Costs

Table 45. Equipment Costs Summary

| Location/ Metric | Grand Ave | North Lewis Ave | Centennial Court | 147th St | S Bennett Ave | 70th St | Zion |
|---|---|---|---|---|---|---|---|
| **Total Equipment Cost including installation** | $88,474 | $66,419 | $107,133 | $69,453 | $142,310 | $142,997 | $124,673 |
| **Average cost per heat pump** | $7,373 | $8,302 | $8,928 | $8,682 | $7,906 | $8,412 | $7,792 |

As seen in Table 45, the average cost per installed heat pump for this pilot was $8,148. This cost includes the ccDHP equipment, associated materials, the ecobee smart thermostat and all labor associated with installation.

The average cost per installed heat pump varied by location with a high average of $8,928 at the Centennial site and a low average of $7,373 at the Grand site.

Centennial's high average was impacted by later identifying the building as a multi-head candidate after the preliminary eight single-head units were installed. This required additional site coordination and a second trip by the contractor to install four additional ccDHP units so there were ultimately four single-head and four multi-head applications. In addition, Centennial basement configuration required running electric and line sets to the outside condensers necessitating additional materials and manpower.

The Grand location, which also was a four single- and four multi-head application (like Centennial after update), received the benefit of all equipment, materials and crews being scheduled at a single time. In addition, the Grand location was logistically beneficial for mobilization of equipment, ladder work and install crew efficiency. For example, the indoor units were located directly adjacent to the exterior mounted outdoor units enabling a faster install with less material.

Please see Appendix D for additional detail for site by site costs.

## 6.2 Measure Cost Effectiveness

The overall cost per kWh for the pilot was $5.68 when accounting for ccDHP equipment, smart thermostats and installation. This figure does not include administration or analysis of the pilot results. The cost per kWh for each site can be found below. The cost for shell treatment is not included as part of this analysis, as it was delivered through a partner program.

The cost-effectiveness of the measure in future programs is dependent on the evaluation methodology. Programs dependent on IL TRM savings calculations would likely experience more favorable cost-effectiveness than a pre- and post-AMI analysis of savings. CMC anticipates that a scaled pre- and post-AMI analysis approach would lead to a cost-effectiveness between $1.56 and $3.26 with a mean acquisition cost of $2.10 kWh for heating.

**Table 46. Cost Per kWh By Site**

| Sites | Units | Capacity (BTU-K) | Equipment & Install Cost with Thermostat ($) | Cost/BTU-K ($) | Mean Normalized Heat Energy Impact (kWh) | Net Heating Savings (kWh) | Cost/kWh Heat ($) |
|---|---|---|---|---|---|---|---|
| **1-A** | 8 | 132 | $88,474 | $670 | 1429 | 11434 | $7.74 |
| **1-B** | 8 | 96 | $66,419 | $692 | 724 | 5792 | $11.47 |
| **1-C** | 8 | 144 | $107,113 | $744 | 814 | 6511 | $16.45 |
| **1-D** | 8 | 72 | $69,453 | $965 | 1925 | 15397 | $4.51 |
| **2-A** | 15 | 264 | $142,310 | $539 | 2476 | 37147 | $3.83 |
| **2-B** | 15 | 207 | $126,174 | $610 | 1812 | 27181 | $4.64 |
| **2-C** | 16 | 144 | $124,673 | $866 | 1514 | 24221 | $5.15 |
| **All** | **78** | **1059** | **$724,616** | **$684** | **1637** | **127683** | **$5.68** |

It should be noted that the overall program cost-effectiveness for a scaled program would be based on potential administration costs, number of units installed and other current unknowns.

