A System Approach to Deep Heating Savings Through Measurement, Management, and Motivation

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Disclaimer

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Nomenclature and List of Acronyms

EMIS	Energy Management and Information System
HEUR	Heating Energy Use Report
HCA	Heat Cost Allocation
SWA	Steven Winter Associates, Inc.

Executive Summary

Across multi-tenant commercial office and multifamily buildings, centrally metered fuel use represents a substantial fraction of whole-building energy use. Energy audit practitioners understand that improving heating distribution efficiency is typically more of an opportunity than combustion efficiency and that differing thermal comfort preferences between tenants are the bane of operators across these building typologies.

There is an unmet market need for retrofit technologies that allow for the delivery of the right amount of heat to the right spaces, at the right time. The Energy Management and Information System (EMIS) package fills this gap through enhanced controls and metering, incorporating low-cost sensors and wireless communication infrastructure to provide a platform for ongoing commissioning and tenant feedback, including heat cost allocation.

With support from the US DOE Building Technologies Office, Steven Winter Associates, Inc. (SWA) partnered with Sentient Buildings, E Source, building owners, and utility and policy stakeholders, to demonstrate a market viable EMIS that achieves a reduction in space heating energy use by reducing heating load, improving control, and positively impacting behavior while providing an acceptable financial return.

In this study, EMIS packages were implemented in two New York City multifamily rental buildings. Both buildings conducted basic mechanical work (e.g., repairing steam traps) to ensure the heating system was operating well before any tenant feedback was layered in. Heating Energy Use Reports (HEUR) were created to provide tenants with social comparisons and energy savings tips to influence their behavior; these were provided monthly to all tenants in both buildings.

Additionally, one building allocated heating costs to a portion of the tenants. Heat cost allocation (HCA) has a long history in the European Union (EU), although it is not common in the US or in steam-heated buildings. SWA leveraged existing EU best practices and stakeholder feedback to develop a Heat Cost Allocation algorithm that was considered equitable and intuitive.

Energy use and tenant behavior impacts were tracked throughout the study. The basic mechanical repair work saved between 11-20% of heating energy. Those savings rose to 17-24% with the addition of tenant feedback. While it may not be possible to precisely determine the impact of COVID-19 on research studies like this, there may have been additional savings realized had the study taken place in a period of normal occupancy patterns.

These types of central heating systems have been a blind spot for utilities, who have traditionally had little visibility into detailed behind-the-meter gas usage. Heating energy savings stayed consistent during the coldest months, indicating the potential for utilities to utilize EMIS packages for peak gas demand reductions or demand response programs.

Tenant comfort was also improved. Post installation, room temperatures more closely matched thermostat set points. Perhaps due to this greater level of control, the vast majority of tenants being billed for heating were accepting of the allocation costs. And tenants receiving heat cost allocations were more likely to reduce their thermostat setpoints than tenants receiving behavioral feedback without financial impacts were.

Variation in building specifics makes it difficult to provide precise energy and financial savings estimates. But within the range of expected conditions, the study identified a few key variables that can have the greatest impact on financial returns: the cost of fuel, the ability and willingness to allocate heating costs to tenants, and a well-functioning heating system as a starting point.

This study focused on two multifamily buildings, but additional use cases, such as commercial buildings and affordable housing, should be explored to better understand the full market potential. While this type of upgrade has the potential for deep energy reductions and cost savings, future projects should take into account the balance of costs and benefits between owners and tenants, especially in the affordable, regulated, or other low-to-moderate income (LMI) segments of the market. Rent credits, utility allowances, or a shared savings program are possible options to accelerate adoption of this strategy in these market segments.

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1 Project Overview

1.1. Background

Since its founding in 1972, Steven Winter Associates, Inc. (SWA) has worked with builders and developers across the country to improve building energy performance. Across the multi-tenant commercial office and multifamily buildings that SWA frequently audits, centrally metered fuel use represents a substantial fraction of energy use. In these buildings, thermal energy for space heating is distributed via hot water or steam piping connected to a central boiler. Energy audit practitioners understand that improving heating distribution efficiency is typically more of an opportunity than combustion efficiency and that differing thermal comfort preferences between tenants are the bane of operators across these building typologies.

There is an unmet market need for retrofit technologies that allow for the delivery of the right amount of heat to the right spaces, at the right time. The Energy Management and Information System (EMIS) package fills this gap through enhanced controls and metering, incorporating low-cost sensors and wireless communication infrastructure, with an ongoing commissioning platform to reduce energy use across multiple building systems with automated fault detection and diagnostics. The proposed package will both reinforce and build on the industry awareness that DOE has garnered around electrical sub-metering. The ideal locations for thermal sub-meters, in the vicinity of tenant heating terminal units, are also ideal control points. Without local controls and balanced distribution, under-heating in some spaces can only be addressed by over-heating other spaces and boiler over-firing. Deep savings can be achieved by utilizing real-time data to address behavioral opportunities with tenants and providing building personnel with a platform to find and fix building operational and energy deficiencies.

1.2. Goals and Objectives

The goal of this project was to demonstrate a market viable EMIS that achieves a reduction in space heating energy use in multi-tenant commercial and/or multifamily buildings by reducing heating load, improving control, and positively impacting behavior with a financial return that is acceptable in the real estate market. Deep savings will be cost-effectively achievable with an approach that targets efficiency improvements across heating, energy management and sensor/control building systems, while engaging tenants and operators with data-driven conservation.

An additional goal was to document the potential for utilities to use this as an option for reducing gas demand on the coldest days, in addition to overall energy use. Some utilities, such as those in the NYC area, are facing issues meeting peak gas demand and looking for ways to manage it. They have historically had little visibility in detailed gas usage (as compared to electricity), especially on larger, central systems. Heat submetering has the potential to fill in this gap, providing behind-the-meter granularity of information, a likely reduction in overall gas usage, and the potential for gas demand reduction programs.

While measuring the thermal energy distributed to different tenant spaces from a central source is technically more challenging than other metering, such as electrical sub-metering, thermal sub-metering also offers additional benefits. Thermal sub-metering can thus be coordinated with enhanced controls as part of a holistic upgrade that improves heating system efficiency by minimizing boiler run time and eliminating the over-heating of many tenant spaces for much of the year that is required to address under-heating in other tenant spaces. Thermal sub-metering implementation is nearly nonexistent in the US market; however, the positive effects of thermal sub-metering have been widely documented in Europe for several decades since "no other remotely comparable measure has such low [carbon] abatement costs as consumption-based [heat] billing."[i] The proposed package takes advantage of emerging wireless sensor and real time energy monitoring trends to cost-effectively deliver a retrofit package tailored to the US market.

2 Methodology, Assumptions, and Procedures

Based on the goals and objectives of the project, the project team developed a plan to execute the research needed to explore the hypothesis noted in Section 1. This included identifying relevant sites, determining which current technologies would support the research, executing the technology installation, and developing an algorithm that would equitably allocate heating energy usage across the tenant spaces.

2.1. Site Selection

2.1.1. Overview

Several sites were evaluated for participation in the demonstration of the EMIS based on the following criteria identified by the project team as being relevant to the study:

- Willingness and ability of the owner to bill for heat, including
    - Tenant type (market-rate, regulated, or affordable)
    - Expected number of lease turnovers during the study period, which affect how quickly and widely billing could be rolled out
    - Ability to amend leases to include a provision to allocate heat costs at lease signing or renewal
- Other building work planned during the study period
    - Avoiding anything that might impact the results of the study
- Applicability to the overall market

Stakeholder discussions indicated that this pilot work should occur in market-rate buildings as a start, where passing through heating costs is allowed under current regulatory conditions in New York State. Passing through heating costs in rent-regulated and affordable housing in this region would require changes in state regulations, which would take time and buy-in from a variety of industry stakeholders. This informed the selection of the demonstration sites for the study.

After reviewing discussing potential options with building owners, two demonstration sites were selected. Their characteristics are listed in Table 1.

Table 1. Demonstration Building Characteristics

	Demonstration Site One	Demonstration Site Two
Year Built	1987	1970
Size (gross square footage)	176,584	290,816
Building Type	Multifamily	Multifamily
Location	New York City	New York City
Lease Structure	Rental	Rental
Number of Units/Type	259 market-rate	131 market-rate 53 rent-stabilized
Tenant Feedback	Heating energy use reports (HEURs) and cost allocation	Heating energy use reports (HEURs) only
Heating System Type	Two-Pipe Steam w/ PTACs Scotch Marine Steam Boiler (2)	Two-Pipe Steam w/ PTACs Scotch Marine Steam Boiler (1)
Heating Energy Source	#4 Fuel Oil	Natural Gas

Both buildings have ground floor retail spaces but the associated overall floor area, and heating energy use were considered negligible compared to that of the multifamily spaces.

2.1.2. Demonstration Site One

Demonstration Site One had recently been renovated at the start of the project. Certain factors made this site ideal for the implementation of this technology:

- The existing heating system had an existing networked thermostat system that was able to be repurposed
- Apartment access was thought to be less challenging than typical apartments due to size (mostly studios and one-bedrooms) and the ability of staff to secure access with the implementing contractor

2.1.3. Demonstration Site Two

At the start of the project, Demonstration Site Two was planning to repair the existing steam heating system as required by local regulations. This timing afforded some benefits related to the installation of the EMIS:

- Access to the apartments was already required to perform basic system maintenance
- The planned project included work to ensure all components of the heating system (e.g., steam traps, fans, filters) were functional

One additional difference for this site is that the owner was not comfortable initially billing tenants for their heating use but instead wanted to provide an incentive for people to use less energy.

2.2. Technology Selection and Installation

The technology selection and installation included all work associated with optimizing the performance of the steam heating system at the selected host sites as well as the deployment of zone-level temperature controls connected to a building-wide wireless network to monitor the performance and usage of the heating system.

The first step was to determine the scope of work required to ensure the heating systems at each site were functional so that adequate local control could be provided. Steam heating systems are typically unbalanced which results in over- and under-heated spaces. In order to equitably allocate heat, early stakeholder feedback indicated that this was a fundamental prerequisite, along with individual control, to enable this solution's acceptance in the market.

Since the two-pipe steam distribution and terminal units were the same at both buildings the mechanical scopes of work to optimize the existing heating system that were developed were similar:

- Demonstration Site One
    - Repair all steam traps in the common areas of the building
    - Repair all steam traps at the terminal units
- Demonstration Site Two
    - Replace all steam traps in the common areas of the building
    - Replace all steam traps at the terminal units
    - Install inlet orifice plates at the terminal units to extend steam trap life
    - Install electronically actuated control valves to replace existing thermostatic control valves

The zone-level temperature controls at both buildings were the same and utilized a Telkonet EcoSmart thermostat. These thermostats allowed for four operating modes (off, auto, heat, and cool) and local set point control, as well as connection to a building-wide wireless network.

At Demonstration Site One, existing thermostats were directly wired to each PTAC and reported back to the building-wide wireless network. This existing system already captured sufficient data for the purposes of this study; however, some minor pieces of hardware were added in order to transmit that data to the central database that was used for the study.

At Demonstration Site Two the existing PTACs were of various ages with different types of local controls. To avoid the costs of running new wiring between the new controls and the PTACs, wireless thermostats were utilized. Each wall-mounted thermostat transmitted commands wirelessly to a control board connected to the PTAC.

Both systems fundamentally functioned the same way, providing the EMIS with the data required to monitor the system performance and allocate heating usage. The thermostats communicated to a gateway located every few floors; those gateways were wired back to a server located in an IT closet or main office.

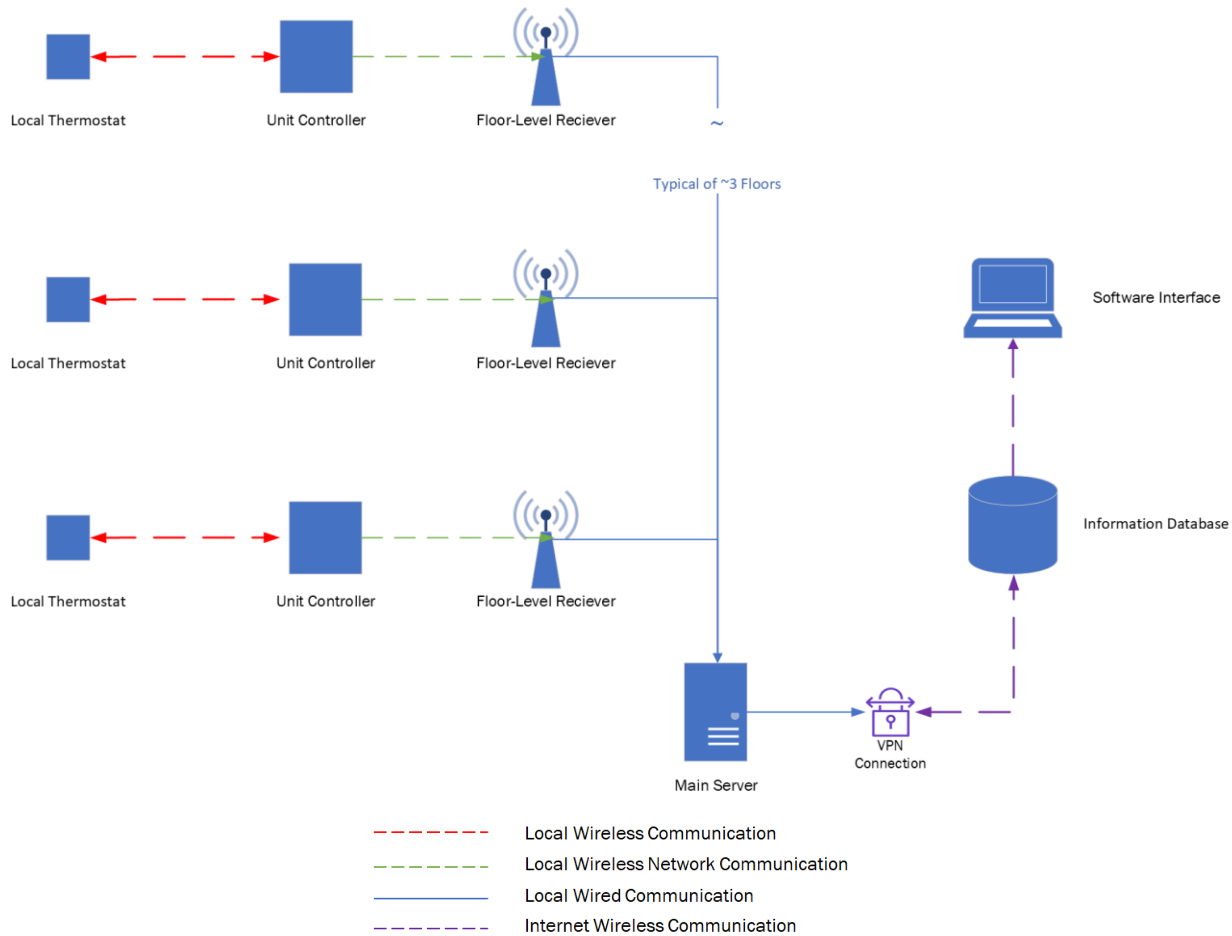

Figure 1 Technology Network Architecture

The local server connected to a cloud-hosted information database, which for the Demonstration Sites was SkySpark software which also provided a user interface. Due to the existing conditions and customer requirements, different operator and tenant interfaces were provided at the two sites. Demonstration Site One utilized the Telkonet EcoCommander platform, while Demonstration Site Two utilized Sentient Building's Neuro™ interface.

Both interfaces provided similar features for the building operations staff to view and control the status of the thermostats and set temperature limits. The Neuro™ interface at Demonstration Site Two had the additional feature of a tenant interface. More information regarding the development and details of the Neuro™ interface can be found in Sections 2.8 and 2.9. 0

After the relevant scopes of work were bid out and contracted, the selected contractors performed the installation and integration. SWA observed sample installations to confirm that they met the requirements of the scopes of work and project intent before the contractors started scaling up throughout the buildings. Both projects submitted applications to existing state and utility incentive opportunities to reduce the cost of the owner-paid portion of the technology installation.

The final costs for each site are outlined in Table 2. The mechanical installation refers to the heating system upgrades and/or repairs required to provide balanced heat throughout the building. In a building with a heating system in good repair and operating condition, this portion of the scope may not have been needed. For any future potential sites, this should be verified by certified and/or competent professionals. The technology installation refers to the addition of sensors, thermostats, and networking components required to provide control to tenants and acquire the data.

Table 2 Technology Installation Costs

Installation Component	Demonstration Site One	Demonstration Site Two
Mechanical	$107,908.00	$335,235.81
Technology	$0.00	$491,203.56
Total	$107,908.00	$826,439.37

2.3. Technology Commissioning and Optimization

After the technology installation was completed, SWA physically inspected a minimum of 10% of the installations to ensure that they were correct. No major issues with the installation were identified during this process.

SWA routinely performed data quality reviews on information generated from the technology installation and altered the appropriate parties (Sentient Buildings, other contractors, or the building) to remedy any identified issues that developed after the initial installation.

Following the installation and initial commissioning, SWA used the available data to optimize the central heating system operation, such as making changes to the heating plant sequences of operation and set points to reduce the overall temperatures in the buildings while continuing to provide tenants with heat and minimizing complaints, in order reduce heating energy use before any behavioral feedback was introduced.

2.4. Lease Language Change

Prior to this study, the apartment leases for the two demonstration sites included heat in the base rent charge. This is typical of the New York City housing market.

In order to create the option for passing through an allocated portion of the heating cost to the tenants in Demonstration Site One, new language needed to be added to leases going forward. SWA worked with the owners of this building, including their operations, leasing, and legal teams, to develop a Heat Apportionment Rider that was appended to new and renewing leases, and which enabled the Heat Cost Allocation (HCA) amount to be passed through to tenants as additional rent.

2.5. Algorithm Development

Before developing an algorithm to allocate heating energy usage to tenant spaces, SWA was able to review similar work that has been done in the European Union (EU). Building on those learnings, SWA analyzed several building characteristics that could impact heating energy usage and discussed the findings with stakeholders before finalizing the Heat Cost Allocation (HCA) algorithm that would be used in this study.

2.5.1. Heat Cost Allocation (HCA) Algorithm Development

To develop the HCA algorithm for this study, SWA built on the existing EU practices and stakeholder feedback while also considering the challenges of steam heating systems, which are uncommon in the EU. Due to the physics of steam heating systems, there is not a technically feasible[ii] way to determine the precise quantity of heating energy that each tenant space is responsible for.

The research resulted in the identification of three key goals desired for the allocation approach:

1. Motivate action by giving tenants a clear signal that both saves heating energy and reduces heating costs
2. Utilize a transparent and intuitive allocation method that allocates heating costs across tenants in a way that they believe fairly represents heating usage
3. Allocate heating costs without directly measuring heating energy flow to each room

SWA began by calculating the correlation between several location-specific (i.e., fixed building features) and time-dependent characteristics (i.e., tenant choices) and actual heating usage. This was done first at the room level, and then aggregated to whole tenant spaces. Characteristics for evaluation were selected based on data commonly available from these buildings as well as captured by current technology.

Different combinations of these characteristics were used as inputs in potential HCA algorithms and assessed based on these considerations:

1. Availability of characteristics based on current best practice and technology
2. Reliability of input data for a given characteristic
3. Variability of characteristics over time and space type
4. Ease of explanation to tenants and stakeholders

From this selection criteria list, the following variables' correlation to heating energy use were evaluated for potential inclusion in the final algorithm:

1. Gross space floor area
2. Exposed exterior wall area
3. Estimated envelope penetration crack length
4. Number of heaters and capacity
5. Heater runtime (where available)
6. Current room/space set point
7. Adjacent room/space set point
8. Indoor room/space air temperature
9. Outdoor air temperature

Overall, it was determined that an allocation algorithm that combines apartment size and set point would likely achieve the desired effects and be considered equitable. It would also be easy to understand and intuitive. The full results of the correlation analysis, as well as additional information on the HCA algorithm development, can be found in the Appendix.

