Replacing Fossil Fuel Heat with Mini-Split Heat Pumps in Urban Housing Stock

Final Report | Report Number 22-04 | March 2022

NEW YORK STATE | NYSERDA

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Our Vision:

New York is a global climate leader building a healthier future with thriving communities; homes and businesses powered by clean energy; and economic opportunities accessible to all New Yorkers.

Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

Replacing Fossil Fuel Heat with Mini-Split Heat Pumps in Urban Housing Stock

Final Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Scott Smith, Program Manager

Owahgena Consulting, Inc.

Cazenovia, NY

Hugh Henderson, Principal

and

The Levy Partnership, Inc.

New York, NY

Jordan Dentz, Vice President
Shengming Zhu, Project Manager

and

Frontier Energy, Inc.

Cazenovia, NY

Nicholas Genzel, Energy Analyst
Carina Paton, Sr. Program Manager

and

Centsible House, Inc.

Brooklyn, NY

Julie Liu, President

NYSERDA Report 22-04 NYSERDA Contract 104080 March 2022

Notice

Preferred Citation

New York State Energy Research and Development Authority (NYSERDA). 2022. "Replacing Fossil Fuel Heat with Mini-Split Heat Pumps in Urban Housing Stock," NYSERDA Report Number 22-04. Prepared by Owahgena Consulting, The Levy Partnership, Frontier Energy and Centsible House. nyserda.ny.gov/publications

Abstract

Replacing Fossil Fuel Heat with Mini-Split Heat Pumps in Urban Housing Stock was a field test project that sought to demonstrate the energy, cost, and greenhouse gas (GHG) savings achievable by installing "cold-climate" air source heat pumps (ccASHP)—or, heat pumps deemed best suited to heat efficiently in cold climates—into one- to three-story existing New York State homes. The ccASHPs were installed, and monitoring equipment was added, from late 2017 through mid-2019. At some of the sites, weatherization improvements were also implemented with the heat pump installation. The ccASHPs were mostly ductless units with multiple indoor heads. The heat pump installed capacity at each site ranged from 2 to 8.5 tons. The average installed cost was $4,483 per installed ton for heat pump equipment (excluding weatherization). The monitoring and analysis approach measured electric consumption at 15-minute intervals for all the installed heat pumps for 12 months or more. Analysis of the measured data showed that fossil savings were realized at 19 of the 20 sites (one site had higher use). On average fossil fuel use for space heating was reduced by 86 percent. The average implied coefficient of performance (COP) was 2.4, or about 80 percent of the rated Heating Seasonal Performance Factor (HSPF) for the heat pumps. There were no cost savings for the sites that replaced natural gas use but some sites with oil heating had cost savings (using local energy costs from 2020 of $0.20/kWh, $1.40/therm and $2.45/gallon). Greenhouse gas (GHG) savings were determined using the regional average emission factor for the electric grid in the Metro NY area as well as using the non-baseload emission factor. The average emission factor, which might be appropriate, assuming wholesale electrification of all heating systems, results in GHG savings of 1,265 pounds of carbon dioxide equivalent per year per installed ton of heat pump capacity. Using the non-baseload factor, which uses the Environmental Protection Agency (EPA)-recommended method of accounting for the marginal benefit of project energy savings, results in GHG savings of 592 pounds of carbon dioxide per year per installed ton.