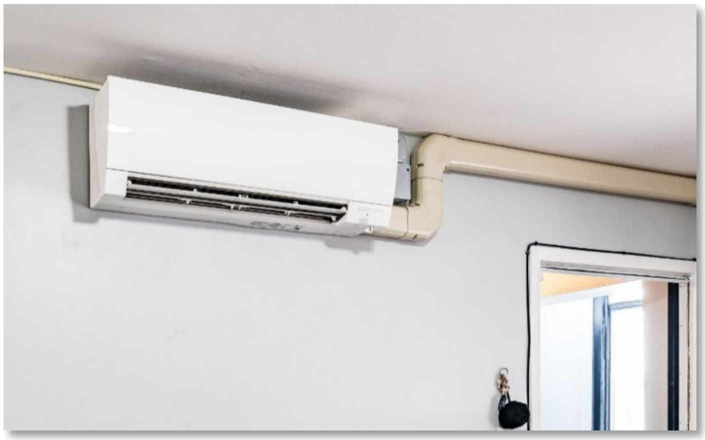
## 6.3 Installation Considerations

### 6.3.1 Low-rise Building Characteristics

Overall building size including square footage and height can impact labor time associated with installation. For example, moving equipment up multiple floors and/or narrow stairwells/common areas will impact the project start to completion timeframe.

In addition, interior apartment units in larger facilities are more difficult to run electric and refrigerant lines to, potentially making ccDHP installation impractical.

### 6.3.2 Overall Building Aesthetics



While not overly disruptive, a ccDHP installation can impact the interior and exterior appearance of a multifamily building. Indoor air handling units are generally wall-mounted and are a new addition to the main living area. The refrigerant piping, condensate removal drain, and electrical conduit are typically non-invasive but may need to be enclosed in decorative chase to improve visual appeal. For the outdoor units, a ground level mounting nearby to the indoor units is the most common. Some property managers or building owners may not like the aesthetics of this design if they feel it lessens the curb appeal of the property, especially with a historic building. Alternative options include placing the outdoor units on the roof or sub-roof to make them less visible.

#### ***Wall Penetrations/Patching and Repair***

Tenants and property managers/owners need to be aware that various equipment mounting and wall penetrations for electrical and other connections will require post-installation patching.

The level of repair needs to be consistent with the property manager’s requirements and returning the building back to pre-installation condition.

Some property managers/owners expressed concern about visible exterior line sets, penetration of interior brick walls and running electrical conduit in areas that might compromise the overall look and marketability of the housing units.

### 6.3.3 Roof Mount vs. Ground Mount

Installation sites with interior protected courtyards or similar locations, lend themselves to ground mounted exterior equipment (condenser). Locations that either did not have viable ground locations for condensers or had concerns about the aesthetics, were potential candidates for roof-mounted equipment.

Roof-mounted equipment required a crane to place condensers on the roof as well as coordination with a roofing contractor to make any roof repairs required from the mounting hardware and roof penetrations experienced in ccDHP installation.

Security cages were required at several ground-mounted locations due to a vandalism risk to the outdoor condensing units. This issue was raised by property managers/owners. In some cases, property managers/owners, being aware of the situation and appreciative of the free equipment as part of this pilot, purchased cages on their own to be fitted to equipment. At one location, CMC included security cages through coordination with the HVAC contractor.

### 6.3.4 Location

The site location can have a noticeable impact on costs related to staging equipment onsite, cleanup of materials and labor time associated with both. There were also security concerns at some of the buildings. Urban and suburban environments present unique challenges for, nearby parking, building entry and access to electrical panels and/or outdoor access when setting outdoor equipment in place.

## 6.4 Program Design Integration

### 6.4.1 Bulk Pricing Discounts

The pilot’s installation phase was significantly compressed and facilitated during peak heating season. In all, 80 apartment units with various single- and multi-head configurations were installed during a less than 90-day period. In a full-scale program, with proper forecasting, manufacturers and distributors can offer price breaks based upon significant, multi-year commitments.