Stakeholders noted that size and set point are the two main drivers of energy use in a single-family home as well (assuming similar envelope, system efficiencies, etc.), and that an algorithm based on these two factors would likely be well accepted by tenants, owners, and utility programs. From these discussions, it was believed that if the billing amount was completely based on fixed data, like apartment characteristics, there would be no motivation for tenants to use less heat. Alternatively, if the billing amount was completely based on the variable tenant usage, people in studio apartments could be charged as much as those living in 3-bedroom apartments, even though their space likely requires less heating energy, even when at the same set point.

Based on this feedback and further analysis, the input characteristics were refined into the selected algorithm.

2.5.2. Selected HCA Algorithm

Once the critical inputs were identified, a repeatable algorithm was developed to be deployed throughout the study.

$$Apt\_Cost_i = HeatCost_{meter} * (Alloc_{SP\_i} + Alloc_{Rem\_i})$$

$$Alloc_{SP\_i} = \frac{SP_i - 68}{15} * Afrac_i$$

$$Alloc_{Rem\_i} = Afrac_i - Average(Alloc_{SP})$$

Where:

Apt_Cost_i = HCAA amount billed out to occupants in a given apartment "i" [dollars]
$HeatCost_{meter}$ = total monthly heating cost for the building, [dollars]
SP_i = room average set point over billing period [°F]
$Afrac_i$ = floor area of room served by thermostat / floor area of all apartments [unitless]

The term $\frac{SP_i - 68}{15}$ normalizes the room set point between 65°F to 80°F (a 15°F range), with an adjustment index of 68°F. The index temperature of 68°F is commonly referenced as a minimum temperature that building owners are legally required to provide during heating season in New York City.[iii] Stakeholder discussions had also indicated that anchoring the set point index to this required temperature could help with tenant acceptance, as it would not seem too aggressive in pushing for savings (as a lower index temperature might). The $Alloc_{rem}$ term is a fixed amount for each apartment and accounts for how much higher or lower a particular apartments' set point is than the whole-building average set point. In total, the algorithm allocates the entire heating bill amount from the utility--there is no "extra" passed through to the tenants.

2.5.2.1. Demonstration Site One Algorithm

Demonstration Site One limits the thermostats to a range between 65°F to 80°F, a total of 15°F. This range is used as the denominator in the $Alloc_{SP\_i}$ term, making the final HCA algorithm for each apartment at this site:

$$Apt\_Cost_i = HeatCost_{meter} * (Alloc_{SP} + Alloc_{Rem})$$

Where

$$Alloc_{SP\_i} = \frac{SP_i - 68}{15} * Afrac_i$$

$$Alloc_{Rem\_i} = Afrac_i - Average(Alloc_{SP})$$

2.5.2.2. *Demonstration Site Two Algorithm*

Demonstration Site Two limits the thermostats to a range between 66°F to 76°F, a total of 10°F. This range is used as the denominator in the $Alloc_{SP\_i}$ term, making the final HCA algorithm for each apartment at this site:

$$Apt\_Cost_i = HeatCost_{meter} * (Alloc_{SP} + Alloc_{Rem})$$

Where

$$Alloc_{SP\_i} = \frac{SP_i - 68}{10} * Afrac_i$$

$$Alloc_{Rem\_i} = Afrac_i - Average(Alloc_{SP})$$

2.6. Behavioral Intervention Development

To supplement the heating energy usage determined by the HCA algorithm, heating energy use reports (HEUR) were developed as part of the heat cost allocation package for each building. These reports were intended to provide clear signals on heating energy use and costs, and to motivate actions to reduce energy use. A literature review, and iterative stakeholder feedback, was conducted to develop a package of behavioral intervention strategies to be used in the HEUR.

2.6.1. Background

Several behavioral intervention strategies have been implemented and researched in various academic and industry-backed studies. The following is a summary of notable studies and strategies that provided a research- and evidence-based framework for development of the HEUR.

A study named "A review of intervention studies aimed at household energy conservation" (Abrahamse 2005) provided two general themes for interventions in energy savings programs.

- Antecedent interventions, which are strategies that are implemented at the start of a program, such as public commitments, information sessions via workshops or mass media campaigns, and home energy audits
- Consequence strategies, which focus on providing feedback during or after a program, such as ongoing monitoring and reporting, comparative feedback, and rewards

Both the antecedent intervention and consequence strategy were used for the heating allocation program. The antecedent intervention came in the form of letters and emails to residents to inform them of the impending changes to heating energy tracking and feedback (described in more detail in the subsequent "Tenant Feedback Execution" section of this report). The consequence strategy came in the form of the HEUR itself, and includes several behavioral intervention sub-themes, such as energy savings tips and social comparisons.

A meta-analysis of energy conservation experiments named "Information strategies and energy conservation behavior: A meta-analysis of experimental studies from 1975 to 2012" (Delmas 2013) tabulated its findings by categorizing individual usage feedback strategies into the following categories:

- Energy savings tips
- Real time feedback
- Audits and consulting
- Monetary savings feedback
- Monetary incentives
- Social comparisons

The following image from the report provides descriptive statistics, including average treatment effect, of the various individual usage feedback strategies.

Table 1
Descriptive statistics.

Study characteristic	Field observations	Mean	Std. Dev	Min	Max	Percent of Observations (%)	Percent of Papers (%)	Weighted average treatment effect (%)
Dependent variable								
Effect size (Percent)	156	−7.441	10.02	−55.00	18.80			−7.4%
Independent variables								
Individual usage feedback	156	0.7564	0.43	0	1	75.6	76.9	−8.5
Energy saving tips	156	0.7243	0.45	0	1	72.4	63.1	−9.6
Real time feedback	156	0.1217	0.33	0	1	12.2	22.0	−11.0
Audits and consulting	156	0.0833	0.28	0	1	8.3	6.2	−13.5
Monetary savings Info	156	0.3012	0.46	0	1	30.1	26.2	−7.7
Monetary incentives	156	0.2179	0.22	0	1	21.8	27.7	−5.7
Social comparisons	156	0.2371	0.42	0	1	23.7	20.0	−11.5
Study level controls								
Control group	156	0.7115	0.45	0	1	71.1	61.5	
Weather	156	0.3141	0.46	0	1	31.4	24.6	
Demographics	156	0.1795	0.38	0	1	17.9	15.4	
Treatment duration (months)	156	7.6872	12.53	0.3	60	100	100	

Figure 2 Overview of Energy Conservation Experiments

The meta-analysis findings provided an evidence-based list of energy conservation and feedback strategies to guide the development of the HEUR, from which SWA selected relevant ones. For example, audits and consulting and real time feedback on each apartment were not feasible; however, social comparisons and energy savings tips were. Therefore, social comparison and energy savings tips, cost allocation (where applicable), and monetary savings info (where applicable) were selected as appropriate strategies for the HEUR.

2.6.2. Methodology and Development of Heating Energy Use Report

2.6.2.1. Report Sections and Design

Based on the initial behavioral research performed, SWA developed a Heating Energy Use Report (HEUR) consisting of five main sections: a header, social comparison, energy savings actions, summary of settings, and FAQs/disclaimer.

The header included the tenant's name and address and the reporting period, as well as custom summaries for each building depending on whether or not the building sends heat apportionment bills.

The social comparison section summarized the tenants' heating energy use performance with three sub-sections: an overall grade, a comparison chart, and a greenhouse gas emission comparison. The overall grade compared the tenant's performance to others with similar apartment types and sizes throughout the building. The overall grade was calculated using the apartment's percentile rank and compared against quartiles calculated based on each apartment type. The comparison chart provided graphical information of the apartment's heating energy consumption over time and compared it against the average (or "typical") and best (or "efficient") performing apartment of each type and size. Finally, the greenhouse gas emission comparison section translated the apartment's allocated heating energy usage into related greenhouse gas emission equivalents. Both demonstration sites were in New York City, therefore the greenhouse gas emissions were translated to NYC subway trips based on published NYC subway emissions.

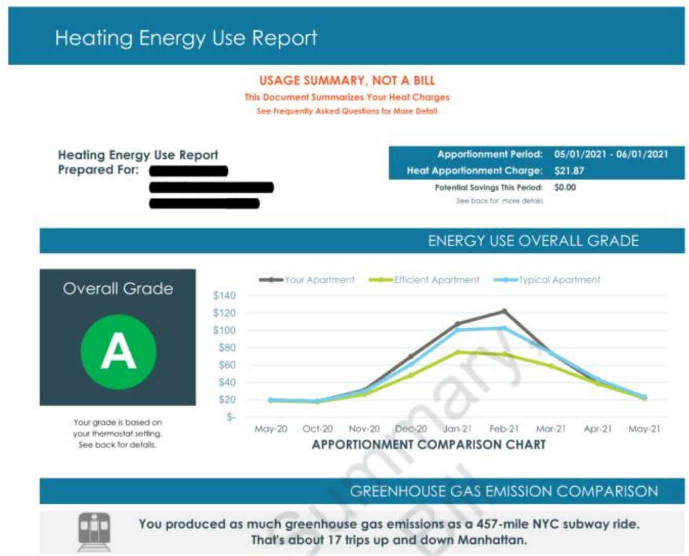

Figure 3 Example of Developed HEUR Cover Page

The energy savings actions section provided several basic energy conservation tips related to the heating system, such as lowering thermostat set points, turning off the heat before leaving, and ensuring windows are fully closed and sealed.

The “summary of settings” section provided an overview of the tenant's average time-weighted set point during the reporting period. This section also provided the building’s average set point for comparative purposes.

Finally, a frequently asked questions (FAQ) section provided information about the report and billing (if applicable) in a question-and-answer format for ease of use. The frequently asked questions section was followed by a disclaimer section regarding data quality and assurance.

Figure 4 Additional Information Provided in HEUR

Demonstration Site One included apportionment charges added to each tenant’s monthly rent statement. The header section of Demonstration Site One's HEUR included a bill amount summary, while an additional Heat Apportionment Charge Breakdown section provided breakdowns and descriptions of the two parts of the apportionment charge (See Figure 4). Demonstration Site Two did not include apportionment charges, and therefore did not include these financial feedback sections. Refer to the Appendix for examples of Demonstration Site Two’s HEURs.

Early iterations of the HEUR were reviewed and revised by the SWA project team and included administrative and marketing professionals. The HEUR was drafted in several Microsoft applications before the final template was made in Excel. Draft HEURs were distributed to building representatives (owners and management) for feedback and approval. The layout and format of the HEUR was carefully reviewed and tested to ensure proper fitment and placement into single-window envelopes. Each month throughout the heating season, paper copies of the HEUR were converted into PDF, printed, folded, and stuffed into envelopes, and mailed to each apartment.

2.6.2.2. Calculations Behind Behavioral Intervention Sections of Heating Energy Use Report

2.6.2.2.1 Performance Grade Calculations

One of five grades (A, B, C, D, and NA) and a respective color-coded icon were displayed on each apartment's HEUR for each billing period. Apartments were grouped by similar size for comparison in order to limit the effects that an apartment's size may have on typical set points. For example, an apartment with multiple rooms would have more thermostats than a studio apartment and likely has different heating needs.

Grades were based on a comparison between each apartment's monthly average set point (mode-mapped to only consider times when the heater was in heating mode) and the set points of all other apartments within its group. An "A" grade was given to apartments that had an average set point less than the 25th percentile. A "D" grade was given to apartments that had an average set point greater than the 75th percentile. The percent rank (or rank value displayed as a percent) of each group's average set point was determined and used as the threshold between a "B" grade and a "C" grade. A "B" grade was given to apartments with an average set point greater than the 25th percentile and less than or equal to the percent rank of the group's average set point. A "C" grade was given to apartments with an average set point greater than the percent rank of the group's average and less than or equal to the 75th percentile. Figure 5, below, shows the grade, its icon, and typical set points observed.

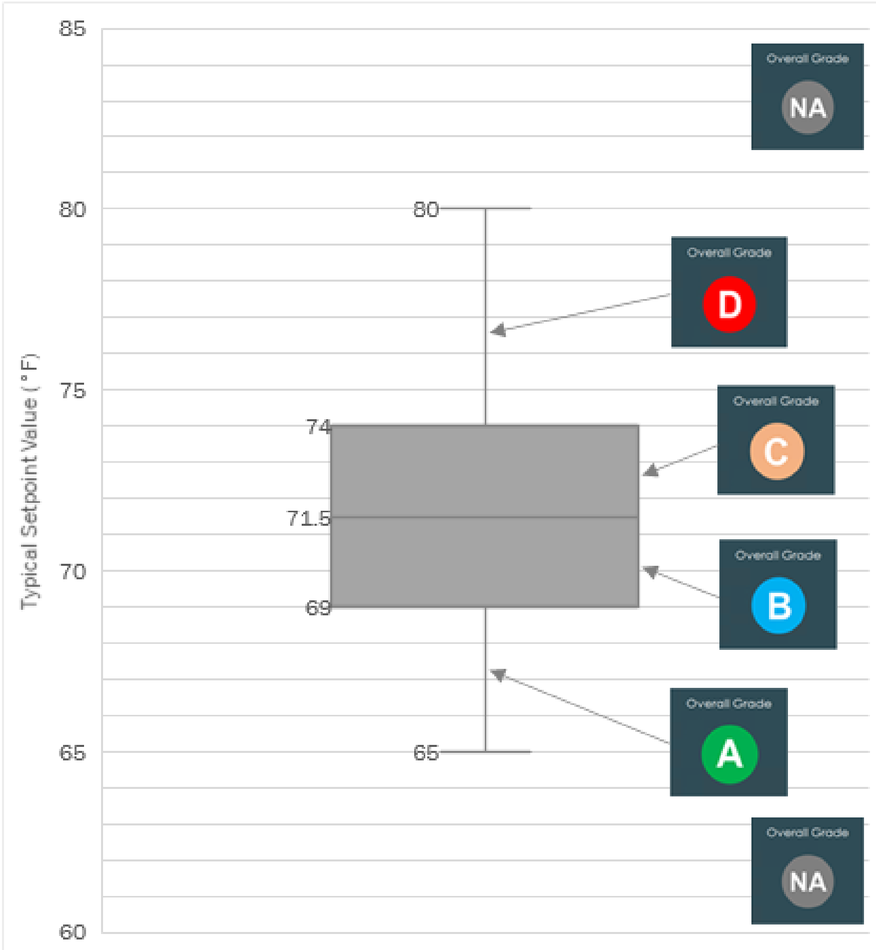

Figure 5 Overview of Performance Grade Calculations

2.6.2.2.2 Comparison Chart Calculations

The comparison chart showed each apartment's annual heating energy consumption pattern compared to the average (or "typical") apartment and to the highest (or "efficient") performing apartment. Similar to the overall grade, comparisons were only made to similar-sized apartments. The X-axis of the chart showed the relevant months of the year, while the Y-axis was either the monthly bill amount or a unitless scale of energy consumption, depending on the demonstration site. The "typical" apartment's data points were simply the average cost or consumption per month. The "efficient" apartment's data points were based on the calculated cost of an apartment with the lowest potential set point. Below are two examples of comparison charts, Figure 6 is an example of a comparison chart from a HEUR sent to Demonstration Site 1, where apportionment charges were distributed to residents. Figure 7 is an example from Demonstration Site 2, where no apportionment charges were distributed.

Figure 6 Grading for Demonstration Site 1

Figure 7 Grading for Demonstration Site 2

2.6.2.2.3 Greenhouse Gas Emissions Calculations

The greenhouse gas emission (GHG) comparison section translated the apartment's estimated heating energy usage into New York City-related GHG equivalent metrics. Both demonstration sites are in New York City, therefore NYC subway miles were used as the related metric.

Commuter rail GHG emissions data from The Climate Registry's Transit Agency Performance Metric Report was used to translate each apartment's heating energy use to equivalent number of commuter miles traveled. According to the 2017 report, published in October of 2020, approximately 0.000123 GHG $mtCO_{2e}$ is emitted per commuter mile. Table 3 shows the GHG emissions per fuel type, based on NYC Local Law 97 (published in 2019), that were used to estimate heating energy use GHG emissions per apartment for each demonstration site.

Table 3 Greenhouse Gas Coefficients

Fuel	tCO_{2e} per kBtu
Natural Gas	0.00005311
#4 Oil	0.00007529

Each billing period, the estimated heating energy use (kBtu) was converted to miles traveled by multiplying the estimated heating energy use by the fuel's GHG emission rate, then dividing by the commuter rail's GHG emission rate. In addition, the equivalent number of trips up and down Manhattan were provided for more context, as the number of miles can be large when heating energy use is high. Figure 8, below is an example of the Greenhouse Gas Emission Comparison section provided in each HEUR.

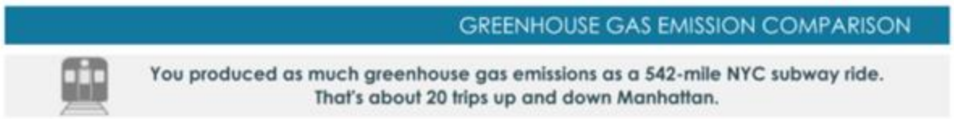

Figure 8 Greenhouse Gas Comparison in HEUR

2.7. Tenant Feedback Execution

With the HCA algorithm determined and the behavioral feedback ready, SWA began executing the algorithm and sending HEURs monthly to the tenants at the two Demonstration Sites.

2.7.1. HCA Execution and HEUR Generation

2.7.1.1. Data Collection and Processing

Data captured from the networked thermostats at both Demonstration Sites was processed monthly to allocate the heating costs to the individual apartments. The data processing and calculations were completed using Python and the purpose-built HCA algorithm.

Thermostat data was reported every ten seconds to a SkySpark cloud database. At the beginning of each month, data for the last month's billing cycle was downloaded. The apartment data consisted of three types, each of which required a separate processing method:

1. Number (e.g., Set point)
2. String (e.g., Mode)
3. Boolean (e.g., Heating Status)

Once all variables had been collected, the timeseries were resampled into 15-minute intervals and start/end times of the variable sets were aligned. During this stage, out-of-range values were considered to be errors and removed so as to not impact later calculations. For example, any Set point values outside of 65-85°F were discarded as those values would be outside of the range allowed by the thermostats. The quantity of removed values for each apartment was stored for later data quality evaluations.

Because this analysis sought to quantify the impact of tenant behavior on heating use, Mode and Heating Status variables were used to remove Set point values whenever the system was "Off." Occupancy was also factored in to ensure that a tenant's bill accurately reflected their usage based on move-in or move-out dates. For example, if a tenant vacated an apartment halfway through the month, the calculations only incorporated Set point data for that apartment before the move-out date. In addition, the utility bill allocated to that tenant was prorated based on the number of days the apartment was occupied.

After the heating allocations were completed, additional metrics were computed to provide insights and guidance to tenants (as described in the Comparison Chart Calculations section).

The calculated heating allocations and additional metrics were input into a report generator to create a PDF report for each apartment in both Demonstration Sites. These HEURs were provided to tenants starting in January 2021.

2.7.1.2. Whole Building Monthly Heating Energy Use Cost Analysis

For Demonstration Site One, where heating apportionment charges were distributed, 24 months of #4 fuel oil delivery data was analyzed prior to each heating season to establish the building's estimated heating fuel consumption rate (gallon/HDD) and the baseload (i.e., domestic hot water) fuel consumption rate (gallon/day). This analysis was necessary due to a lack of ability to accurately track daily oil consumption and the irregularity of oil tank refills. The utility regression analysis and estimated heating fuel consumption rate was updated on an annual basis, as opposed to monthly, to prevent inaccurate predictions of baseload fuel consumption during high heating demand months where baseload data was unavailable (i.e., no days with 0 HDD). This annual analysis helped smooth out the effects from the irregular oil delivery data.