Keywords

cold climate air source heat pumps, field monitoring, measurement and verification

Acknowledgments

The authors would like to thank the following people for their guidance, support, and encouragement throughout this project: Scott Smith, NYSERDA Clean Heating and Cooling Program Manager, Mark Boyd and Rick Nortz of Mitsubishi Electric Trane, Michael Psihoules of Fujitsu General, Julian Mercado and Jon Hacker of Daikin North America. We are also indebted to many contractors and tradespeople who installed the equipment and weatherization measures, and most importantly the homeowners and residents of the demonstration sites.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AC	air conditioning
ACCA	Air Conditioning Contractors of America
ACH50	air change rate or leakage at 50 Pascals normalized by house volume
AHU	air handling unit
ASHP	air source heat pump, also air-to-air heat pump
ccASHP	cold climate air source heat pump
cfm50	leakage airflow rate at 50 Pascals
COP	coefficient of performance
CT	current transducer
DHW	domestic hot water
EFG	Energy Futures Group
EPA	Environmental Protection Agency
FE	Frontier Energy (formerly CDH Energy)
FFT	flip flop test
ft	feet or foot
GHG	greenhouse gas
GSHP	ground-source heat pump
head	indoor component of a ductless ccASHP. Also known as section or unit
HOBO®	brand of battery-powered data logger from Onset Computer Corp.
HSPF	heating seasonal performance factor
HVAC	heating, ventilating and air conditioning
kW	kilowatt
kWh	kilowatt hours
MW	megawatt
NEEP	Northeast Energy Efficiency Partnerships
NY	New York
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
PON	Program Opportunity Notice
PV	photovoltaic
QA	quality assurance
SEER	seasonal energy efficiency ratio
sq	square
TLP	The Levy Partnership
TRM	Technical Resource Manual
W	watts

Executive Summary

The project was initiated under New York State Energy Research and Development Authority's (NYSERDA) Emerging Technology and Accelerated Commercialization (ETAC) program, or Program Opportunity Notice 3127. The Levy Partnership (TLP) team identified and recruited twenty sites to install cold climate air source heat pumps (ccASHPs) to replace fossil fuel systems (most had boilers with hot water or steam distribution) at one to three family houses in the New York Metro area. NYSERDA hired Frontier Energy to conduct the measurement and verification at these sites as well as for other similar ETAC projects. The ccASHPs were installed and monitoring equipment added, from late 2017 through mid-2019. At some of the sites, weatherization improvements were also implemented with the heat pump installation. The ccASHPs were mostly ductless units with multiple indoor heads. From one to three heat pump systems were installed with up to twelve indoor heads. The heat pump installed capacity at each site ranged from 2 to 8.5 tons. The average installed cost was $4,483 per installed ton for heat pump equipment (excluding weatherization).

The monitoring and analysis approach measured electric consumption at 15-minute intervals for all the installed heat pumps for 12 months or more. The project team also collected pre- and post-retrofit monthly natural gas bills or fuel delivery logs for homes that used fuel oil. Loggers were also installed to measure space temperatures in some rooms in each house. Ambient temperature data were collected from nearby weather stations. Fuel use and heat pump electric consumption was related to ambient temperature using regression analysis to develop load lines to predict energy use in both the pre-retrofit and post-retrofit periods—while accounting for baseline fuel use for domestic water heating and other non-space heating uses with a change-point model. Then typical year weather data was used in a bin analysis to predict annual heating impacts. The analysis approach inherently assumes that the occupants maintained similar set points and behavior patterns in both the pre- and post-retrofit periods. The savings from the heat pumps alone were separately discerned from the total site savings by subtracting out the contractor-estimated weatherization or envelope savings. A "flip-flop" test (where the home temporarily reverted to fossil fuel heating) completed at one site confirmed the estimated weatherization savings were valid.

Analysis of the measured data showed that fossil savings were realized at 19 of the 20 sites (one site had higher use). On average fossil fuel use for space heating was reduced by 86 percent. The average implied coefficient of performance (COP) was 2.4, or about 80 percent of the rated Heating Seasonal Performance

Factor (HSPF) for the heat pumps. There were no cost savings for the sites that replaced natural gas use but some sites with oil heating had cost savings (using local energy costs from 2020 of $0.20/kWh, $1.40/therm and $2.45/gallon).