When considering product volume discounts, the program must consider the availability of product (system type, appropriate sizing), the distribution of the product (how it impacts timely delivery) and where/if the product will be stored if the program implementor purchase commitment requires taking possession of a minimum quantity of equipment

### 6.4.2 Contractor Engagement

There could be substantial pricing savings opportunities if contractors were included in the initial analysis for a building's participation in a ccDHP project. For example, during the pilot, prospective contractors could not view the participating buildings and had to price the projects "sight unseen." More knowledge of the proposed buildings would have led to greater pricing accuracy. For this pilot, the HVAC contractor was required to provide estimated pricing, scheduling timeframes and establish the scope of work with only a general understanding of the conditions of the potential buildings to be included in the pilot.

Also, based on feedback from the pilot HVAC contractor and additional input from industry sources, there is a potential savings of 5-10 percent on the labor portion of the total installation as the estimate can be more 'dialed in' once seeing the actual specifics of the site.

A full-scale program would include a customer acquisition model, where the HVAC contractor(s) would join the program energy advisors on site visits before buildings were fully admitted to the program. The ability to vet the specific building conditions and align with a suitable ccDHP application will increase the accuracy of pricing, efficiency of installation, and performance of the ccDHP systems.

### 6.4.3 Installation Seasonality

Many HVAC contractors have "off-peak" periods that occur during the transition of heating season to cooling and cooling to heating. While off-peak can vary based upon weather, typically this period falls in the March/April and August/September time frames.

HVAC contractors have increased capacity during off-peak and this period is often used for training, encouraging use of vacation time, performance of routine maintenance around office, and customer maintenance tune ups. Some firms are forced to cut technician work hours or consider layoffs if they do not provide complimentary products or services that can be engaged during off peak.

With the favorability of off-peak time for the HVAC contractor, a full-scale program should consider schedule incentives for the property owners as well. Encouraging the work to be completed during this period is less impactful for tenants and contractors so a project discount, gift card promotion or credit to utility bill should be considered in exchange for off-peak scheduling.

According to HVAC industry experts, HVAC contractors should adopt a practice of reducing pricing 5-10 percent to encourage system installations during off-peak periods. With many costs associated with their installation crews are fixed costs, a reduced margin during off-peak periods will enable the contractor to keep their crews on staff and engaged, without requiring layoffs. The cost of laying off, rehiring and retraining during peak time is then mitigated. There is sound financial and company performance tied to keeping the teams busy, even if at a "reduced rate," during off peak.

### 6.4.4 Competitive Bid Process

During the pilot, time constraints existed and required CMC to select a single contractor that could service the entire market of the participating buildings. In addition, the contractor needed to have significant experience, DHP training and a relationship with the ccDHP manufacturer so equipment, materials and multiple installation crews could be deployed rapidly. In a full-scale program, there is an opportunity to consider alternate ccDHP manufacturers, as well as establish a competitive bid process to award multiple contractors. Having multiple contractors engaged through this bid process not only generates an opportunity for competitive pricing, but also provides redundancy should one of the HVAC contractors have performance or capacity issues.

The competitive bid process should not rely on pricing alone as there are significant factors in selecting participating HVAC contractors for a full-scale program, including:

- Regional presence
- Distribution network
- Training programs
- Certifications/credentials
- Dedicated crews
- Service ability
- Manufacturer support/presence

# 7 EVALUATION OF MERITS AND ABILITY TO TRANSITION TO FULL-SCALE PROGRAM

## 7.1 Optimizing Savings and Reducing Costs

### 7.1.1 Savings

The results of the study indicate several important considerations for a scaled program. From a data analysis perspective, these include the critical role pre-heating usage profiles play in final heating energy impacts, the benefits of comprehensive shell retrofits completed in conjunction with DHP installations and the necessity of both ambient air lock-out devices and consistent customer engagement. Limiting the use of multi-head systems, due to lower efficiencies and heating energy impacts, to only the most necessary scenarios, is also important.