Each month, outdoor air temperature (HDD) data and oil delivery costs were collected to estimate the heating fuel cost per reporting period (monthly). The estimated heating energy consumption rate (gallon/HDD) was multiplied by the HDDs each month to get total heating fuel consumption, which was then converted to dollars using the monthly oil cost rates ($/gallon).

The calculated heating allocations were then uploaded to the tenant management system to integrate with the building's existing rent billing process for those tenants whose leases included heat cost allocation rider agreement. The percentage of tenants receiving this allocation started small and reached ~25% by the end of 2020. In January 2021, there was a large batch of lease renewals, resulting in 75% of tenants that were subject to this allocation.

2.7.2. Mock Billing Period

Before rolling out the actual billing portion of the study, there was a period of mock billing at Demonstration Site One. These mock HEURs included cost information, but only to prepare tenants for the upcoming actual billing for heating energy usage and to provide a sense of the anticipated costs. Costs were not included in monthly rent statements during this period. Refer to the Appendix for examples of mock HEURs.

After January 2021, when most of the tenants (greater than 75%) in Demonstration Site One were billed for their heating energy usage, the mock HEURs continued to be sent to tenants not yet in the heat cost allocation rider agreement to continue providing behavioral feedback.

The period of mock HEURs provided SWA with initial tenant feedback. Multiple inquiries were related to cost allocations despite tenant claims of low thermostat set points. This prompted SWA to provide more detail on the HCA algorithm and the breakdown of costs between a base charge and a usage charge in the HEURs, as well as additional information on the tenant's average thermostat set point for the month.

2.8. Tenant Interface

Building on the HEURs, the long-term goal would be to incorporate the messaging from the reports into a tenant-facing mobile application with the capability to access most, if not all, of their heating energy usage information in real time. To support this effort, Sentient Buildings developed a few different versions of a tenant-facing interface that integrates with the data collected by the EMIS.

The first version was a web-based tenant interface which generated a unique Access Code for each apartment that was emailed to the main leaseholder for the apartment.

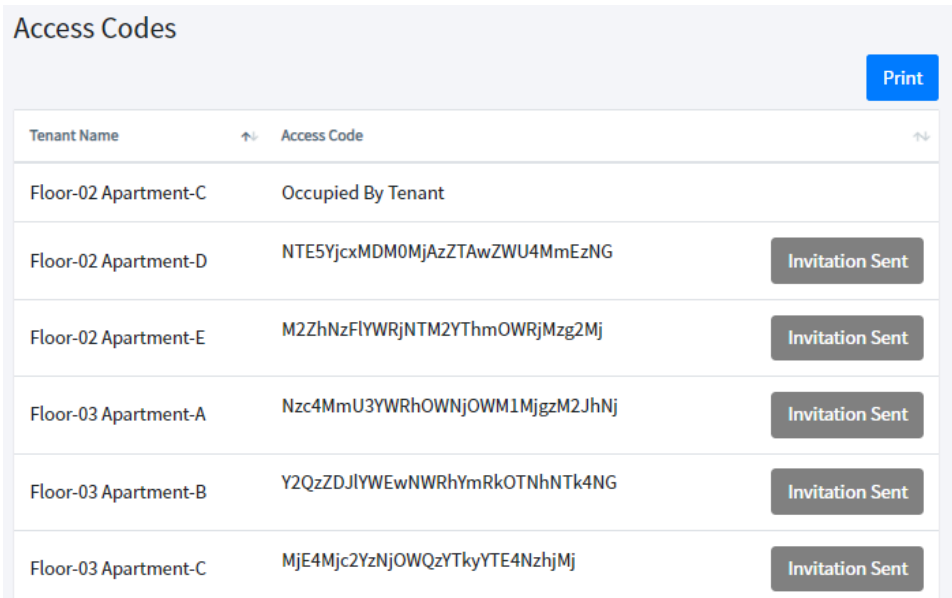

Figure 9 Tenant Interface Access Codes

The initial roll out resulted in a sign-up rate of ~9%. After reviewing the features with stakeholders, it was determined that, given the prevalence of mobile apps, it was unlikely that a web-based interface for tenants was going to result in sufficient user activity to support the overall goals of tenant engagement, and ultimately, energy reduction. To address this issue Sentient Buildings developed a mobile app that was being tested at the end of the study period for future deployment into the market. The app currently allows tenants to remotely control their thermostats and set schedules to automatically change set points, which should improve energy performance. The app does not yet incorporate the heating energy use report features, but that is planned for future releases.

Figure 10 Tenant Mobile Interface

2.9. Building Personnel Interface

Over the course of the project SWA and Sentient Buildings solicited feedback from Demonstration Site Two to optimize a building personnel interface in development, Neuro™. The key themes from those stakeholder discussions were related to integrating with their existing processes and helping them prioritize issues.

The EMIS should integrate with the building's workload management tools, which are often what building operators look at to plan out their day or shift. Providing one consolidated list of tasks will improve user engagement, and ultimately improve performance as a result.

Stakeholders also noted that building operators often deal with multiple issues each day. In order for an EMIS to enhance their ability to operate the building and not just add more noise and tasks to their list, it needs to have the ability to prioritize, acknowledge, and categorize issues that come up. This will help them address the most pressing issues soonest, and mitigate the risk of issue overload, which could result in them ignoring the system completely.

This feedback spurred the customization of fault diagnostic and detection (FDD) algorithms, automatic reporting features, and user access controls. Figure 11 shows what the building personnel sees when they sign in; it is the entry point to the building details. If an owner or operator has multiple properties in the system, they would see a grid of these images, one for each building.

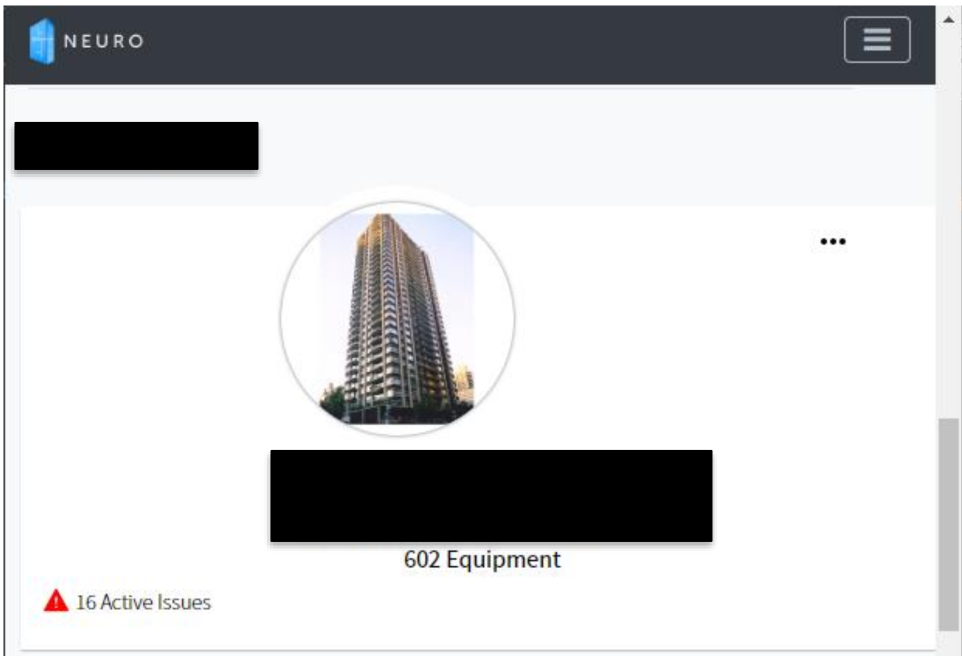

Figure 11 Operator Main Screen

Once logged in the operator can see, and control, all major operational set points for the tenant thermostats. The list can be filtered by floor down to the individual apartment in order to help building operators identify issues and potential solutions. Two different views (list and card) are provided through the interface as shown below in Figure 12.

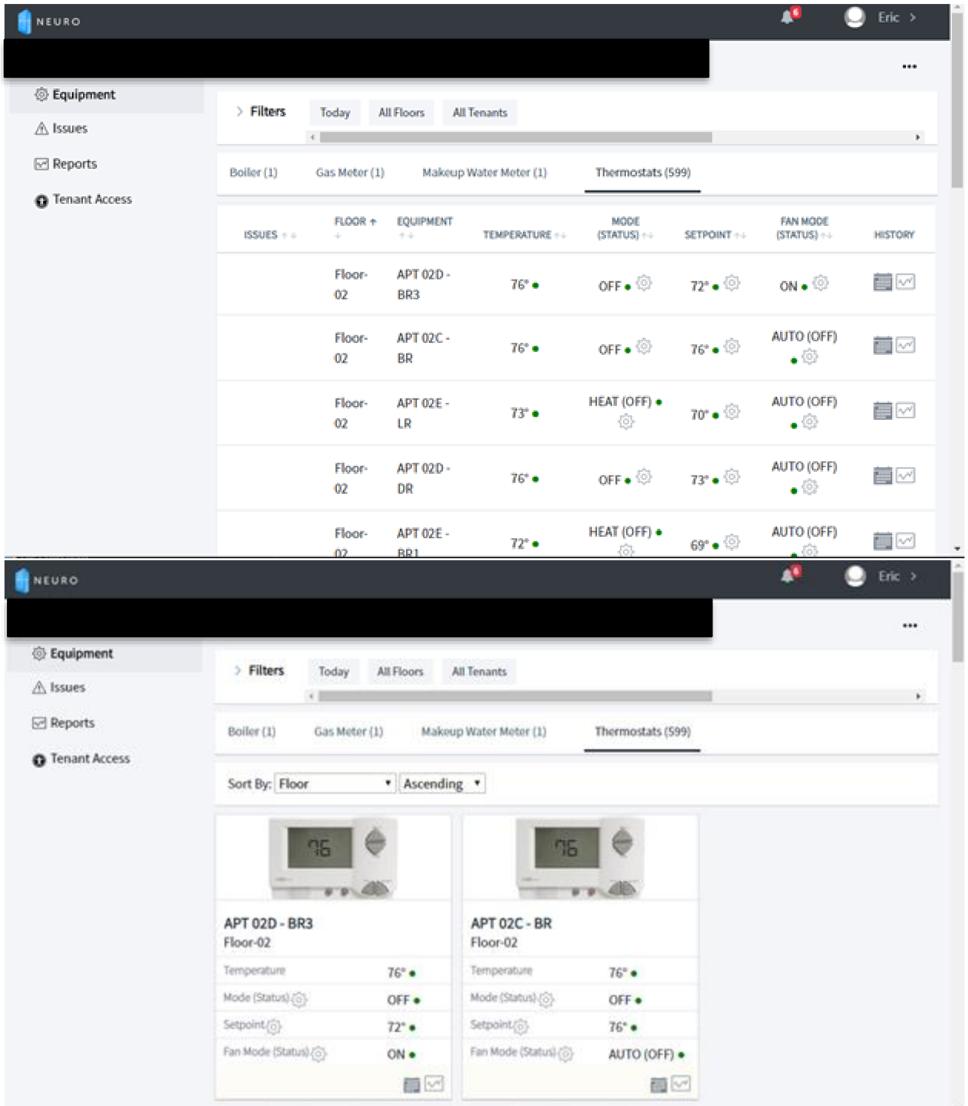

Figure 12 Operator Control Interface

The history for all data generated by equipment connected to the interface can be viewed over various time periods so personnel can look at trends over the course of a day, week, month, or other customized date range as seen in Figure 13.

Figure 13 Equipment Trend Data Overview

A separate issues module is available to keep track of active and past issues. Similar to the equipment view, the issues can be filtered so that the operator can easily identify types of issues to address with appropriate parties (e.g., those for in-house staff vs. outside service firms). The issues can also be filtered by floor or apartment if desired as shown in Figure 14 & Figure 15 shown below.

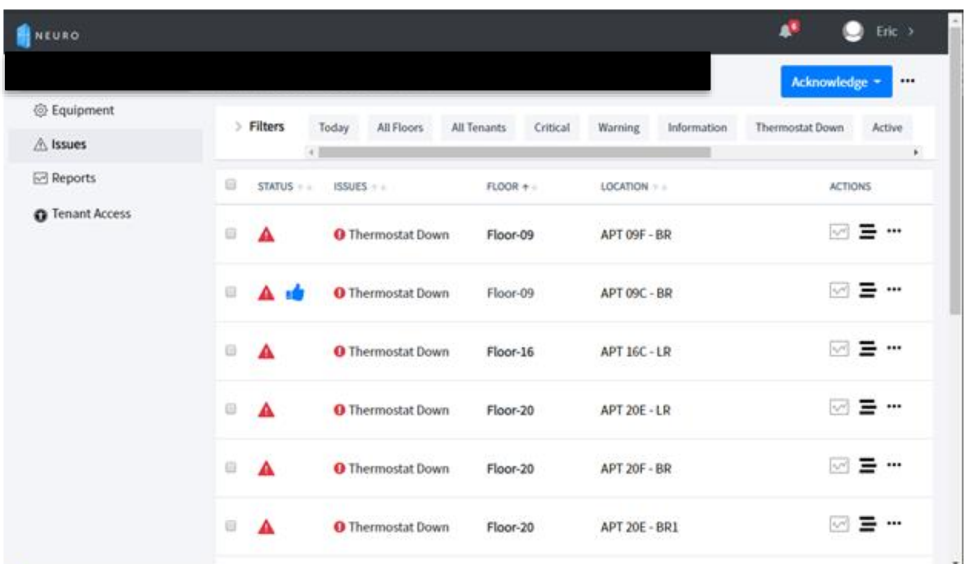

Figure 14 Equipment Issues Overview

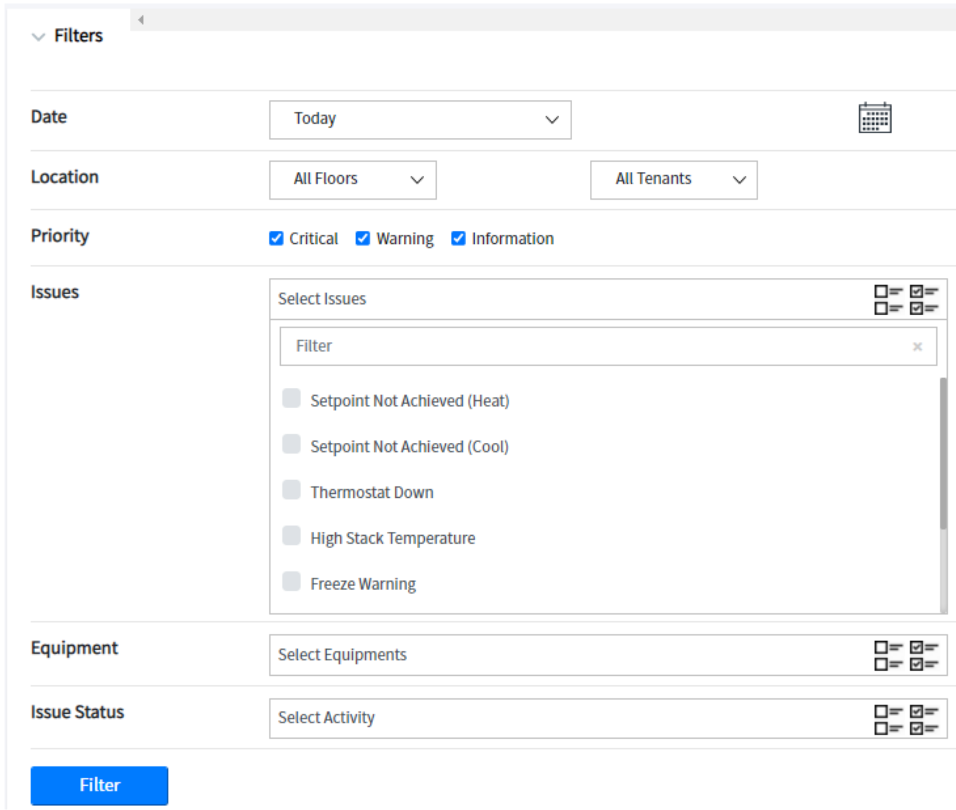

Figure 15 Equipment Issues Overview Filter

3 Results and Discussion

After implementing the technology installation and tenant feedback, SWA analyzed the Demonstration Sites' energy usage based on available fuel usage data to evaluate the study's outcomes. Overall, an energy reduction of 17.5-24.2% was achieved over time between the two Demonstration Sites. Details of the energy analysis methodology can be found in the Appendix.

3.1. Energy Savings

3.1.1. Demonstration Site One

Oil delivery data was analyzed to evaluate energy use from January 2018 through April 2021.The following Table 4 and Figure 16 summarize the changes in the Demonstration Site One's heat slope (BTU/HDD/SF), based on a weather-normalized utility analysis, separated by intervention period.

Table 4 Demonstration Site One Energy Savings

Analysis Period	Period Range	Heat Slope (Btu/HDD/SF)	Percent Savings from Baseline
Pre steam upgrade (baseline)	Jan. 2018 to Nov. 2018	11.28	-
Post steam upgrade	Nov. 2018 to Mar. 2020	8.99	20.3%
Tenant feedback w/o billing	Mar. 2020 to Jan. 2021	9.45	16.2%
Tenant feedback and majority receive bills [1]	Jan. 2021 to Apr. 2021	8.55	24.2%

[1] In December 2020 19% of tenants were billed for heat, in January 2021 75% of tenants were billed for heat. The large increase was marked as the start of the "majority receive bills" analysis period.

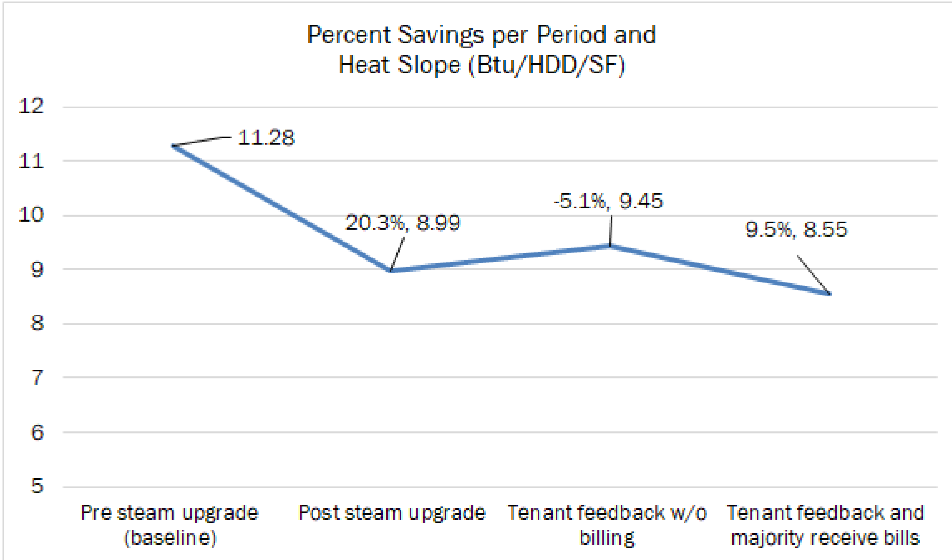

Figure 16 Trend of Demonstration Site One Energy Savings

3.1.2. Demonstration Site Two

Natural gas utility data was analyzed to evaluate energy use from June 2017 through May 2021. Table 5 and Figure 17 summarize the changes in Demonstration Site Two's heat slope, based on a weather-normalized utility analysis, separated by intervention period.