Greenhouse gas (GHG) savings were determined using the regional average emission factor for the electric grid in the Metro NY area as well as using the non-baseload emission factor. The average emission factor, which might be appropriate, assuming wholesale electrification of all heating systems, results in GHG savings of 1,265 pounds of carbon dioxide equivalent per year per installed ton of heat pump capacity. Using the non-baseload factor, which uses the Environmental Protection Agency (EPA)-recommended method of accounting for the marginal benefit of project energy savings, results in GHG savings of 592 pounds of carbon dioxide per year per installed ton.

At three of the twenty homes, the heat pumps were used initially, but then the homeowners reverted to relying more on the fossil fuel boilers in subsequent seasons—reportedly due to comfort concerns. This at least partially explains why not all fossil fuel use was eliminated even though the heat pumps were adequately sized to meet all the space heating load.

The homeowner surveys indicated that most homeowners were satisfied with the heat pump system and thought the installation process was no more onerous than a simple replacement of their original heating and cooling systems. The main homeowner motivations for installing the heat pumps were to lower operating costs and improve comfort.

While most homeowners were satisfied with the heating performance of these ccASHP systems, at least three of the homes did express comfort concerns and used their heat pumps less than expected. Contractors must proactively address issues of thermal distribution and comfort when designing and installing ccASHP systems to meet homeowner expectations. One key issue is that using multiple indoor ductless heads is often a compromise in terms of fully and evenly distributing heat to satisfy whole house heating loads. Installing indoor heads in every room is often impractical because indoor heads are too large for some rooms and installation costs can become prohibitive. Other solutions such as installing compact ducted units to serve multiple rooms may help to alleviate these issues.

1 Project Introduction and Overview

1.1 NYSERDA's Original Goals for Program Opportunity Notice 3127

NYSERDA's Program Opportunity Notice (PON) 3127, the Emerging Technologies Demonstration Projects—Residential HVAC was initiated to identify ways to accelerate the market uptake of commercially available, but underused building technologies and strategies in the residential sector. The PON solicited projects that would deliver significant and measurable energy savings and GHG reductions for existing homes and residential buildings. PON 3127 sought proposals for multi-site demonstration or pilot projects that addressed the barriers to wider commercialization of various eligible heating, ventilation, and air conditioning (HVAC) systems in the existing residential building market (excluding new construction). This project focused on cold-climate air source heat pumps (ccASHPs), including ductless and ducted "mini-split" systems.

NYSERDA's goals for PON 3127 were threefold. First, to demonstrate the energy savings and GHG reductions resulting from switching to alternative heating technologies in multiple homes. Second, to further understand New York State-specific barriers to full-market adoption of these technologies. Third, to transfer the findings from the first two goals through a Technology Transfer process reaching market actors that could include customers, installer contractors, distributors, and manufacturers.

1.2 Program Approach

The following criteria and approach underlay the demonstration project:

- All buildings were in the downstate New York City area.
- Buildings were all 1–3 family residential.
- Space conditioning systems were fossil-fuel fired.
- Cold climate air source heat pumps (primarily ductless) were installed to meet all or nearly all the building heating and cooling load.
- Weatherization measures (insulation and air sealing) measures were implemented wherever possible, based on need and budget, but also dependent on owner preferences.
- An incentive of $5,250 was provided from the demonstration program to defray costs for the owner. This was combined with manufacturer discounts and other incentives (e.g., Weatherization Assistance Program) where possible.

TLP, with recruitment partner Centsible House, Inc., facilitated the demonstrations including the following activities.

1.2.1 Site Recruitment

Sites were screened and recruited based on evaluation criteria listed above. TLP issued a Site Recommendation Report for each site deemed acceptable, including address, ownership type, characteristics of the mechanical systems and building enclosure, assessment of the overall building condition, fuel type(s), other pertinent factors that might impact the value of the site to the project and the likelihood of follow-through. Once NYSERDA approved each site, TLP prepared a Site Agreement and executed it with the homeowner. A sample site agreement is provided in appendix A.