CMC has utilized these various pilot attributes to create an anticipated savings value for a scaled program based on our recommendations. For a scaled program with usage participation guidelines, where at least 50 percent of the buildings are treated with shell retrofits, there are 5 percent or less multi-head installations and at least 40 percent of the buildings feature ambient lock-out controls, the expected mean savings per installation would be 2,816 +/- 1006 kWh for low-rise LI multifamily buildings. This would likely represent a 36.7 percent mean pre- and post-heating reduction. Considering future scaled cost per installation, CMC anticipates the mean cost/kWh, utilizing pre and post in place of deemed TRM savings, to be between $1.56 and $3.26 with a mean acquisition cost of $2.10 kWh for heating.

### 7.1.2 Costs

Understanding and managing the residential HVAC equipment supply chain is essential for minimizing costs and maximizing the cost effectiveness of a full-scale program. The major manufacturers of DHP systems are Mitsubishi, Daiken, Fujitsu and LG. Like most HVAC products, DHPs are sold through the two-step distribution process. Two-step distributors buy products from the HVAC equipment manufacturers and then sell the products to independent HVAC contractors. The contractors, in turn, sell and install the systems for the end user, thereby earning the two-step definition. Each step requires a requisite profit margin for the business involved but also offers an opportunity for the utility sponsor to leverage volume discounts in a full-scale program.

Distributors add value by maintaining broad inventory of equipment and ancillary supplies, offering credit, monitoring local market demand and providing technical training and field services. Considering the relative complexity of DHP systems, selecting a manufacturer-distributor channel with a robust technical training infrastructure in place is essential.

When considering a full-scale ccDHP program design, CMC recommends the following:

Manufacturers:

- For simplicity, choose only two preferred manufacturers of Energy Star, ccDHP equipment that complies with NEEP cold climate heating performance specification of COP≥1.75 @5F.
- Collaborate with manufacturers' engineering team on building selection criteria, sizing techniques and applications to assure best performance and energy efficiency.
- Select an equipment manufacturer with an understanding and commitment to utility energy efficiency programs, TRM savings calculations, and the unique challenges of EM&V requirements.

Distributors:

- Select participating distributors who can commit to the necessary inventory levels and provide competitive, firm pricing quotes on an annual basis.
- The distributors must have a significant presence and understanding of the Chicago market enabling them to have regional access to equipment and the ability to facilitate ongoing

technical training.

- In addition to DHP systems pricing discounts, negotiate volume discounts on **all** the controls and ancillary supplies needed to complete a proper installation.
- Consult with distributors to create prepackaged install kits for standard installations.

Installation Contractors:

- Arrange and secure pricing through a competitive bidding process among top-tier HVAC installation contractors.
- Select only contractors who have committed to training dedicated DHP installation crews and service technicians, delivering prompt warranty service and maintaining an adequate parts inventory.
- Require contractors to deliver meaningful equipment start-up and operation education and provide guidance on maximizing the energy savings potential of the DHP system.

In general, product installations vary based on site characteristics and application and, therefore, installed product pricing will vary from job to job. However, if specific building types are chosen and prequalified and installation scenarios are modeled and identified as “ideal,” total installed costs can be reduced by creating a production-line environment for installs. Ideal sites would be evaluated and determined to be currently “heat-pump ready” or made heat-pump ready through shell retrofits and weatherization.

In addition, installation costs can be reduced if the work is conducted primarily during the non-peak periods of the residential HVAC industry such as February to April. Installation contractors are beholden to seasonal demands and are often anxious to find projects in the “shoulder months” to keep the field force engaged in productive activities. With proper planning and development of an installation pipeline for the slower months, even top tier HVAC contractors will be more likely to accept lower installation prices.

Below is a simple chart that demonstrates the potential savings a larger scale program could expect to realize based on several variables, such as equipment discounts based on volume, standardize installation packages and controls. These estimates could be impacted positively and negatively based on decreased or increased quantities.  Pricing is based on interviews with vendors and current market conditions.

| **DHP Pilot Program- Average Single Head System Installed Cost** | **$7,500 each** | **Quantity (80)** |
|---|---|---|
| Manufacturer/Distributor Equipment & Supplies Volume Discount | - 12% | **Quantity (1,000)** |
| Simplified and Standardized Install Package & Controls Discount | - 6% | |
| Competitive Contractor Bidding Process Discount | - 15% | |
| Improved Install Site Evaluation and Selection process | - 4% | |
| | | |
| Full scale program discount estimate – 1,000 single head systems installed annually | **$ 4,725 each** | |

Forecasting the future equipment costs and installation pricing as the ccDHP technology matures is dependent on several factors including larger scale consumer adoption of heat pumps in colder climates, commodities pricing and potentially the introduction of new refrigerants.