Table 5 Demonstration Site Two Energy Savings

Analysis Period	Period Range	Heat Slope (Btu/HDD/SF)	Percent Savings from Baseline
Pre steam upgrade (baseline)	June 2017 to June 2018	9.38	-
Transition (upgrade occurring)	June 2018 to June 2019	8.95	4.5%
Post steam upgrade	June 2019 to June 2020	8.28	11.7%
Tenant feedback	June 2020 to May 2021	7.74	17.5%

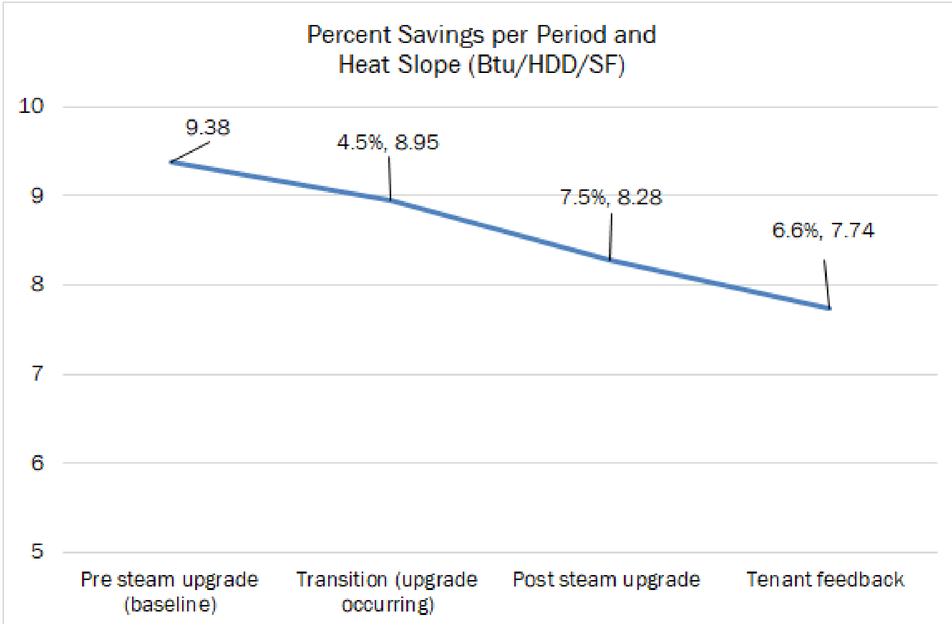

Figure 17 Trend of Demonstration Site Two Energy Savings

Preliminary analyses, performed at shorter or longer time frames, had shown sharp increases in baseload (domestic hot water) fuel consumption throughout the research period. The increase in baseload fuel consumption was determined to be due to a known boiler water loss issue. Figure 18, shown below, illustrates the total boiler make up water consumed per month. The water loss was occurring at the steam boiler's fire tubes, as rust was observed on the fire sides of the boiler as well as at the top of the chimney, indicating high levels of condensation in the flue gases. Increases in boiler water loss during winter months is attributed to the boiler's higher operating pressures during heating system operation, which increased the pressure differential and flow of water through the leaks, in addition to the longer run times in colder weather.

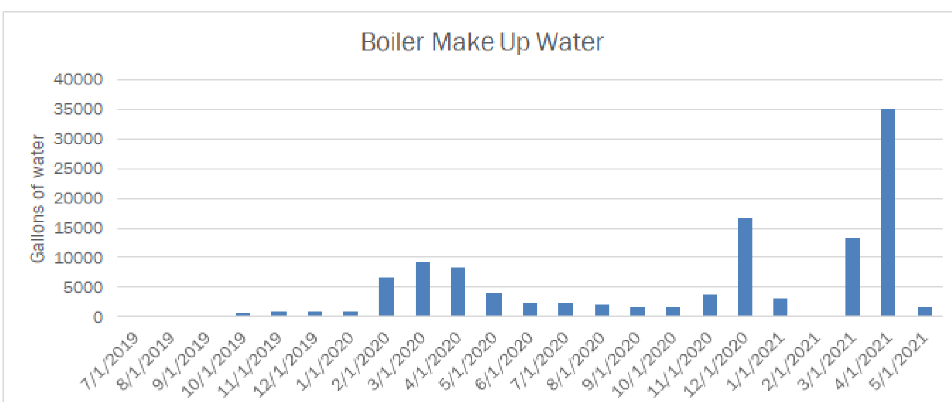

Figure 18 Demonstration Site Two Boiler Water Loss

Therefore, a year-over-year analysis, as shown in Table 6, was chosen to provide adequate and consistent baseload fuel consumption data to the regression analysis models. June was selected as the beginning month as it closely aligned with each analysis period's start and end dates. The regression analysis separated baseload fuel consumption from heating system fuel consumption, isolating changes in baseload consumption, which correlated strongly with the increase in boiler make up water, from the heating fuel savings results.

Table 6shows the average heat slope for Demonstration Site Two during months with cold outdoor air temperatures (defined as those with an average monthly temperature of less than 25°F). This shows a trend similar to the results above, indicating that heating energy use decreased from the baseline period to the final "tenant feedback" period. This level of savings when gas demands are at their peak suggests this upgrade would be applicable to utilities interested in gas demand reductions and demand response programs, such as those located in and around New York City.

Table 6 Cold Weather Performance of Demonstration Site Two

Period	Cold Weather (<25°F) Fuel Demand[1] (BTU/HDD/SF)	Percent Savings from Baseline
Pre steam upgrade (baseline)	10.37	-
Transition (upgrade occurring)	10.66	-2.8%
Post steam upgrade	9.20	11.3%
Tenant feedback	8.64	16.7%

[1]Includes both heating and domestic hot water fuel demand

3.2. Behavioral Intervention

In addition to the energy outcomes of the study, SWA analyzed the behavioral impacts of the tenant feedback provided. The tenant's primary means of engaging with the heating system was through their thermostats, which SWA analyzed in two ways: by looking at the average set points over the course of the study and at the frequency of set point changes.

3.2.1. Impact Analysis and Results

3.2.1.1. Demonstration Site One

The impact of the heat cost allocation (HCA) and heating energy use reports (HEUR) on tenant energy conserving behavior was evaluated based on changes to average thermostat set points and changes in thermostat adjustment frequency. The following results illustrate the measured behavioral and energy conserving impacts.

The following analyses of Demonstration Site One data were performed on apartments that held continuous leases by the same tenant for the entire duration of the study (approximately 25% of the building). This prevented the analyses from being skewed by new tenants, who experienced the upgrades and HCA feedback at distinct stages.

Figure 19 below shows the average room temperature (in dark shaded colors) compared to the average room set point (in light shaded colors). A relatively large difference between the average room temperature and set point occurs in the pre steam upgrade period, indicating that the room temperature did not match the set point and that apartments were overheated. The differences between room temperature and set point decrease for subsequent periods, indicating a greater degree of indoor temperature control and comfort. Average room temperatures were higher in the tenant feedback and heat cost allocation period than they were in the post steam upgrade period, yet fuel consumption was at its lowest during this final period. This potentially indicates a reduction in overall building air movement, perhaps a reduction in open windows, which was one of the suggested energy savings tips included in the HEURs. The largest and most consistent reductions in set points occurred after the post steam upgrade and during mild outdoor air conditions, as opposed to extreme cold conditions.

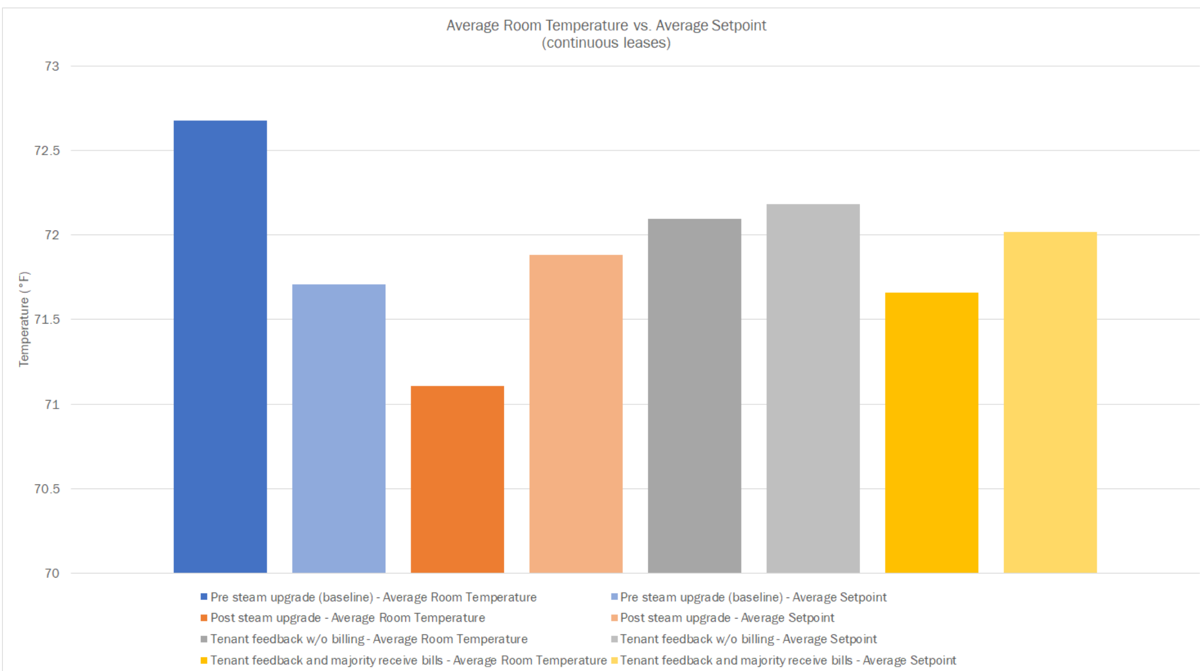

Figure 19 Temperature and Set Point for Demonstration Site One

Figure 20 shows the average number of set point changes per day for apartments with continuous leases. The greatest number of set point changes per day occurs in the pre steam upgrade period, for all HDD conditions. This may also indicate that the steam heating system was inconsistent in its delivery of heat, and that an imbalanced system led to discomfort and frequent set point adjustments. Set point adjustments decreased for the "Post steam upgrade" and "Tenant feedback w/o billing" periods, which could indicate a greater degree of control over room temperature, requiring fewer changes in set point to maintain comfort. Finally, the number of set point changes increased throughout most of the weather bins during the "Tenant feedback and majority receive bills” period, suggesting that financial billing led to tenants more actively engaging with their thermostats.

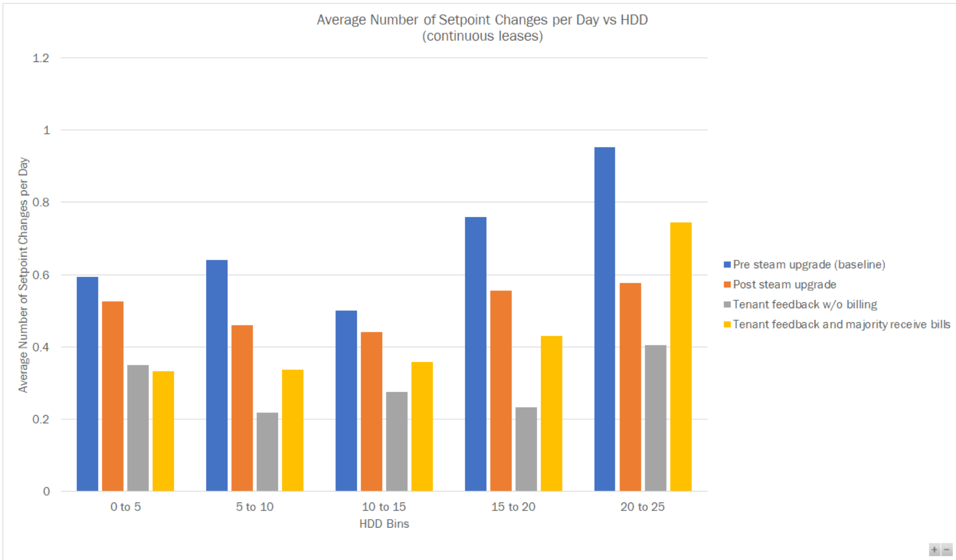

Figure 20 Set Point Changes for Demonstration Site One

Figure 21 shows the results of an analysis evaluating the changes in thermostat usage on the least and most active thermostat users (i.e., those with lowest and highest average daily set point changes). The average number of daily set point changes were calculated per apartment and for all four analysis periods, then filtered to show the bottom 25th percentile (least active) and the top 75th percentile (most active) apartments. The results show that tenants who actively used their thermostats in early periods were more likely to continue using their thermostats and showed an increase in usage during heat cost allocations. Tenants who rarely used their thermostats continued to mostly leave them untouched.

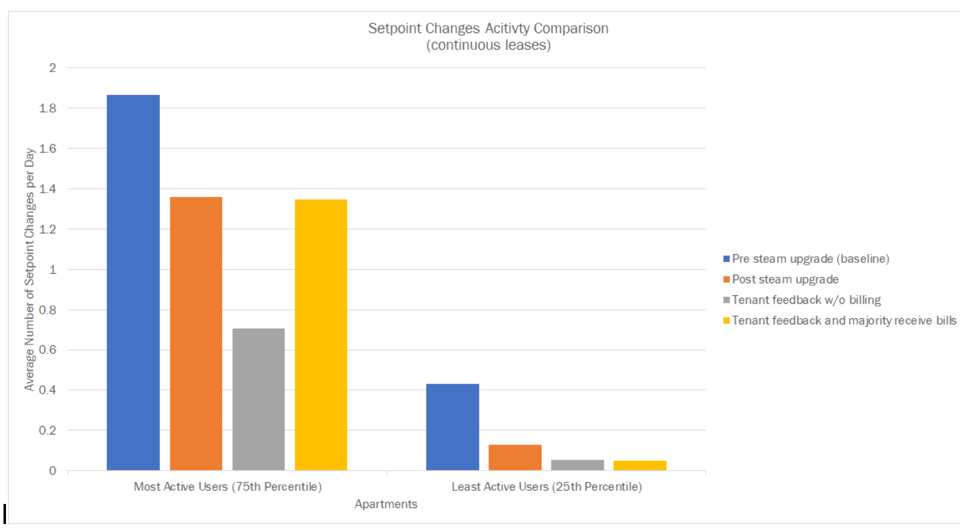

Figure 21 Outlier Thermostat Interaction for Demonstration Site One

3.2.1.2. Demonstration Site Two

Analyses similar to those performed on Demonstration Site One were performed on Demonstration Site Two, to further investigate the impact of heating energy use reports (HEUR) on resident energy conserving behavior. Unlike Demonstration Site One, tenants at Demonstrate Site Two were not billed for heat in the final "tenant feedback" period, and thermostat data was not available during the "pre steam upgrade (baseline)" period.

These analyses were performed on all apartments in Demonstration Site Two, as opposed to only the subset of Demonstration Site One apartments that were known to be continuously leased (and therefore retained the same tenant).

Figure 22 shows the average room temperature (in dark shaded colors) compared to the average room set point (in light shaded colors). Similar to Demonstration Site One, Demonstration Site Two showed a relatively large difference between the average room temperature and set point in the pre steam upgrade period, indicating that the room temperature did not match the set point and that apartments were overheated. This disparity decreases for subsequent periods, indicating a greater degree of indoor temperature control and comfort.

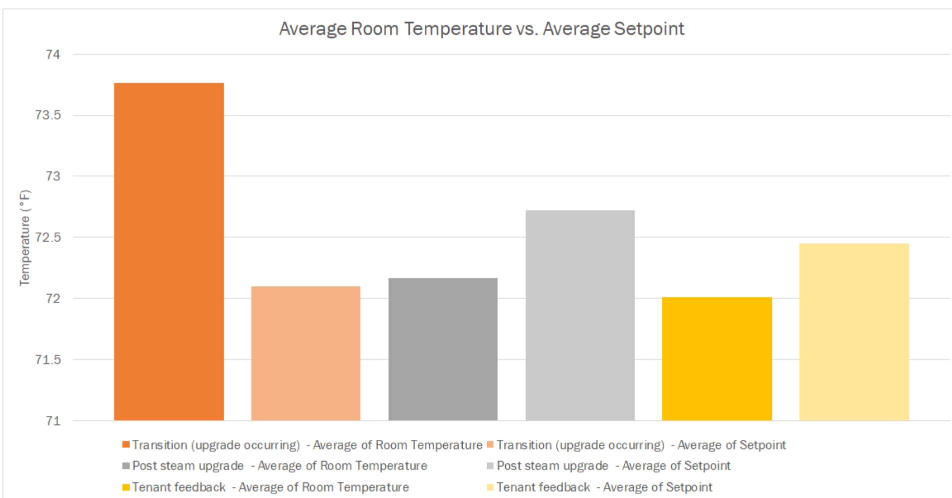

Figure 22 Temperature and Set Point for Demonstration Site Two

Figure 23 shows the average number of set point changes per day. For most analysis periods, the greatest number of set point changes per day occurs in the "transition (upgrade occurring)" period. Similar to Demonstration Site One, the same conclusion can be drawn regarding inconsistent delivery of heat requiring additional set point adjustments. The lack of billing at Demonstration Site Two may result in a less effective motivation to adjust set points.

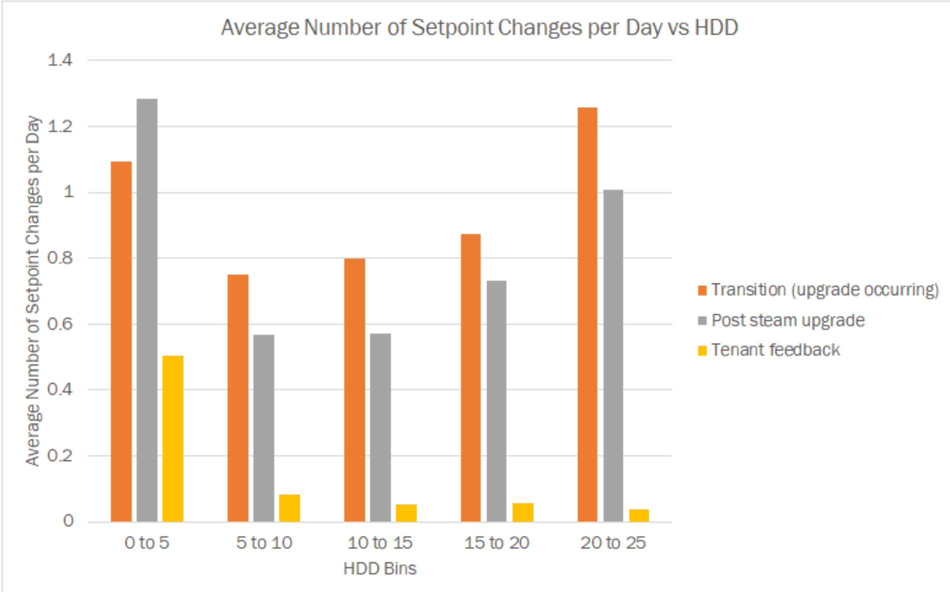

Figure 23 Set Point Changes for Demonstration Site Two

Figure 24 shows the results of an analysis evaluating the changes in thermostat usage on the least and most active thermostat users (i.e., those with lowest and highest average daily set point changes). Similar to the results at Demonstration Site One, the tenants who actively used their thermostats in early periods were more likely to continue using their thermostats in the "post steam upgrade" period. Unlike the results at Demonstration Site One, however, the average number of set point changes did not increase again during the final period, which may be due to the lack of heat cost allocations.