# 8 FINAL RECOMMENDATIONS

## 8.1 Lessons Learned

- Cold-climate ductless heat pumps are a viable technology for the ComEd service territory in a larger program because there are demonstratable energy savings for customers, it enables ComEd to provide low- and moderate-income customers access to a new technology that can help them save energy, the technology also can help ComEd increase customer satisfaction with the company and build more trust with customers who are frequently doubtful of ***any*** utility motives.
- Income-eligible customers may have less interest or financial incentive to participate in ccDHP because many are on fixed energy rates. This points to a greater need to focus recruitment efforts on property managers, who would have a more marketable property with the upgraded technology. That could also lead to less tenant turn-over.
- Education can be an effective tool in changing customer behavior, but typically is not sufficient as a stand-alone energy efficiency tool.
- Layered and frequent customer messaging and reeducation for new tenants will drive greater energy savings.

## 8.2 Key Insights and Recommendations

The results of the study indicate several important considerations for a scaled program. From a data analysis perspective, these include the critical role pre-heating usage profiles play in final heating energy impacts, the benefits of comprehensive shell retrofits completed in conjunction with DHP installations and the necessity of both ambient air lock-out devices and consistent customer engagement. Limiting the use of multi-head systems, due to lower efficiencies and heating energy impacts, to only the most necessary scenarios, is also important.

CMC has utilized these various pilot attributes to create an anticipated savings value for a scaled program based on our recommendations. For a scaled program with usage participation guidelines, where at least 50 percent of the buildings are treated with shell retrofits, there are 5 percent or less multi-head installations and at least 40 percent of the buildings feature ambient lock-out controls, the expected mean savings per installation would be 2,816 +/- 1006 kWh for low-rise LI multifamily buildings. This would likely represent a 36.7 percent mean pre- and post-heating reduction. Considering future scaled cost per installation, CMC anticipates the mean cost/kWh, utilizing pre and post in place of deemed TRM savings, to be between $1.56 and $3.26 with a mean acquisition cost of $2.10 kWh for heating. While the application of these recommendations will likely increase mean savings per installation for a scaled program as compared to the pilot study results, occupant behavior, balance points, and other factors will always create variation in results.

There are other important qualitative and logistical insights CMC has prepared that will help inform future program design. Key insights and recommendations for scaled programs can be found below.

1. Pre-heat (baseline heating use) usage is directly correlated to heating energy impacts. There is a directional relationship where lower pre-heat usage led to less positive or negative heating energy impacts, while higher pre-heat usage led to more positive heating energy impacts.

   **Program Recommendation: Pre-Heat Usage Guidelines**

   CMC recommends that all buildings approved for DHP installation in a scaled program meet a minimum of 4,000 kWh per unit mean pre heat usage. This will ensure less variation in results and allow the program to better cost-effectiveness for the program overall.

2. Building shell treatment

   **Program Recommendation: Weatherization for Future Participants**

   CMC recommends shell retrofits—or weatherization— to make ccDHP installation sites heat pump ready. This should include insulation whenever possible. In addition, CMC recommends a mean pre-heat usage threshold per apartment of 3,500 kWh for buildings receiving shell treatments before or immediately after the installation of ccDHP systems, which is lower than CMC's kWh participation recommendation.

3. CMC found that units receiving ambient lock-out controls had more positive heating energy

impacts.

### Program Recommendation: ComEd Should Consider Using Lock-Out Technology

In the case of a scaled program, ambient lock-out technology can be a cost-effective addition to ensure the appropriate level of electric resistance displacement. CMC recommends calculating load profiles and plotting de-rated DHP capacity to determine the outdoor temperature at which the electric resistance can be energized via lock-out control. This would be in place of the pilot approach, which was to use a static ambient temperature (15°F) lock-out for the control devices on 20 of the 80 ccDHP systems. This approach may have the two-fold benefit of assured occupant comfort and safety, along with encouraging the least amount of electric resistance heating usage.

4. CMC tested the viability of multi-head systems as part of this pilot program with mixed results. The COP and heating energy impacts of multi-head systems overall were lower than single-head systems, though showed to be useful in specific scenarios.

### Program Recommendation: Emphasize Single-head Units Vs. Multi-head

CMC recommends the limited application of multi-head units for a scaled program, based on heating load calculations and pre-heat usage requirements. It should be stressed that single-head systems generally deliver higher efficiencies and lower costs, and this study has shown that the mean heating energy impacts for single-head units are more positive. Future studies should consider specific survey questions around this point for more qualitative, customer-focused context.

5. The pilot's installation requirement that all 80 ccDHPs needed to be installed by January 1, 2019, added some costs to the project because CMC was required to find a qualified HVAC contractor during the height of winter preparation period.

### Program Recommendation: Implement Program to Take Advantage of Off-Peak Shoulder Months

CMC recommends that ComEd implement the program to allow for most of the installation activity to take place during off-peak (shoulder) months when HVAC contractors have more capacity. Installation costs can be reduced if the work is conducted primarily during the non-peak periods of the residential HVAC industry such as February to April. Installation contractors are beholden to seasonal demands and are often anxious to find projects in the "shoulder months" to keep the field force engaged in productive activities. With proper planning and development of an installation pipeline for the slower months, contractors will be more likely to accept lower installation prices. This will enable the contractor to keep their crews on staff and engaged, without requiring seasonal layoffs. It also will lower program costs as many HVAC contractors reduce their prices during off-peak periods by 5-10 percent. A full-scale program should also consider schedule incentives for the property owners as well. Encouraging the work to be completed during the off-peak period is less impactful for tenants and contractors so a project discount, gift card promotion or credit to utility bill could be considered for the property owner in exchange for off-peak scheduling.

6. Due to the truncated installation period of this plot, CMC included apartment buildings in this pilot that were not ready for ccDHP installation. This caused delays and added costs to the pilot.

### Program Recommendation: Create/Target "Heat Pump Ready" Buildings

To improve the speed of ccDHP installations and the readiness of facilities, we recommend allowing for time to correct/adjust building conditions prior to participation. For example, electrical panel upgrades, pre-existing code violations, health and safety concerns can be documented and corrected in advance. For example, if specific building types are chosen and prequalified and installation scenarios are modeled and identified as "ideal," total installed costs can be reduced by creating a production environment. Ideal sites would be evaluated and determined to be currently "heat-pump ready" or made heat-pump ready through shell retrofits and weatherization.

To compliment this effort, CMC also recommends implementing a full pre-qualification system using tools like Google Earth to grade sites (e.g., target specific suburbs, garden apartments, etc.). This will streamline the process and result in more qualified sites. In addition, including trade partners in the selection process will result in a more accurate qualification.

Finally, include a customer acquisition model where the HVAC contractor(s) joins the program energy advisors on site visits before buildings are fully admitted to the program. The ability to vet the specific building conditions and align with a suitable ccDHP application will increase the accuracy of pricing, efficiency of installation and performance of the ccDHP systems.

7. CMC was fortunate to work with Mitsubishi because of the performance of their Hyper-Heat cold-climate product, the availability of the specified heating units and access to Mitsubishi's Diamond Contractor network. In a full-scale program, pricing for the ccDHPs should be lower with time allowed for a competitive bid process for equipment.