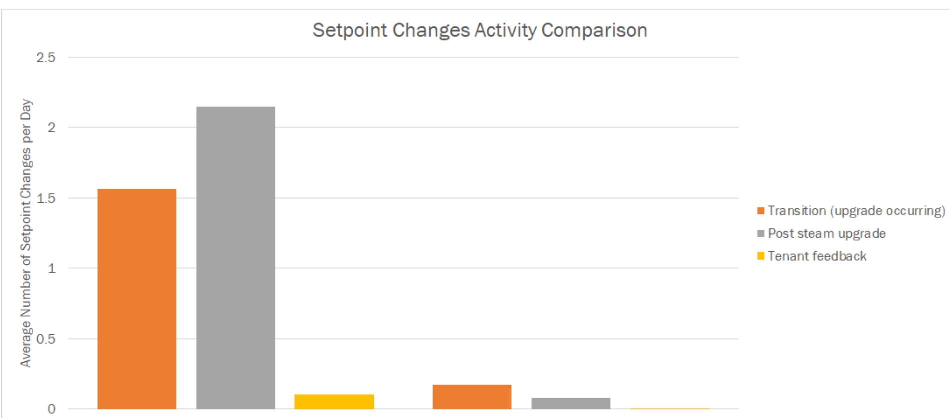

Figure 24 Outlier Thermostat Interaction for Demonstration Site Two

3.2.1.3. Boomerang Effect

One concern raised during stakeholder discussions was the potential for a boomerang effect, where some tenants who receive high overall grades and/or low heating cost allocations may increase their set points after seeing how well their energy usage compares to that of their peers.

Table 7 shows the percent of apartments that increased and decreased their set points by at least 1.5°F, between the first and last study periods. In Demonstration Site One, a slightly higher number of apartments decreased their set points compared to those who increased their set points. In contrast, in Demonstration Site Two, significantly more apartments increased their set points. This may reflect the lack of billing at Demonstration Site Two. Although this data analysis investigating the potential for a boomerang effect was inconclusive, the positive energy savings of both sites suggests it did not result in overall negative impacts.

Table 7 Boomerang Effect

	Period	**Compared to**	**Percentage of apartments that decreased set point by more than 1.5°F.**	**Percentage of apartments that increased set point by more than 1.5°F.**
Demonstration Site One	Pre steam upgrade (baseline)	Tenant feedback and majority receive bills	20%[1]	16%[1]
Demonstration Site Two	Transition (upgrade occurring)	Tenant feedback	0%[2]	16%[2]

[1] For Demonstration Site One, this was the percentage of the total number of apartments that had the same tenant throughout the research project, ~25% of the building's apartments.
[2] For Demonstration Site Two, this was the percentage of the total number of apartments in the building, given the low turnover rate experienced during the study.

3.2.2. COVID-19 Impacts

COVID-19 has been perceived to have an impact on energy usage as tenants have relocated, begun working from home, and reduced social activities. While it may not be possible to precisely determine COVID-19's impact on this study, it does not appear that the observed energy savings were higher than expected; however, additional savings may have been achieved had the study been conducted during a more consistent, and normal, occupancy period.

One major change in the NYC housing market during the study was a decrease in the building leased area. It was documented in the news that many tenants left the region, including the demonstration sites, during the pandemic. Figure 25 shows the building occupancy percentage of Demonstration Site One with an overlay of some key stages of the NYC COVID-19 response, periods of heating, and the average leased area during the heating season for the analysis periods.

The most drastic decrease in occupancy was observed during the summer of 2020, when leased area dropped to as low as 80% in July, as shown in Figure 25. While this is a substantial change from business-as-usual, the decrease in occupancy during the heating season, when this solution has an impact, was less pronounced. Looking across heating seasons, Demonstration Site One saw a decrease in average occupancy percentage from 94% during 2019 to an average of 84% for the winter of 2020-21. This relatively limited change, as well as inertia in the heating system (e.g., steam distribution piping largely remains heated even if tenancy drops), suggests a minimal impact on the energy savings analysis.

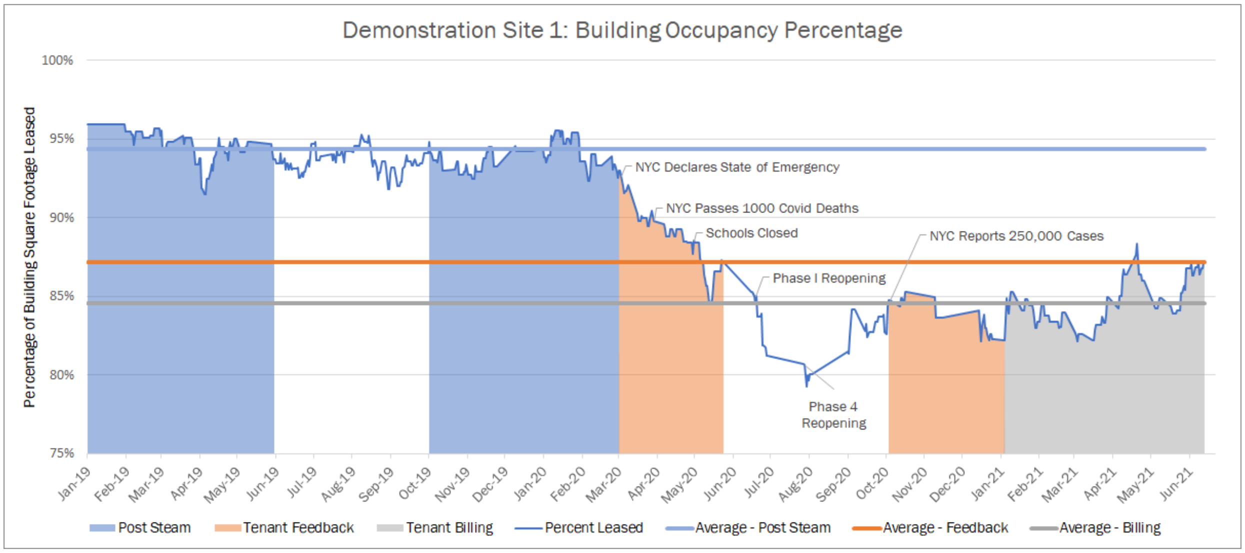

Figure 25 Occupancy Impacts During COVID-19

However, it is possible that the pandemic has caused the energy savings results of this study to be lower than they might otherwise have been. For example, it was anticipated that many tenants would be encouraged to reduce their heating use during the day when leaving to go to work. With most offices closed and many people either working from home or unemployed, this potential savings was likely not achieved.

3.3. Economic Analysis

Based on actual technology implementation costs, and energy savings achieved, the potential financial value proposition of this approach for building owners was calculated under several scenarios. This analysis showed that a savings-to-investment ratio (SIR) range of 0.2 to 6.0 can be expected from the implementation of HCA. SIR was calculated as the investment cost divided by the total financial savings over the assumed useful life of the technology, which for this upgrade was considered to be 10 years. The results in Table 8 show the upper and lower bounds of expected SIR, based on these main variables.

Table 8 Financial Savings Based on SIR

	Low Fuel Cost		*High Fuel Cost*	
Installation Cost	Allocation	No Allocation	Allocation	No Allocation
Low	4.0	0.5	6.0	0.7
High	1.0	0.2	1.6	0.3

During the financial evaluation, a few key factors impacting the estimated financial returns for a potential building were identified.

The willingness, or ability, to allocate heating costs to tenants seemingly has the largest impact on the financial viability of a given project. While this practice, as previously stated, is accepted in the EU, various market and regulatory conditions exist in the US that may prevent, or cause hesitation by, owners to implement HCA. One example would be where regulations (whether state, regional, or local), do not allow this kind of heating energy allocation, even though the practice of submetering in general (e.g., electric submetering), is widely accepted as a method of reducing energy consumption and typically results in the vast majority of tenants saving money overall. Including allocation in the project was assumed to recover 80% of the total heating bill, while not including allocation was assumed to result in a 17% heating energy savings.

Existing conditions at a building impact the initial investment required to implement the technology. For example, Demonstration Site One already had an existing, centralized thermostat network that was sufficient to be used for HCA. Additionally, the mechanical systems required minimal repairs (steam trap maintenance) which dramatically reduced the installation costs. Conversely, Demonstration Site Two required substantial upgrades, both on the technology and mechanical sides, to reach a state where HCA would be possible. Depending on the audience and current work required (such as end of useful life repairs/upgrades), these may be viewed as a single project, the technology as an incremental upgrade (shifting the SIR up), or some combination of both. A low installation cost, reflecting a minimal amount of required installation work due to either a well-functioning heating system and/or an existing network technology may be $0.60/SF, while a high installation cost of $3.00/SF would reflect a building that needs significant heating system and technology investment.

A low fuel cost, assumed to be $9.50/MMBtu, reflects current natural gas prices in the NYC region, while a high fuel cost assumption of $14.30/MMBtu reflects current market prices for fuel oil.

An often-overlooked factor in the long-term SIR of these types of solutions is on-going maintenance costs. Recurring costs such as equipment service agreements, data hosting, allocation costs, and other continuing costs must be considered in a financial analysis.

4 Conclusions

4.1. Energy Savings

The data shows that significant savings can be achieved in steam heating systems, both from balancing the system and from providing tenant feedback. Demonstration Site One achieved a greater energy savings than Demonstration Site Two (24.2% vs. 17.5%). It is not clear whether this was due to the additional financial feedback at Demonstration Site One (which allocated heating costs to the tenants), the higher starting heat slope at Demonstration Site One, a combination of the two, and/or some other unaccounted factors.

4.2. Tenant Impacts

After the heating system balancing work was completed, there was a decrease in frequency of set point changes, which suggests that tenants were more comfortable once the basic functioning of the system was improved, even before receiving any behavioral feedback. Additionally, average room temperatures more closely matched thermostat set points, indicating that the system was better able to maintain desired temperatures, making the tenant controls more effective. Not only can this improve tenant comfort, but it may also be a requirement for successful heat cost allocation. If tenants do not believe they have a meaningful level of control, they could be more likely to push back against any financial costs associated with their heating energy usage.

Although there was a noticeable reduction in average room temperature between the pre-retrofit and final study periods, there was not a comparable change in average set points. A greater percentage of Demonstration Site One tenants, who received heat cost allocations, reduced their set points as compared to Demonstration Site Two tenants, who did not receive heat cost allocations. The additional financial incentive may be the main driver of this difference. However, the overall energy savings achieved suggests that any boomerang effect, from tenants increasing their set point after seeing how well their energy usage compares to that of their peers, was negligible.

Most tenants in Demonstration Site One accepted the additional heating cost allocation without complaint. There were minimal tenant complaints early on, and those tapered off after additional explanations were provided and added to the HEURs. Given this reception, it does not appear that tenants paying for heat is a barrier.

4.3. Market Potential

As with most energy-related retrofits, the economics of any project vary based on the building specifics. This study showed that this retrofit can provide a better economic return in cases where the cost for heating fuel is high (e.g., in buildings using fuel oil), where the heating costs will be allocated to tenants, and/or where the basic heating system is in good working order, limiting the costs of installation and/or ongoing operation. These factors must be evaluated in order to determine whether the solution is well-suited for any particular application.

5 Recommendations and Next Steps

5.1. Recommendations

This study provided some lessons on how to improve the success and/or expand the applicability of any future pilots or installations.

In addition to conveying feedback in the Heating Energy Usage Reports (HEURs) clearly, the messaging and roll-out of such a program are also important to achieve tenant engagement and the desired energy savings. Heat cost allocation will be a change for tenants, and some means of outreach to educate them both about the program itself and how to best use the new technology, are critical.

As with any installation work that includes access to apartments, coordinating and minimizing the number of entries can have an outsize effect on the cost and success of the project. Best practices would include installing the network infrastructure in advance, so that terminal network devices can be installed and connected during a single apartment visit. Additionally, training the building personnel on some basic component troubleshooting can help keep the system in good working condition while minimizing outside maintenance costs and system downtime.

The economic analysis indicates that the greatest energy savings can be achieved when the heating energy cost is allocated to the tenants. While those costs can be passed through as additional rent within certain segments of the market (e.g., market-rate housing), it is critical to consider some form of utility allowance or rent credit in affordable, regulated, or other low-to-moderate (LMI) housing to avoid increasing their energy and housing cost burden while allowing the project to be viable and equitable for both owners and tenants. This retrofit has the potential to provide deep heating savings and GHG emission reductions at reasonable costs (i.e., compared to other options like electrification), but it must take into account the balance of costs and benefits between owners and tenants.

This may also affect if and how utilities may be able to offer incentives for these projects. Traditionally, utility energy efficiency incentive programs have been designed to reduce costs for customers, either in the form of a first reduction for installation, an operating cost reduction, or a combination of both. Heat cost allocation can reduce the overall costs for the building, but depending on how heat submetering is implemented, it may also result in the shifting of costs from one group or ratepayers to another. Utilities should work with relevant stakeholder groups to develop an incentive structure that can be beneficial, or at least neutral, for both landlords and tenants. Other options such as rent credits, utility allowances, or shared savings programs, instead of additional charges, could be offered to accelerate adoption of this strategy in certain markets. In some regions regulations may need to be amended or changed as well.

A level of transparency regarding energy costs would most likely help with market acceptance; this is required in the EU market. Whole-building energy usage is public in many municipalities that have energy benchmarking laws, but it is not common to provide this information at the apartment level. Considerations for disclosing personally identifiable information must also be considered when crafting programs that have an impact at the apartment, building, or larger-scale (e.g., portfolio, utility, city/state program, etc.) levels.

This transparency may also help mitigate the conversation around split incentives between owners and tenants. With new laws regulating building performance being passed in various municipalities, there is an additional reason for owners to not simply pass heating costs onto tenants, but to also maintain and optimize the performance of their systems. This type of upgrade can provide additional non-energy benefits that accrue to owners, such as operations and maintenance improvements.

Tenants may gain improved comfort as a result of a balanced heating system and a digital, programmable thermostat, which could be considered an upgrade from the typical heating controls most central heating systems have currently. The thermostat temperature analysis results do suggest an improvement in tenant comfort post installation.

5.2. Next Steps

As with many research pilot projects, this study was subject to some limitations, which may have impacted the results. There are opportunities to expand upon this pilot project to gather additional data on the effectiveness of this retrofit and/or expand its applicability in the market.

The process of heat cost allocation and HEURs resulted in a delay in providing information to the tenants. The feedback was provided to tenants ~3 weeks after the end of the relevant month's heating energy usage. This amount of time delay is typical of most forms of submetering, but it might have affected the impact of the feedback, particularly since this study had a defined end date. There was only half of a heating season for the feedback to make an impact. A longer study, allowing for more time for tenants to absorb and act on the feedback, may give different results.

Some of the behavioral research conducted indicated that providing more real-time feedback can lead to increased savings. This is another opportunity to explore to improve the effectiveness of this retrofit. The Neuro™ tenant-facing app being developed by Sentient Buildings may provide this ability in the future, and there are likely other options on the market as well.

This upgrade is widely applicable to buildings with central heating systems. These are very common in older multifamily buildings, particularly in the Northeast and Midwest, as well as in much of the low-to-moderate (LMI) housing stock. This study focused on two market-rate (or largely market-rate) multifamily buildings. Some stakeholder discussions suggested the possibility that market-rate tenants may behave differently than those living in regulated or affordable housing. Commercial office buildings are another potential use case, with different challenges and opportunities. Conducting additional pilots on these types of buildings and tenancies would expand on this study's reach and help inform its greater market potential.

With this study's limited number of demonstration sites, it is difficult to get a sense of what typical installation costs may be if this type of project begins to scale up. Even so, the economic analysis suggests that there will be a cost effectiveness range, depending on project specifics, such as existing conditions and the heat cost allocation details. And within that range, there will be projects, such as those with higher fuel costs, or lower anticipated installation costs, that will be more attractive candidates. In the meantime, utility and/or other incentives will likely be required to drive adoption.

Both Demonstration Sites had steam PTACs, which are powered terminal units. This ready access to line voltage allowed for many options in terms of valve actuators and networking devices. There are many buildings with PTACs or other powered terminal units; however, there is a much larger portion of the market that utilizes passive heaters (e.g., convector cabinets, cast iron radiators, baseboard, etc.), which do not have a ready source of power at the terminal unit. Running new line voltage wiring to these heaters would increase the expected installation costs and complexity of the work to unacceptable levels. Battery-powered actuators and networking devices do exist, but the current options are not as robust and long-lasting as the market desires. Battery life for these can be as short as one year, which would require additional and unwanted maintenance requirements from the building staff. Additionally, the actuators have a relatively low ambient temperature rating (~122^{o}F), which is lower what a typical piping configuration would result in, and this can further limit battery life.

Although data showed that a portion of tenants use their thermostats often, there is still a large percentage of them that do not actively manage their thermostat settings. For this population, programming their thermostats with efficient set points and schedules at the beginning of this program can be a big driver of savings. Stakeholders suggested additional ways to encourage this beneficial setup, such providing a small incentive, like a gift card to a nearby café, to those tenants who attend a thermostat training or allow for a preset schedule to be programmed.

It is recognized that COVID-19 potentially impacted many research studies during this period. While it may not be possible to precisely determine COVID-19's impact on this study, it does not appear that the observed energy savings were higher than expected, although they may have been lower.

Additional projects should be pursued to test the solution, as it was deemed to be financially viable under certain conditions, to understand the full potential of heat allocation in the United States.

6 Appendices

6.1. Additional Heat Cost Allocation Information

6.1.1. Review of Heat Cost Allocation Existing Methods

In the European Union (EU), under the Energy Efficiency Directive (EED)[iv], heating costs are required to be allocated to tenants of buildings heated by central hot water systems starting in 2017, though the practice was in place earlier than that. Each EU member state can introduce specific rules for how heating cost is allocated to tenants, which must be transparent in logic to “ensure transparency and accuracy of accounting for individual consumption.”[v]

While all EU countries are required to allocate heating costs, it is up to each country to promulgate rules on the specific logic and correction factors to be used, or if they chose, leave it more open. There are several aspects to the heat cost allocation methods used in the EU to account for the complexities of heat flow in a multi-tenant building. The most common methods used involve bracketing charge amounts, area-based multipliers, or location-specific correction factors. Each member state can determine which adjustments to use, if any. Additionally, the total amount of heating cost allocated to the apartments may or may not include the heating energy used for the common spaces.

Additionally, adjustment factors are allowed in EU member states’ heat cost allocation methods, but they do not necessarily correct for heat transfer between neighboring apartments. Studies have shown that measured heating use of individual apartments fluctuates within a building over time, more than building-wide heating use does. The presumption in one study is that this is due to heat flow between apartments, and this is a limitation on using consumption directly for heat cost allocation.[vi]

Bracketed charge amounts, which set minimum and maximum charges based on some multiple of the building average charge are intended to keep any one tenant from paying a grossly disproportionate amount of heating costs, which may be the result neighbors using use little-to-no heating, thereby skewing the percentage of heating allocated to those who operate their heaters and transfer heat to other apartments through neighboring walls or airflow. As an example, Hungary requires that no tenant costs can exceed 250% of the building average, and Czechoslovakia requires that no tenant costs exceed 200% or are less than 80% of the building average costs.vii

Many member states have adopted an allocation method that involves some portion of the building’s heating cost to be allocated across all tenant spaces regardless of individual usage, colloquially called the “fixed” component of the allocation, combined with another portion based on the measured or calculated “variable” heating use by each tenant space. A summary of some allocation methods is shown in Figure 26. [viii]

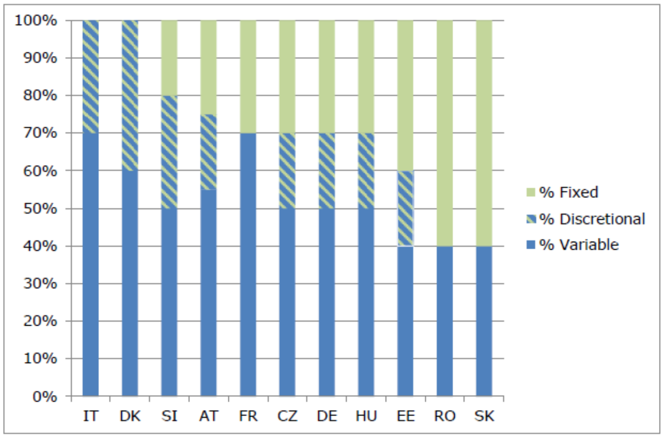

Figure 26. Summary of Space Heating Allocation by Different EU Members

One type of system used to capture the "variable" heating use measures the hot water flow rate through the apartment heaters and the water temperature differential across the heaters. From these values, the heating energy emitted by the heaters can be calculated. For each apartment, the total energy is summed per month, and the building heating cost is allocated in some proportional way.

In other cases, devices are used to estimate the thermal output of each radiator. Each radiator type must be analyzed in a test chamber to develop the heat transfer coefficients. Much like a rated heater capacity, the radiator characteristic coefficients are included with the radiator specifications. The radiator characteristics, combined with the continuously measured radiator and room temperatures, result in an "indirect estimate" of heating use that is incorporated into the allocation.[ix] The values of the radiator characteristics strongly influence the calculated heater output.

Location-specific correction factors are intended to account for the differences in expected heating loads based on solar gains, the amount of exposed wall and roof area, and/or being located over a conditioned or unconditioned basement. Hungary's correction factors are shown in Figure 27. Location based Correction Factors as an example. The measured heat consumption (the "variable" heating use described above) is reduced by some factor – down to 70% of the metered amount in the example at the bottom of the figure – and added to the volume-based "fixed" component to add up to the total heating charge for each apartment.

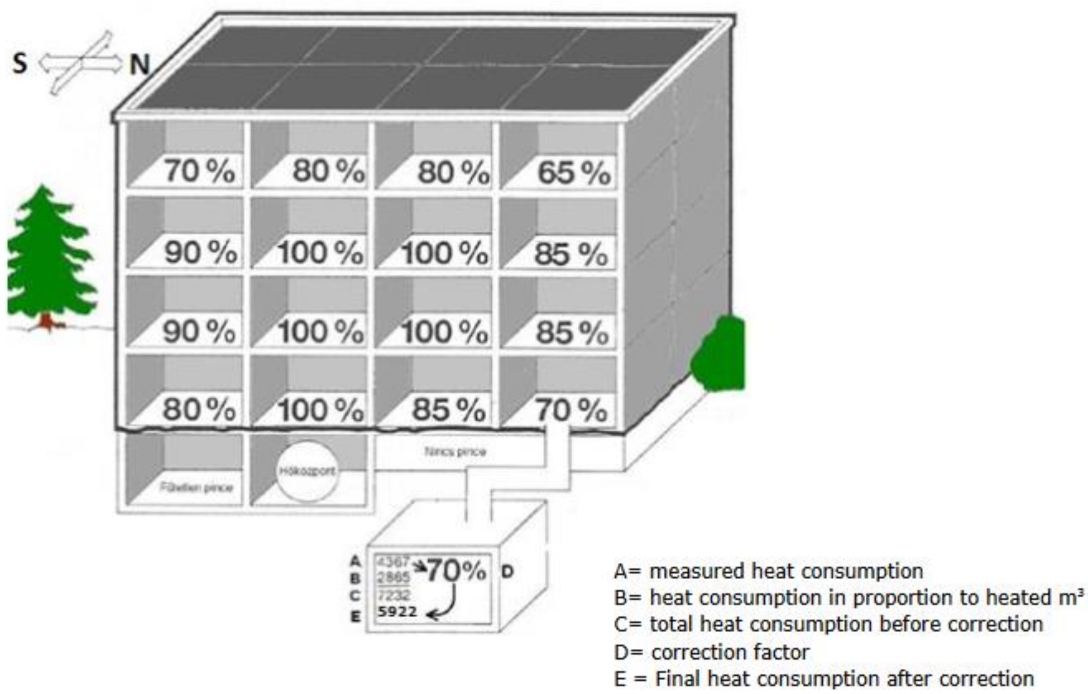

Figure 27. Location based Correction Factors[x]

6.1.2. Algorithm Development Methodology

To develop the algorithm, an assessment of heat use in specific rooms, and apartments, was performed relative to several location-specific, time-independent characteristics – building characteristic parameters – and several time-dependent characteristics – occupant choice parameters.

The buildings where the HCA algorithm was to be implemented have steam heat, where heater output and heat use can't be reliably measured. In contrast, the heating use in electric resistance heat buildings can be reliably measured and correlated to room, apartment, and building-wide characteristics. The electric resistance heated building analysis results in correlation coefficients that inform what building and occupant choice parameters are most important to include in the HCA algorithm.

An electric resistance baseboard building outfitted with room-by-room sensors capable of collecting the occupant choice parameters was used to compare variation in characteristics to heat use through a correlation study. The example building "Electric Building 1", an electric resistance baseboard heater building, was chosen because that type of heating system has a simple calculation for actual heater output (heater size * runtime). A second building "Steam Building 2", was also analyzed as a more similar proxy to the initial test building, "Steam Building 1." Two additional electric buildings, "Electric Building 2" and "Electric Building 3", were compared for building characteristics, but were not analyzed for temperature, set point, and energy consumption characteristics.

Even though the correlation analysis showed that any one apartment's heating usage is impacted by the relative set point of the adjacent units (referred to here as the "neighbor score"), stakeholders thought it would be difficult to message at best, and potentially harmful to the overall goal at worst.

Tenants have no control over their neighbor and would likely resist being charged based on their neighbor's behavior.

There are a number of ways to quantify the occupant choice portion of the HCA algorithms. One option is where each tenant's set point is ranked, and the allocation is based on a position within that range. Alternatively, each tenant's set point could be compared to something considered more "neutral," such as a baseline set point temperature as a point of comparison. There may not end up being a big difference in the bill amounts calculated with those two options but making sure the message is perceived as fair will play a critical role in tenant engagement.

Putting limits on the range of bills may also help in buildings that have a diverse population. For example, people who work from home or don't work are more likely to be home during the day and are less likely to be able to turn their set point down during the day. Having boundaries on how much any one apartment is charged compared to the group could help limit some tenant's resistance to this effort by limiting the perception of a penalty for certain groups of people. However, as with direct metering of other utilities such as water and electricity, the occupant pays for what is used. If the occupant is home more often and thus can't take advantage of unoccupied times to lower the set point, then the occupant is using the service more than if the apartment sat unoccupied at all times.

Overall, an allocation algorithm that combines apartment size and set point would likely be considered fair. It is also easy to understand and intuitive. Stakeholders noted that size and set point are the two main drivers of energy use in a single-family home as well (assuming equivalent envelope, system efficiencies, etc.), and that an algorithm based on these two factors would likely be well accepted by the tenants.

6.1.3. Algorithm Parameters

A final HCA algorithm was determined to use total building heating energy cost, room floor area, and temperature set point parameters to define how the total heating cost is allocated to all apartments (as sums of rooms). These characteristics are simple to measure and track and directly influence heating energy use. Floor area is fixed from month to month for a given apartment, while set point is variable and completely under the occupant's control. While other parameters also influence heating energy use, the two selected parameters account for the influence of the other parameters.

The number of windows, heaters, and heater capacity all trend with floor area. The correlation between factors that drive energy use and floor area depends on the building. As part of this study, several buildings were analyzed to determine the level of correlation. For the sample buildings in **Error! Reference source not found.**, key characteristics are compared to apartment floor area.

Table 9 Correlation Coefficients Between Apartment Floor Area and Other Characteristics

	Steam Building 1	Steam Building 2	Electric Building 1	Electric Building 2	Electric Building 3
Floor Area [ft2]	1	1	1	1	1
Crack Length [ft]	0.89	0.98	0.50	0.76	0.56
Exposed Wall Area [ft2]	0.48	0.78	0.93	0.73	0.56
Number of Heaters	0.90	0.98	0.79	0.81	0.90
Existing Heater Capacity	0.90	0.97	0.87	0.82	0.85

The whole-building heating cost is allocated out to each apartment based on floor area with an adjustment based on temperature set point. By allocating cost using set point, the occupant's choice is recorded directly, instead of the heating system's reaction to the occupant's choice and interaction with other more external factors.

6.1.4. Algorithm Calculation Logic

Step 1: Input building total heating cost from utility bill or whole building

Step 2: Calculate average SP for all rooms and heaters

The building heating system may have multiple modes for the thermostat. For the steam building in this demonstration, the thermostat has four modes, each of which is treated differently in determining the average heating SP.

Thermostat Modes and instructions for any timestamp with thermostat in Mode:

- Mode 0: **Off**: overwrite points as minimum SP value that can be set at the thermostat
- Mode 1: **Auto**: (can switch between heating or cooling): use points, as the occupant is voting for that specific set point.
- Mode 2: **Heat**: use points
- Mode 3: **Cool**: overwrite points as a non-number placeholder

For unusable data points, such as when a thermostat does not report back to the communication platform at a given time, a non-number placeholder is used for that timestep. For rooms where less than 25% of data from a given thermostat was used in a given month, all room SP data is discarded under the assumption that there was a sensor issue in the room and the data is not reliable. Once all usable data is collected, the building-wide average SP is calculated. For all apartments with an insufficient number of data points, the building-wide average SP is assigned.

Step 3: Apply HCAA formula to all rooms resulting in heating cost for the billing period.

$$Apt\_Cost_i = HeatCost_{meter} * (Alloc_{SP} + Alloc_{Rem})$$

$$Alloc_{SP\_i} = \frac{SP_i - 68}{15} * Afrac_i$$

$$Alloc_{Rem\_i} = Afrac_i - Average(Alloc_{SP})$$

Where

Apt_Cost_i = HCAA amount billed out to occupants in a given apartment "i" [dollars]
$HeatCost_{meter}$ = total monthly heating cost for the building, [dollars]
SP_i = room average set point over billing period [°F]
$Afrac_i$ = floor area of room served by thermostat / floor area of all apartments [unitless]

6.1.5. Benefits and Limitations of Parameter Choices

The following outlines the key parameters used in the HCA algorithm, their purpose, benefits, and potential limitations.

HeatCost

Purpose: Billing period heating cost for the whole building, [dollars]

Benefits: By using the actual heating energy use and cost incurred by the building, several parameters are accounted for. Building construction, overall envelope condition, and building-wide average set point and indoor temperatures factor into how much heating is required by the entire building.

There is typically little variation in window and wall construction between apartments in the same building. These envelope components affect heat loss as a total for the building and can therefore be accounted for at the building level. Occupants do not have direct control over their own envelope components.

Limitations: Using the building total and allocating out fractions implicitly includes a comparison of one room's fraction to the fraction for other rooms with other set points. For apartment buildings where many apartments are left empty and with a minimum SP temperature, the occupied apartments will bear a larger portion of the heating bill because they choose to occupy the space, unlike their neighbors. While the total bill in such a building will likely be lower than if the building were fully occupied, some occupants may see this as an unfair method of allocation. However, it still makes the most sense to have the sum of all apartment bills add up to the building's total heating bill, and to do so, some true up is necessary.

$Afrac_i$:

Purpose: Floor area of room / floor area of all rooms subject to HCA algorithm [unitless]
Benefits: The heating energy required for a space depends heavily on the volume of air in the space, the internal gains, and the amount of exterior wall and window exposure of the space. These components of space heating use scale with floor area, meaning that larger rooms tend to have more windows and exposed wall area.

Occupants choose apartments based on overall size of the apartment, and other characteristics that drive heat loss are typically secondary if considered at all. Allocating cost based on floor area is relatively straightforward and intuitive to occupants compared to a count of windows, exterior wall area, sun exposure, and other building characteristic parameters.

Limitations: Some similarly sized apartments may not have equivalent heat load because of limited exposed wall area or contain fewer drivers of infiltration, such as window and AC perimeter length (where air can move into and out of the building). These apartments will receive the same allocation as those with more exposure, even though the actual heating energy need is likely less. In **Error! Reference source not found.** above, the difference between floor area and other building characteristics is shown across buildings. The electrically heated test building has a couple of apartment layouts that have relatively low floor area but more windows and infiltration crack length. As a result, the whole building correlation between floor area and heating demand in that building is lower than for the two steam buildings. Because of the relative ease of measuring floor area, and the ability to use already-known measurements, the floor area is still the most implementable metric to use to approximate relative heating use at a given set point.

That being said, room floor area needs to be consistently measured across all apartments for fair allocation. Different uses for floor area have different conventions for measurement, such as inclusion or exclusion of closets, bathrooms, and wall thicknesses in floor area. In creating the floor area database for allocation, the methodology over what is included and what is excluded should be noted in some way, so that if floor area changes are made, the measurements for any changed spaces can be allocated consistent with the rest of the building.

SP_i:
Purpose: room average set point over billing period [°F]

Benefits: Set point (SP) is directly under the occupant's control as a setting on the thermostat that can be modified at any time. The SP of a room also serves as the connection between the occupant choice and the central heating system.

Neighbors' set points and the resulting heat transfer with adjacent rooms do not impact the space's heating allocation in this algorithm. By design, any extra heat use for a higher set point room that transfers heat to colder neighboring rooms is not reflected in the allocation, even if heating energy is required to maintain the warmer room's SP.

Along the same line, correction factors for orientation, exposure, and location within the building, do not need to be calculated, since those are downstream of the SP choice, and heating energy required to maintain SP is not accounted for on the room-by-room level.

As occupants respond to the allocation of heating cost as well as behavioral feedback, the overall building average temperature should decrease, which will translate into lower heating bills overall. If a particular occupant has a SP higher than the building average, they would receive a larger portion of the central heating bill, but that may be evened out by the building using less heating energy overall. This is anticipated to help with messaging, as it there are both benefits at the individual and building-wide (or "community") level.

Limitations: Set point is not a direct measurement of energy use. The room SP could be kept at a low setting, but the heating may still run because of a high level of heat loss (e.g., open or leaky windows). This is where the proper messaging to the occupants is crucial. By indicating how the occupant can be comfortable at a lower set point (e.g., through reducing drafts and making sure the heaters are working properly), the set point can be a fair way to approximate relative heating use for a given area.

The thermostat could be artificially cooled so that the SP is never satisfied at the thermostat, even at a low setting, while the room is excessively warmed as the heating system continues to supply heat. However, with proper indicators of atypical behavior, such has relatively high runtime at low set points, this kind of situation can be flagged by the energy manager or building staff.

Rooms with large internal gains from occupancy or appliances may use little heating energy even at a higher set point. Occupants need to be clearly instructed to maintain the minimum SP where they are comfortable, not necessarily the minimum air temperature they wish to have in their space. With proper messaging to tenants about lowering the set point to the minimum at which they are comfortable is one way to approach this issue. The choice that the occupants make is to change their set point, and while some education may be needed on how set point affects heating use, it seems an appropriate metric to use for affecting occupant motivation to reduce heating energy use.

6.1.6. HCA Algorithm Example Calculations

A room with a set point of 80°F in a building where the average set point was 65°F for the month will have a normalized SP term of:

$$\frac{80-68}{15} = +0.8 .$$

The remainder term incorporating the building average is

$$\frac{\sum_1^n \left(\frac{65-68}{15} * Afrac_i\right)}{nApts} = -0.2$$

The resulting allocation for the room is:

$$Apt\_Cost_i = HeatCost_{meter} * Afrac_i * \left(1 + 0.8 - (-0.2)\right) = 2 * \; HeatCost_{meter} * Afrac_i$$

In contrast, a room with a set point of 65°F in a building where the average set point was 75°F for the month will have a normalized SP term of:

$$\frac{65-68}{15} = -0.2$$

The remainder term incorporating the building average is:

$$\frac{\sum_1^n \left(\frac{75-68}{15} * Afrac_i\right)}{nApts} = 0.45$$

. The resulting allocation for the room is:

$$Apt\_Cost_i = HeatCost_{meter} * Afrac_i * \left(1 + (-0.2) - (0.45)\right)$$
$$= 0.35 * HeatCost_{meter} * Afrac_i$$

6.1.7. Expanded Definition of Parameters Used in Correlation Analysis

Building engineering drawings were used to determine the following characteristics for every room for all test and control buildings. Bold indicates those discussed in **Error! Reference source not found.** section.

- Room floor area [ft2]
    - Note that volume is not calculated separately from floor area, since all ceiling heights are the same so all correlations would be the same.
    - Apartment line, used to look up adjacent rooms and apartments. For example, apartment 03B is next to 03A and 03C.
    - Exposure direction [N/E/S/W] used as an indicator of relative solar gains and prevailing winds (which were not tracked directly)
    - Number of bedrooms [#], which is a simple indicator of apartment size, approximation of occupant count and number of heaters
    - Floor Number [#] – vertical location in building for thermal stack effect considerations and to look up vertically adjacent rooms and apartments. For example, apartment 03B is below 04B and above 02B.
- Total heating capacity of heaters per room – [BTU/hr]
    - The existing heater's energy capacity, an indicator of a previous load sizing study at the building's construction or latest heating system replacement.
- Number of windows [#]
    - Count of the number of windows within a given space
- Crack length
    - Perimeter of windows and air conditioners per room (infiltration crack length) [ft], used as an indicator of relative air infiltration. This parameter is a direct result of number and size of windows and number of air conditioners
- Exposed Wall Area [ft^2]
    - How much of a room is exposed to the outdoor conditions, driving heat loss through indoor-outdoor temperature difference

Time-dependent data was downloaded from the web host using bulk queries of all Boolean, string, and number data types, downloaded through an FTP in 15-minute time steps. The data was downloaded in bulk for the whole building in 1-2 weeklong packages. Python 3.7 with Pandas and Numpy were used for data handling, correlation calculations, and HCAA application.

Interim analysis steps to determine large scale implementation in Python was performed on subsets of data in Microsoft Excel.

Primary parameters from cloud-based monitoring and data hosting platform:

- Time-scale resolution - every 15 minutes
- Room temperature [°F]
- Heating set point (SP) [°F]
- Heater status [on/off] – summed as run time per 15-minute step
- Heater mode [off/auto/heat/cool] – predominant setting used per 15-minute step
- Outdoor air temperature [°F]
- Weather conditions – outdoor air temperature, humidity, sky cover, and precipitation

6.1.7.1. Resampling

"Resampling" data is a capability of the Pandas Python package that is used to change the resolution/timescale of time series data. For example, data that is recorded every 5 minutes can be "resampled" at 15 minutes. The user chooses the resample method as well as timescale (sum of values, mean of values, etc.). For multi-month continuous analysis, the data may be resampled into 1- or 2-hour blocks to reduce computation time and data size.

Each sensor reports on a 15-minute interval, so first the bulk data is resampled into 15-minute intervals. Sensors often report data at different seconds at the 15-minute intervals, so resampling is useful to align all data into one timestamp per interval.

6.1.7.2. Data Cleaning

The following steps were used to clean the raw time-series data set into usable data for analysis:

Parameter cleaning for Correlation Analysis

- Cleaning of raw data
    - Remove strings and convert data to numerical format
    - Align all samples along 15-minute timestamps
- Temperature range
    - Use only recorded temperature data between 60°F and 90°F as extremely hot or cold temperatures are indicative of a different, unidentified issue that is either a sensor error or erratic tenant behavior and will corrupt averages.
- Outlier detection
    - The data is passed through a screen that applies Tukey's Method for determining outliers[xi]. The method involves calculating the interquartile range and flagging data points that are less than Q1 – 1.5*IQR or greater than Q3 + 1.5*IQR, where Q1 is the 25th percentile of the data, Q3 is the 75th percentile, and IQR is Q3-Q1. The screening is applied to each room individually to identify outliers within the room's data set.
- Set point range
    - Set point values outside of the thermostat programmed limit (e.g., in the initial building, the limits were 65°F-80°F) were replaced with a non-number placeholder. The hardware thermostats in the apartments are limited to this range, so any set point reading outside this range is an error.
    - Aligning set point data with thermostat mode data to determine heating set points distinct from deactivated thermostats or those in cooling mode.

- Count of good data
    - Percent of empty data points per zone per time period is calculated. Zones with more than 25% of raw data missing are removed from analysis
- Heat runtime range – binned to 0%<=heat use<=100% per sample

The figure below shows an example of the data points removed from the analysis in a given month.