### Program Recommendation: Create a Bid Process to Secure Best Prices Available

Consider ccDHP manufacturers with the right credentials as mentioned above and establish a competitive bid process based on bulk purchase commitments. Having several manufactures engaged through this bid process not only generates an opportunity for lower unit pricing, but also assures product availability should one of the manufacturers have performance or capacity issues.

8. CMC's efforts to get 80 ccDHPs installed in less than three months were greatly enhanced using a Mitsubishi Diamond Certified installer, Four Seasons HVAC.

   **Program Recommendation: Select Two or Three Highly Qualified HVAC Install Contractors**

   CMC recommends the selection of at least two or three highly qualified HVAC installers who specialize in installing ccDHPs, and who have committed to continuing training on cold climate installation guidelines, local codes, and technical service. The relatively complex nature of ccDHPs requires that experienced technicians be involved in the initial site survey, equipment sizing calculations, skillful install, and the equipment start-up.

9. As CMC was searching for potential participants for the ccDHP pilot, there was not a clear definition of which buildings would be a good fit for the project.

   **Program Recommendation: Create a ComEd-owned Database of Potential Building Participants**

   Build a clear line-of-sight into the buildings within ComEd's territory that have electric resistance heat. While ComEd has multiple programs that touch on the targeted multifamily buildings that would benefit from ccDHPs, there does not appear to be a coordinated effort to compile that information. For example, Franklin Energy has been capturing this data (and electric water heating data) during the last several years of multifamily program work. Working collaboratively with ComEd, and other stakeholders This data could be collected in a central repository that would assist program marketing campaigns and customer acquisition.

10. CMC was fortunate to have partners that had completed prior energy efficiency projects with multifamily building owners because that enabled a quicker "sale" for potential pilot participants. A broader program would require a fine-tuned customer acquisition strategy.

    **Program Recommendation: Focus Customer Acquisition Efforts on Property Managers**

    CMC recommends focusing the sales process on property managers as opposed to tenants. Income-eligible customers may have less interest or financial incentive to participate in ccDHP because many are on fixed energy rates. Property managers would have a more marketable property with the upgraded technology, and that should lead to less tenant turn-over.

11. Participant education for tenants and property managers was key to proper use of the ccDHP for this pilot. We saw, however, that additional education for both groups could contribute to even

more energy savings.

### Program Recommendation: Increase Educational Opportunities for Program Participants

We recommend incorporating additional on-site instruction and leave-behind materials with the tenants and property managers to enhance the overall customer experience. These materials should include marketing collateral for tips and maintenance, an instructional video on regular and extended care, and handy product tags for quick reference on how to operate the ccDHP unit.

Many of the tenant related issues or concerns were behavioral so instruction on proper ccDHP operation is critical. In addition, the turnover high rate of tenants and property managers warrants the need for leave-behind materials for property managers to discuss with the new occupants. Continued educational messaging to tenants could solidify the energy savings potential of ccDHPs.

Property managers would also benefit from increased communications. To encourage adoption of ccDHP technology by property managers/owners, we recommend developing a full sales process and collateral to overcome owner skepticism and deliver a clear value proposition to the property owner. In the pilot, half of the assessments converted to sales. We expect the close rate will be less in a full-scale program with greater participation and savings goals. For example, CMC's experience in the more mature New Jersey Direct Install program for small business owners has a conversion rate of 30 percent.

In addition, tenants and property managers should be provided additional instruction when switching to cooling season to help them use the ccDHPs more effectively.

12. This pilot focused on LMI low-rise multifamily properties out of necessity given the short window for project implementation.

### Program Recommendation: Expand potential market to include properties outside of Chicago metro and include single-family homes.

Most of the electrically space-heated buildings were found outside of Chicago, primarily North and West of the city, including hot spots in Lake County such as Zion, Gurnee and Waukegan. We recommend expanding the potential audience for the program expansion.

In addition, we believe there is a substantial number of LMI customers who live in single-family homes with electric resistance heating who would also benefit from the ccDHP technology. Based on the results of the multifamily pilot, CMC is confident that our recommendations would deliver energy savings and improved comfort to ComEd's single-family customers.