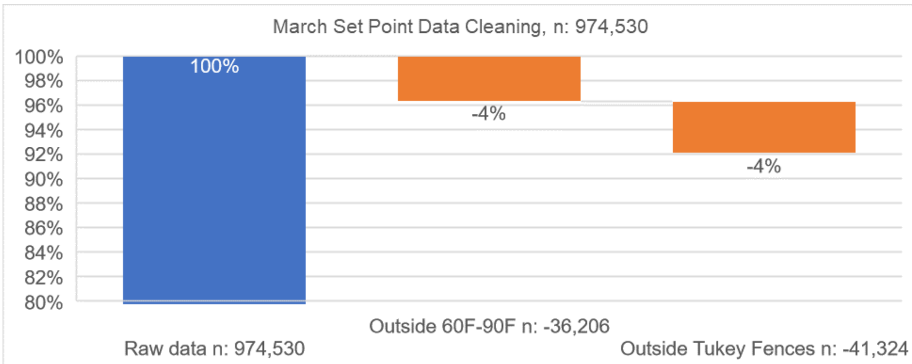

Figure 28. Example of Data Cleaning for March 2019

6.1.7.3. Steam Building 2 Correlation Study

Correlation coefficients of building characteristics and occupant choice parameters.

Table 10. Correlation between heating usage and potential HCAA parameters for Steam Building 2

Heat Use Correlation with Independent Variables	0: no correlation -1 and +1: perfect correlations
Apartment Characteristics	
Floor Area	0.49
Line	0.35
Floor Number	-0.23
Number of heating terminal units	0.51
Infiltration Crack Length [ft]	0.49
Exposed Wall Area	0.51
Flag - high or low zone temp StDev	0.10
Occupant Temp Set point (TSP) Control Choices	
Neighbor Score: Avg TSP – Neighbor TSP	0.29
Avg TSP	0.36
How much the TSP is changed over time	0.11
Average TSP – OAT	0.35
Above Floor Score: Avg TSP – floor below TSP	0.32

Table 11. Correlations for Steam Building 2 After Building Characteristic Corrections

Actual - Corrected / Actual Difference	*Diff %*
Diff %	1
Neighbor Score	0.437
Set Point Avg	0.524
Set point StDev	0.213
Set Point - OAT Average	0.519
Above Floor Score	0.298

These correlations indicate how much of the remaining variation in heating use correlates to these characteristics. Figure 29 summarizes the comparison. The drop lines from each point are a visual guide to show where on the distribution of heating cost each apartment falls. Note the disparity between left and right charts, where left is to allocated cost simply by runtime, and right is to use the HCA algorithm, with the 90th percentile apartment paying 215% of the average and the 10th percentile paying nothing. On right, the HCAA for the same sample set and time period. The smallest apartments with the lowest set points pay 35% of the average, while the maximum is less than 150% of the average. The heat cost allocation shown on the x-axis of each graph as a percent of the average bill and on left if cost was allocated purely according to heater runtime.

6.1.7.4. HCA Algorithm Application to Control Building

In Electric Building 1, the HCA algorithm was applied to a month of heating consumption data and the distribution of heating costs were compared between the HCA algorithm and the result of charging each apartment purely based on measured electricity consumption for space heating. **Error! Reference source not found.** summarizes the comparison. The drop lines from each point are a visual guide to show where on the distribution of heating cost each apartment falls. Note the disparity between left and right charts, where left is to allocated cost simply by runtime, and right is to use the HCA algorithm, with the 90th percentile apartment paying 215% of the average and the 10th percentile paying nothing. On right, the HCAA for the same sample set and time period. The smallest apartments with the lowest set points pay 35% of the average, while the maximum is less than 150% of the average.

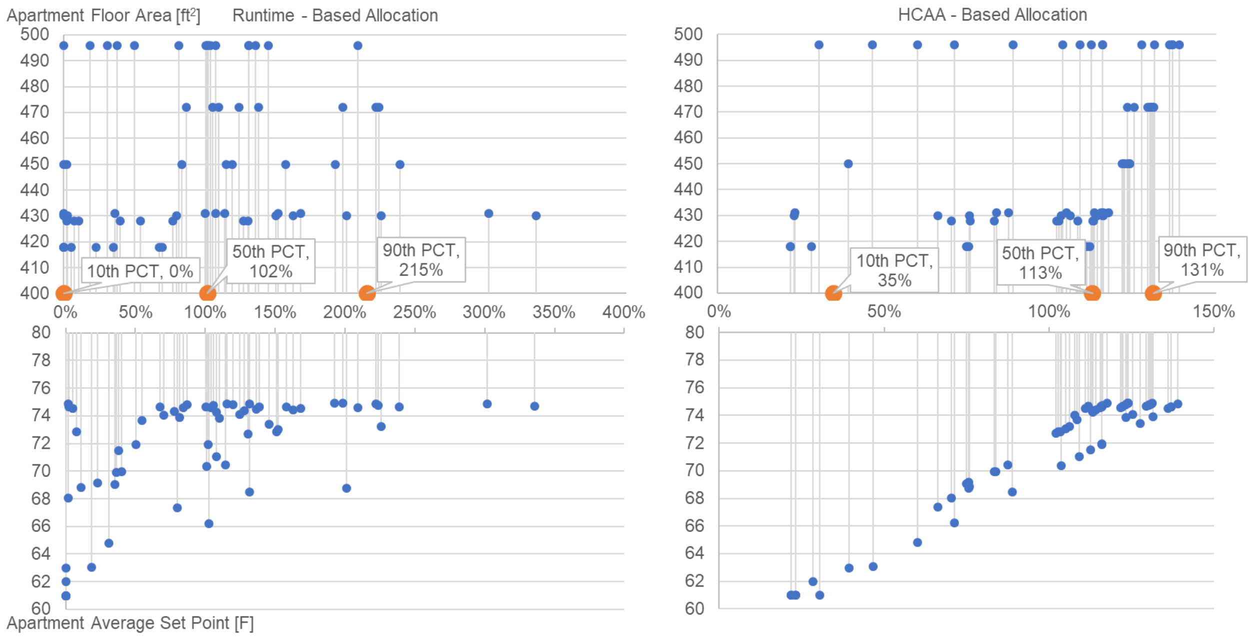

Figure 29. Differences Between Heat Cost Allocation Methods

6.2. Additional Behavioral Intervention Information

6.2.1. Background Research

A study named "Nonprice incentives and energy conservation" (Asensio 2014) highlights environment and health-based messaging strategies. In a randomized controlled trial with real-time appliance level energy metering, environment and health-based information strategies were found to outperform monetary savings information to drive behavioral change in the home. Environment and health-based information treatments motivated 8% energy savings versus control and were particularly effective on families with children, who achieved up to 19% energy savings. Two psychology-based mechanisms were considered in the study:

- Amplification of prosocial conservation, which leverages a motivation to reduce undesirable effects on others.
- Amplification of private benefits, which leverages a motivation to reduce undesirable effects on oneself.

A study named "Social norms and energy conservation" (Alcott 2010) summarizes home energy reports created by the company Opower. The home energy reports were made up of two distinct modules or sections:

- Social comparison module, which presents a descriptive norm, includes a comparison between the household's energy use to the mean and the 20th percentile of its comparison group. This module also presents an injunctive norm, through an efficiency standing section by categorizing the household as "Great", "Good", or "Below Average."

- Action steps module, which provides customized energy conservation tips to each household based on historical energy use patterns.

Prosocial and environmental related feedback identified in Asensio 2014, and the social comparison and action steps modules identified in Alcott 2010, were influential in the development of the HEUR. Additionally, SWA recognized that concise, impactful, and relevant feedback was critical in nudging heat and energy conserving behavior. The HEUR layout, format, and legibility went through several iterations to balance transparent and detailed information with concise and illustrative feedback.

6.2.2. Heating Energy Use Report Examples

The following images are full examples of HEURs that were distributed to Demonstration Site One during the course of the project.

Heating Energy Use Report

USAGE SUMMARY, NOT A BILL
This Document Summarizes Your Heat Charges
See Frequently Asked Questions for More Detail

Heating Energy Use Report
Prepared For: [redacted]

Apportionment Period:	05/01/2021 - 06/01/2021
Heat Apportionment Charge:	$31.03
Potential Savings This Period:	$2.94

See back for more details

ENERGY USE OVERALL GRADE

Overall Grade
D

Your grade is based on your thermostat setting. See back for details.

Your Apartment — Efficient Apartment — Typical Apartment
$200 $150 $100 $50 $-
May-20 Oct-20 Nov-20 Dec-20 Jan-21 Feb-21 Mar-21 Apr-21 May-21
APPORTIONMENT COMPARISON CHART

GREENHOUSE GAS EMISSION COMPARISON

You produced as much greenhouse gas emissions as a 705-mile NYC subway ride. That's about 26 trips up and down Manhattan.

ENERGY SAVING ACTIONS

Thermostat
- Lowering your thermostat by 1.9 degree(s) would have saved you $2.94 dollar(s).
- Don't forget to turn off your heat before you leave.
- Higher thermostat settings do not heat your space more quickly, we recommend increasing your thermostat in small increments when necessary.

Heater
- Keep the hot air in and the cold air out.
- Don't obstruct the heater, it requires air circulation to operate efficiently.

Windows
- You should not have to open your window to cool your space in the winter.
- Ensure that windows can close fully to create continuous seals.

SUMMARY OF SETTINGS

Your Average Thermostat Setting
Your average heat setpoint was 66.8°F

Building Average Thermostat Setting
The building's average heat setpoint was 66.1°F

HEAT APPORTIONMENT CHARGE BREAKDOWN

Usage Charge Amount based on heating demand, calculated from your average thermostat setting.	$2.94
Service Charge Standard charge based on apartment size.	$28.09
Total Charge Sum of Service Charge and Usage Charge.	$31.03

FREQUENTLY ASKED QUESTIONS

ABOUT THIS REPORT:

Why am I receiving this?
Murray Hill Marquis has embarked on a heating system optimization program to reduce our building's energy demand. Research has shown that residents who are responsible for paying for their heat are more aware of their energy consuming behaviors and will reduce excess consumption. We believe this billing structure will allow us to improve the building's performance, making NYC a cleaner, healthier, and more sustainable city for all.

How is my bill calculated?
The Heat Apportionment Charge is made of two components, the Usage Charge and Service Charge. The Usage Charge is based on your average thermostat setting and apartment size. Higher temperature setpoints in Heat mode yield higher charges. The Service Charge is a standard charge for the building's minimum heating requirement, and is distributed evenly among similar sized apartments. Larger apartments receive a slightly larger charge due to factors such as more windows and more heaters.

GENERAL INFORMATION:

Where do I make my payment?
Your Heat Apportionment Charge will automatically be added to your rent statement, no additional payment based on this report required.

Is there a minimum monthly bill requirement?
There is a minimum temperature that must be maintained in the building. The cost for this provision is distributed to all apartments based on their size and is incorporated into your Service Charge.

How does this impact my current utility bills (i.e. wifi, electricity, and/or cooking gas)?
This Heat Apportionment Charge is separate from all other resident paid utility bills. This does not supersede your other current utility billing services.

How do my actions make a difference?
Lowering the setting of your thermostat(s) and turning them off when not home reduces your bill since your apartment requires less heat.

For all other questions or comments, please feel free to email us at apportionment@swinter.com.

Potential savings is based on a comparison between your heating charge and the lowest charge of a similarly-sized apartment. The lowest setting your thermostat is capable of is 65°F.

The bill includes a $5 billing service charge, included in the Service Charge.

Disclaimer: The information to prepare these findings was provided by Sentient Buildings, LLC and building management. Steven Winter Associates, Inc. is not responsible for any errors or omissions, or for the results obtained from the use of this information. All information in this report is provided, with no guarantee of completeness, accuracy, timeliness or of the results obtained from the use of this information without warranties of any kind expressed or implied. Actual savings may vary based upon use and applicable rates.

Heating Energy Use Report

USAGE SUMMARY, NOT A BILL
This Document Summarizes Your Heat Charges
See Frequently Asked Questions for More Detail

Heating Energy Use Report
Prepared For: [redacted]

Apportionment Period:	05/01/2021 - 06/01/2021
Heat Apportionment Charge:	$21.87
Potential Savings This Period:	$0.00

See back for more details

ENERGY USE OVERALL GRADE

Overall Grade
A

Your grade is based on your thermostat setting. See back for details.

Your Apartment — Efficient Apartment — Typical Apartment
$140 $120 $100 $80 $60 $40 $20 $-
May-20 Oct-20 Nov-20 Dec-20 Jan-21 Feb-21 Mar-21 Apr-21 May-21
APPORTIONMENT COMPARISON CHART

GREENHOUSE GAS EMISSION COMPARISON

You produced as much greenhouse gas emissions as a 457-mile NYC subway ride. That's about 17 trips up and down Manhattan.

ENERGY SAVING ACTIONS

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- Don't forget to turn off your heat before you leave.
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- You should not have to open your window to cool your space in the winter.
- Ensure that windows can close fully to create continuous seals.

SUMMARY OF SETTINGS

Your Average Thermostat Setting
Your average heat setpoint was 65.°F

Building Average Thermostat Setting
The building's average heat setpoint was 66.1°F

HEAT APPORTIONMENT CHARGE BREAKDOWN

Usage Charge Amount based on heating demand, calculated from your average thermostat setting.	$0.00
Service Charge Standard charge based on apartment size.	$21.87
Total Charge Sum of Service Charge and Usage Charge.	$21.87

FREQUENTLY ASKED QUESTIONS

ABOUT THIS REPORT:

Why am I receiving this?
Murray Hill Marquis has embarked on a heating system optimization program to reduce our building's energy demand. Research has shown that residents who are responsible for paying for their heat are more aware of their energy consuming behaviors and will reduce excess consumption. We believe this billing structure will allow us to improve the building's performance, making NYC a cleaner, healthier, and more sustainable city for all.

How is my bill calculated?
The Heat Apportionment Charge is made of two components, the Usage Charge and Service Charge. The Usage Charge is based on your average thermostat setting and apartment size. Higher temperature setpoints in Heat mode yield higher charges. The Service Charge is a standard charge for the building's minimum heating requirement, and is distributed evenly among similar sized apartments. Larger apartments receive a slightly larger charge due to factors such as more windows and more heaters.

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There is a minimum temperature that must be maintained in the building. The cost for this provision is distributed to all apartments based on their size and is incorporated into your Service Charge.

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This Heat Apportionment Charge is separate from all other resident paid utility bills. This does not supersede your other current utility billing services.

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Lowering the setting of your thermostat(s) and turning them off when not home reduces your bill since your apartment requires less heat.

For all other questions or comments, please feel free to email us at apportionment@swinter.com.

Potential savings is based on a comparison between your heating charge and the lowest charge of a similarly-sized apartment. The lowest setting your thermostat is capable of is 65°F.

The bill includes a $5 billing service charge, included in the Service Charge.

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Figure 30 Examples of Mock Bills Provided to Tenants

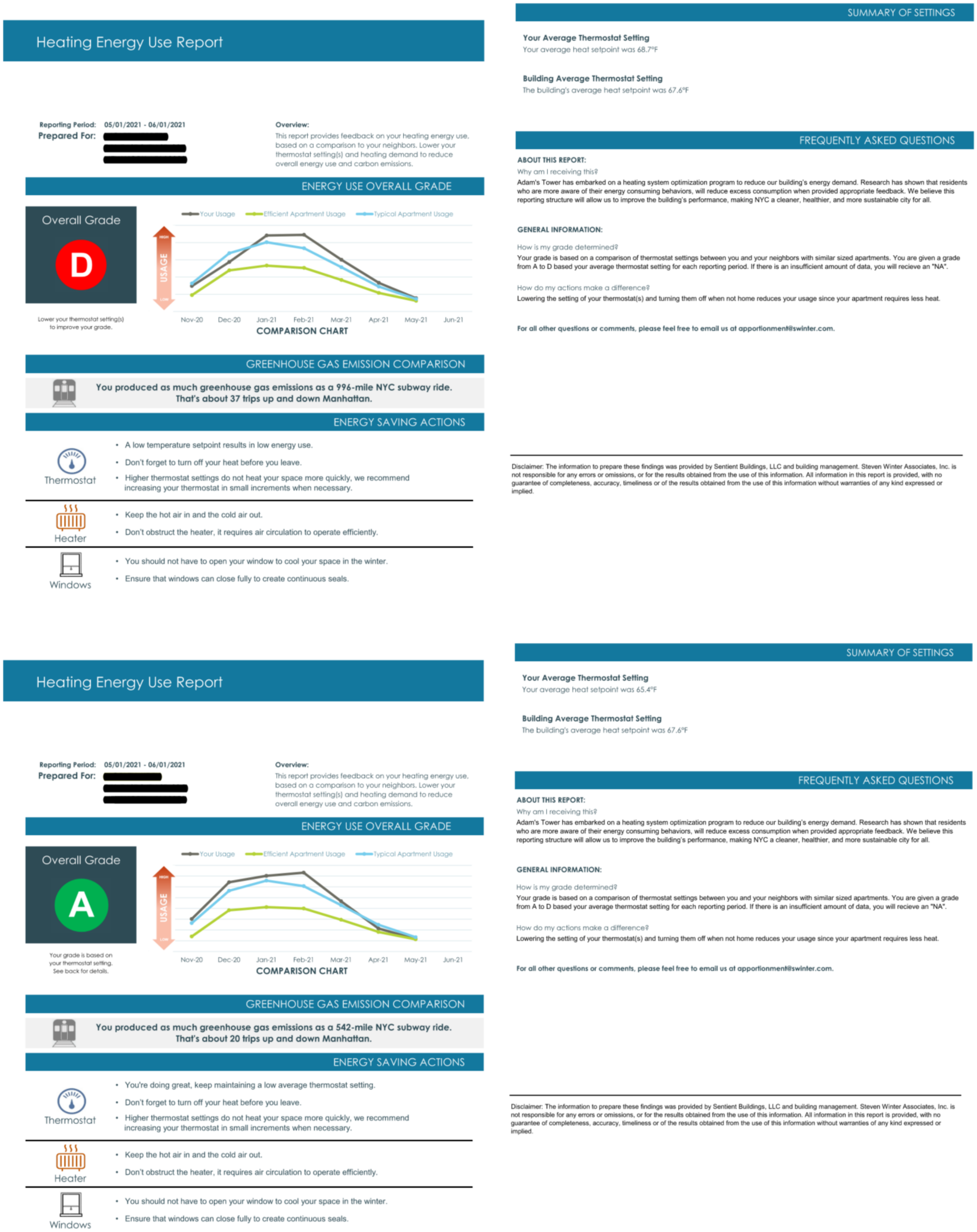

Figure 31 Examples of Mock Bills Provided to Tenants

6.3. Additional Analysis Information

6.3.1. Energy Savings Analysis Methodology

A least squares analysis was used to determine the building's heating and domestic hot water energy usage. The following was the governing equation for the regression analysis, where *V* was the estimated total oil usage, α_0 was the domestic hot water energy use (baseload), and α_1 was the heating degree day (HDD) dependent energy use.

$$V = \alpha_0 + \alpha_1 * HDD$$

The difference between V and actual usage was then squared iteratively through different values of α_0 and α_1 until an optimal solution was found.

6.3.2. Energy Data Monitoring

6.3.2.1. Demonstration Site One

The Demonstration Site One's boiler plant burned #4 fuel oil which was assumed to have a heating value of approximately 145 kBtu per gallon. Oil was delivered to the building's 15,000-gallon tank on an as-needed basis, with a typical delivery amount of 5,000 gallons. Unlike electric and natural gas that are traditionally metered on a regular basis, the quantity of delivered gallons of oil was used as a proxy for oil usage between delivery dates. Oil delivery data (i.e., date, volume, and costs) was tracked throughout the study period by building management and provided to SWA.

An ultrasonic level transmitter was installed and connected to the building management system to track oil tank levels. Data was unavailable during the baseline period of the study but was available starting in January 2019.

Condensate flow meters and temperature sensors were installed in three locations. One was located on the condensate discharge line from the heating distribution system's vacuum pump; this measured the volume and temperature of condensate returning from the heating system back to the boiler feed tank. The other two meters and sensors were installed on the feed tank discharge lines (two boilers, one meter and sensor for each boiler return line). These measured volume and temperature of the condensate returning from both the heating and domestic hot water systems. Together the meters and sensors collected data on energy consumed by the heating and domestic hot water systems. Data was unavailable during the baseline period of the study but was available starting in January 2019.

Data on total square feet leased to tenants (leased area) was provided to SWA by building management. Data was collected to approximate whole building occupancy and used during energy savings analyses to adjust heating energy savings by occupancy rates.

6.3.2.2. Demonstration Site Two

Demonstration Site Two's boiler plant burned natural gas, which was assumed to have a heating value of approximately 100 kBtu per therm. This natural gas was directly metered by the utility. Total monthly gas consumption and billing data was available throughout the research period by the building owner and the utility provider's online portal.

A pulse output was installed on the utility gas meter and connected to the EMIS to track daily gas consumption on a more granular basis than was possible through utility bills alone. Data became available starting in April 2019.

6.3.3. Analysis Details and Considerations

When occupancy data was available, a least squares analysis was used to determine the building's occupancy-based heating and domestic hot water energy usage. The following was the governing equation for the regression analysis, where *V* was the estimated total oil usage, α_0 was the domestic hot water energy use (baseload), α_1 was the heating degree day (HDD) dependent energy use, α_2 was the occupancy dependent domestic hot water energy use, and α_3 was the occupancy and heating degree day (HDD) dependent energy use.

$$V_c = \alpha_{c,0} + \alpha_{c,1} * HDD_c + \alpha_{c,2} * Occ_c + \alpha_{c,3} * \frac{Occ}{HDD^c}$$

The difference between V and actual usage was then squared iteratively through different values of α_0, α_1, α_2, and α_3 until an optimal solution was found.

Several data sets and analysis methods had been considered as part of Demonstration Site One's energy savings analysis. Oil delivery, oil tank level, and condensate flow and temperature data sets were used in distinct regression analyses. Data on total square feet leased to tenants was used in additional regression analyses in attempt to correct for major changes in building occupancy.

Oil tank level data and condensate flow and temperature data sets were evaluated for completeness and accuracy. Both data sets did not span the entirety of the research period and displayed considerable inaccuracy and therefore were deemed inadequate for final energy savings analysis. Oil tank level data displayed approximately 11% less usage than the oil delivery data indicated. Condensate flow and temperature data yielded inconsistent trends, where several periods displayed higher energy consumption than the total energy content of oil consumed. Ultimately, the oil delivery data was utilized for the analysis.

A~10% reduction in building leased area occurred throughout the research period, from the baseline period to the "tenant feedback and majority receive bill" period. Occupancy (leased area)-dependent regression analyses were inconclusive and did not show a consistent relationship between estimated whole building energy use and building's leased area data. This suggested variables such as the steam distribution system's operational requirements (i.e., constant steam pressure for domestic hot water production, heating distribution piping outside of any tenant control, minimum indoor air temperature requirements, etc.) may outweigh the building's heating energy use dependency on leased area.

Digital thermostat indoor air temperature (IAT) data was evaluated to correlate whole building IAT data with each energy savings analysis method. IAT data was area-weighted by associating each data point to its zone's (i.e., Bedroom, Living Room) floor area. The area-weighted-average per month was then broken up into similar outdoor air conditions (by 5 HDD-interval bins) and evaluated. No clear conclusions were drawn, so monthly IAT area-weighted-averages were then weight-averaged by

HDD. IAT during months with high HDDs was given a higher weight than months with low HDDs due to higher fuel use during colder months (high HDDs). The energy savings analysis method with the highest correlation between IAT changes and heating energy usage was one which used oil delivery data and did not correct for occupancy changes.

The above IAT and energy savings analysis assumed a constant air change rate and U-value across all periods. One confounding factor and potential error in correlating IAT to the heating energy use is the lack of data on open windows throughout the different periods. One recommended energy savings action in the Heating Energy Use Reports was to prompt tenants to close their windows during the heating season, which is a typical energy efficiency issue in New York City.

Weather-normalized heating fuel consumption was expected to decrease throughout all analysis periods. However, an increase in fuel use occurred during the "tenant feedback w/o billing" period as shown in Table 4. Whole building indoor air temperature data was analyzed and showed a slight increase in the "tenant feedback w/o billing" period, as shown in Figure 32. This is consistent with an increase in heating energy use during that period.

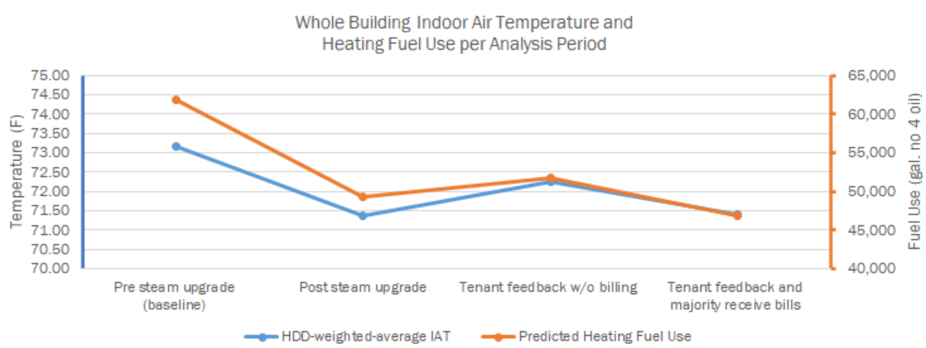

Figure 32 Weather Normalized Fuel Consumption for Demonstration Site Two

6.3.4. Additional Behavioral Impact Analyses and Considerations

The following chart shows the average set point of apartments that were leased by the same tenant for all upgrade periods (approximately 25% of the building) in Demonstration Site One. Average set points are shown per intervention period and delineated into bins of heating degree days (HDD). An additional group of average set points are shown on the right of the chart and shows weighted averages by HDD, where set points on colder days (higher HDDs) have higher weight than those on mild days. The graph shows that set points were relatively low in pre steam upgrade periods for several bins, which may be attributed to imbalances in the steam system (described in subsequent sections). In mild outdoor temperatures (HDDs of 0 to 15) average set points trended down throughout the upgrade periods, indicating that residents may have greater flexibility for comfort during such conditions. This trend does not continue into colder temperatures. Overall, changes in set points were relatively small, where the HDD weighted-average set points varied less than 0.5°F.

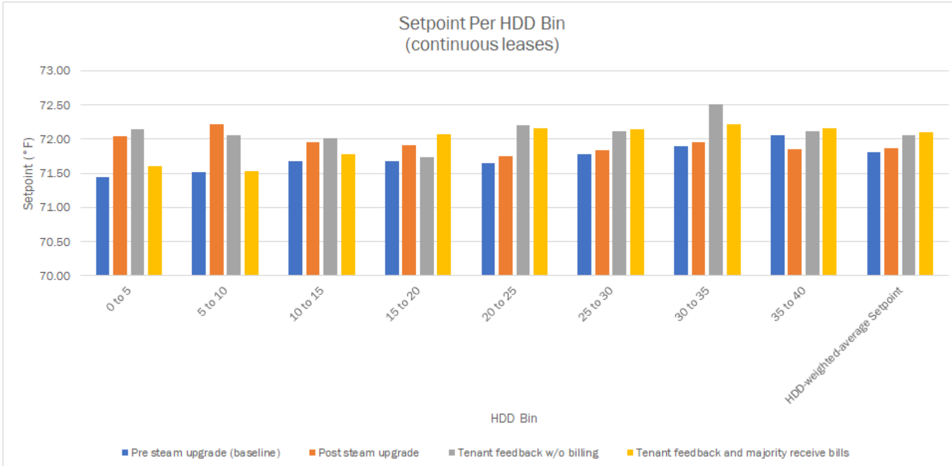

Figure 33 Demonstration Site One Setpoints over Temperature Ranges for Continuous Leases

The following chart shows average set points per upgrade period and delineated into bins of heating degree days (HDD) for Demonstration Site Two. Similar to Demonstration Site One, the graph shows that set points were relatively low in the early period "transition (upgrade occurring)," which again may be attributed to imbalances in the steam system.

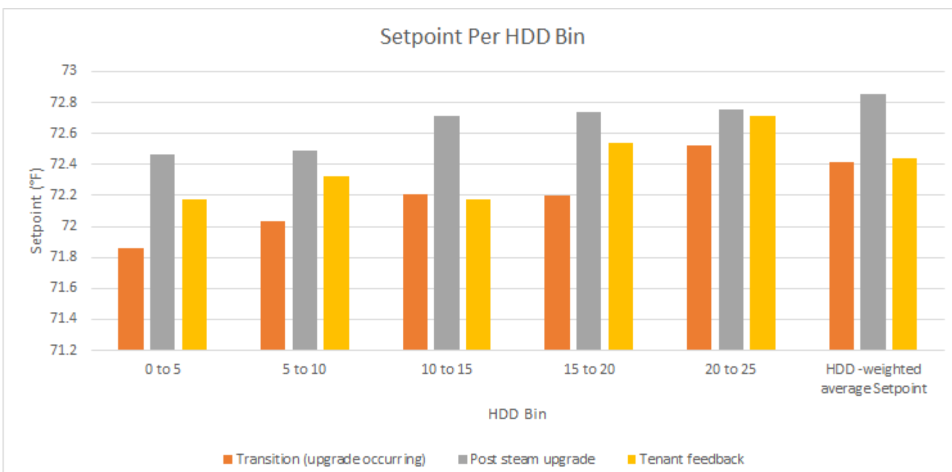

Figure 34 Demonstration Site Two Setpoints over Temperature Ranges

7 References

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[x] Supra 6, Figure 9
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Deep Heating Savings through Behavior-driven Heating Controls

Executive Summary

- Solution combines networked in-unit controls and behavioral feedback to achieve cost-effective, deep heating energy savings
- DOE- and NYSERDA-sponsored pilot results ranged from 11-24% savings of heating energy usage
- Non-energy benefits including improved tenant comfort and reduced maintenance costs
- Applicable to building stock with central heating systems, including multifamily (market-rate, low-to-moderate income), commercial office, and others

Heating waste is a large, but addressable problem

- Buildings with central heating systems are heated so the coldest space is satisfied
- Most tenants end up overheated, and, lacking individual controls, open windows, resulting in over 20% wasted heating energy
- Traditional low-touch solutions, such as central controls, have resulted in disappointing energy savings, but more comprehensive in-unit retrofits have typically not been cost effective
- Transparency into energy usage is increasing; some buildings will get a poor mark
- Upcoming building performance mandates will mean financial penalties for excessive usage

Open windows (circled in red) on a winter day

Better controls and behavioral feedback can address this problem

- Retrofit combining in-unit HVAC controls and central Energy Management Information System (EMIS)
  - Tenants can control their own temperatures – windows stay closed in winter!
  - Algorithms disaggregate individual heating usage and alert tenants of high consumption through heating energy use reports (HEURs)
  - Heating <u>costs</u> can equitably, and defensibly, be allocated to tenants
  - Potential to save ~20% annual heating <u>energy</u>
- Leverages existing IoT trends (increasing technology availability with decreasing costs)
- Similar allocation approaches are implemented in Europe using current technology, but allocation is not common in the US

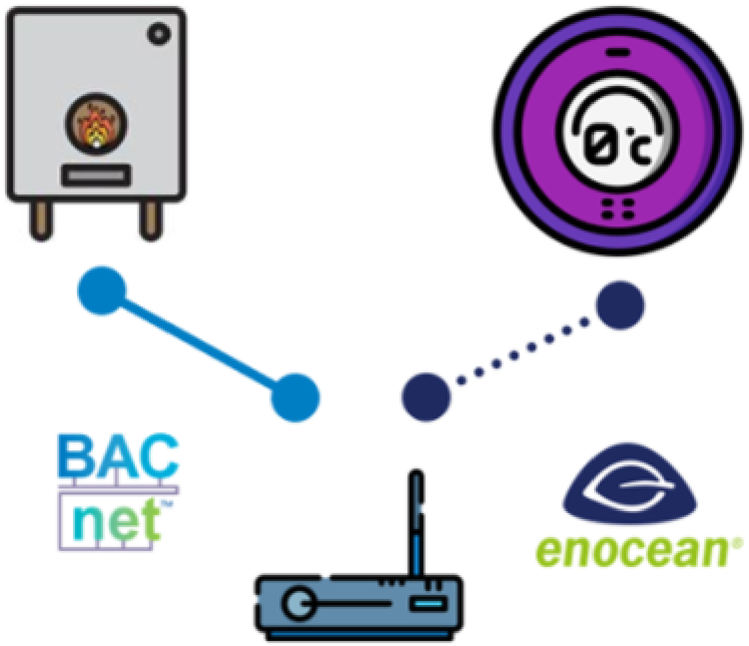
The approach has been tested and validated in the US market

- Funded by DOE, NYSERDA, and real estate owners
  - 2019: System upgrades installed
  - Winter 2019-2020: upgrades only, no behavioral feedback
  - Winter 2020-2021: added tenant feedback (with billing at lease turns where applicable)

Year Built	Size (SF)	Unit Count/Type	Heating System	Fuel Type	Upgrades Completed	Tenant Feedback
1987	177,000	259 market-rate	Two-pipe Steam with PTACs	#4 Fuel Oil	Steam trap replacements	Heating energy use reports (HEURs) and billing
1970	290,000	131 market-rate 53 rent-stabilized	Two-pipe Steam with PTACs	Natural Gas	Steam trap replacements Wireless control valves Network	Heating energy use reports (HEURs) only

The solution implementation requires some planning

- Basic system in good working order (i.e., functional steam traps) in both common areas and tenant spaces
- Reliable central network to handle and store expected data flows
- Networked controls at every heating terminal unit
- Utilize networking standards that prevent “vendor-lock”
- Protect data security at all points in the process



Savings of 11-24% while offering additional non-energy benefits

- Building-wide heating savings were 11-20% from the system upgrade/optimization alone
- Savings rose to 17-24% with behavior (HEURs) layered in
  - Heat cost allocation was accepted by tenants
- Tenants had more control over their comfort
- Building personnel gain better visibility into operations
- Note: COVID hit mid-pilot, affecting vacancy rates, lease turnovers, and setpoints, potentially impacting results

Additional cooling benefits can be achieved

- The same network and controls infrastructure can provide behavioral feedback to tenants on their cooling usage, potentially providing summertime savings

The solution can be economically implemented

- Cost effectiveness depends on installation and fuel costs
- Allocation of heat improves results and the owner financial return
- Savings to investment ratios (SIR) presented do not reflect incentives

Savings to Investment Ratio (SIR)	Low Fuel Cost		High Fuel Cost	
Installation Cost	Allocation	No Allocation	Allocation	No Allocation
Low	4.0	0.5	6.0	0.7
High	1.0	0.2	1.6	0.3

- Installation Costs
  - Low - $0.60/SF
  - High - $3.00/SF
- Fuel Costs
  - Low - $9.50/MMBtu
  - High - $14.30/MMBtu
- Expected measure lifetime is 10 years

This approach is well-suited for buildings with central heating systems

- Demonstrated track record in Europe
- Savings of 11-24% in a DOE- and NYSERDA-funded NYC pilot
- Significantly better savings than low-touch approaches and is more cost-effective than deeper retrofits
- Well-suited for MF and LMI buildings
  - Projects must be appropriately structured to avoid landlord-tenant split incentive
- Non-energy benefits: enhanced occupant comfort, better building control, decreased maintenance through EMIS

Where does this approach work?

- Widely applicable in older MF building stock
- Applicable to hydronic systems in addition to steam
- May have applicability in other settings, such as commercial buildings, college dormitories, and assisted living centers

Questions?

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  - Solution disaggregates individual heating usage for cost allocation
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  - Potential to save ~20% annual heating energy, cost allocation accrues to owners
- Leverages existing IoT trends (increasing technology availability with decreasing costs)
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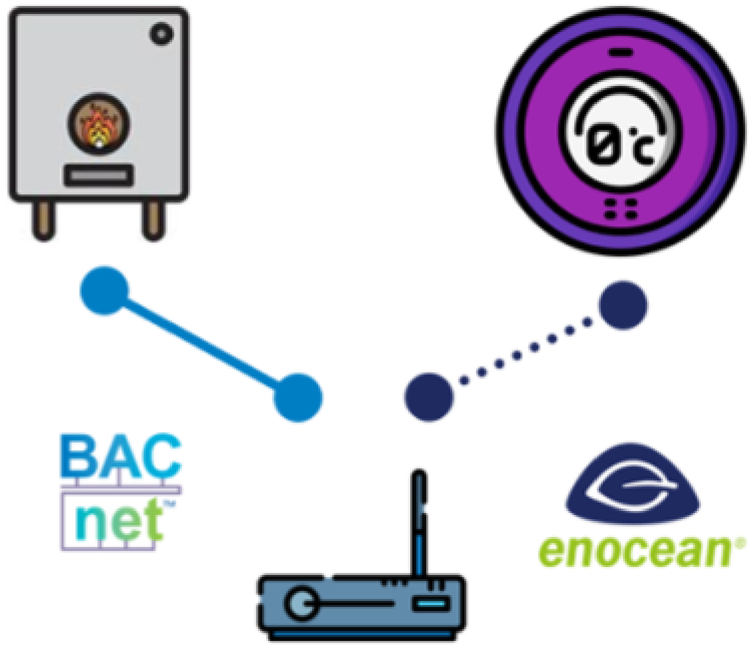
- Utilize networking standards that prevent “vendor-lock”
- Protect data security at all points in the process



Savings of 11-24% while offering additional non-energy benefits

- Building-wide heating savings were 11-20% from the system upgrade/optimization alone
- Savings rose to 17-24% with behavior (HEURs) layered in
- Tenants had more control over their comfort
- Building personnel gain better visibility into operations
- Note: COVID hit mid-pilot, affecting vacancy rates, lease turnovers, and setpoints, potentially impacting results

Additional cooling benefits can be achieved

- The same network and controls infrastructure can provide behavioral feedback to tenants on their cooling usage, potentially providing summertime savings

The solution can be economically implemented

- Cost effectiveness depends on installation and fuel costs
- Allocation of heat improves results and the owner financial return
- Savings to investment ratios (SIR) presented do not reflect incentives

Savings to Investment Ratio (SIR)	Low Fuel Cost		High Fuel Cost	
Installation Cost	Allocation	No Allocation	Allocation	No Allocation
Low	4.0	0.5	6.0	0.7
High	1.0	0.2	1.6	0.3

- Installation Costs
  - Low - $0.60/SF
  - High - $3.00/SF
- Fuel Costs
  - Low - $9.50/MMBtu
  - High - $14.30/MMBtu
- Expected measure lifetime is 10 years

This approach is well-suited for gas utility efficiency efforts

- Demonstrated track record in Europe
- Savings of 11-24% in a DOE- and NYSERDA-funded NYC pilot
  - Peak fuel demand savings reduced by similar amount
- Significantly better savings than low-touch approaches and is more cost-effective than deeper retrofits
- Well-suited for MF and LMI programs
  - Pilots or programs must be appropriately structured to avoid landlord-tenant split incentive
- Non-energy benefits: enhanced occupant comfort, better building control, decreased maintenance through EMIS

Where does this approach work?

- Widely applicable in utility service territories with older MF building stock
- Applicable to hydronic systems in addition to steam
- May have applicability in other settings, such as commercial buildings, college dormitories, and assisted living centers
- Additional cooling savings may be possible in summertime

Questions?