The project completed 20 demonstration sites in New York City, Yonkers, and Long Island. Sites selected include 1–3 family brick and wood frame homes, from 1–4 stories, and with 750–4,650 square feet of conditioned space. They included a roughly equal share of oil and gas-fired boilers for space heating and most used window or through-wall air conditioners for cooling.

1.2.2 Design

Once site agreements were executed, a site inspection was conducted to document existing building systems, thermal envelope properties, and take building measurements. These data included:

- Fuel bills for at least one year.
- Overall home measurements to capture areas for energy modeling and load calculations.
- Window areas and types.
- Wall and roof condition, material, and insulation details.
- Mechanical system type, efficiency, age, and condition—including heating, cooling, and ventilation.
- Observations of significant deficiencies in the home such as major disruptions in the air barrier, signs of mold, other hazards that may need mitigation to proceed (lead, asbestos, etc.).
- Interview with homeowner to ascertain goals, preferences, and thermal comfort in the home.

Based on the site information, a retrofit plan tailored to the needs of each building was prepared. Envelope improvements were identified based on the building's needs and owner budget. A Manual J load calculation was prepared to determine the heating and cooling loads of the building, after the planned envelope improvements. The retrofit plan identified a specific heat pump design and equipment selection (including location of indoor units in the home). Cost estimates for each measure were also included in the report summarizing the retrofit plan. The designs used between one and five condensing units and four to 12 indoor heads to form the HVAC layout, considering equipment capacity, compatibility, and installation feasibility. Wall-mounted indoor heads were used in most of the sites, while ducted units were installed at one home and ceiling cassettes at another.

1.2.3 Installation

Information was provided on financing to each homeowner. Sources included rebates from Con Edison and PSEG, a discount from Mitsubishi and an incentive from the NYSERDA demonstration project budget. The project team coordinated with equipment supplier partners and the contractor to deliver equipment as needed; install all measures; and document the retrofit. Heat pump installation was done by manufacturer-approved installers. Installers were instructed to comply with manufacturer installation guidelines, Northeast Energy Efficiency Partnerships (NEEP) cold climate air source heat pump installation recommendations, and applicable building codes.

NYSERDA's Air Source Heat Pump Commissioning Checklist (appendix A) was used to confirm installation quality. All installation measures and the final financial package were documented for each project site.

Education was crucial for residents switching from a boiler or furnace-based heating system to ductless heat pumps. The project team informed building residents about the existence, purpose, and operation of all installed measures. The team provided recommendations to occupants on preparing for the retrofits; and provided information to homeowners and tenants regarding proper use of the new heating and cooling systems.

2 Home Characteristics and Equipment Details

Twenty sites participated in this study. Figure 1 shows pictures of the all the homes. The houses were one to three family homes located in outer boroughs of New York City with some on Long Island and in Yonkers. First, this section describes the homes and provides the characteristics of the original heating and cooling systems. Second, the section describes the details of the heat pumps that were installed as well as weatherization improvements.

2.1 House Characteristics

Table 1 summarizes the style and size of each house along with the original heating fuel. Sites ranged in size from 750 square feet (sq ft) to 4,650 sq ft. Thirteen of the homes were detached single family homes and seven were attached, brownstone-style buildings. Half of the sites had oil-fired and half gas-fired space heating systems. None of the houses originally had central cooling except for S41. S41 also had a warm air furnace while the other houses had boilers with hydronic or steam distribution.

Table 1. Home Characteristics and Original Heating and Cooling Information

Site	City or Borough	Heated Area (sq ft)	House Type	Construction Type	No of Apts.	Space Heating Fuel	Water Heating Fuel
S1	Brooklyn	1,600	Attached	Masonry	2	Gas	Gas
S3	Brooklyn	4,650	Detached	Wood frame	1	Oil	Electric
S5	Brooklyn	3,370	Detached	Frame/stucco	1	Gas	Gas
S10	Brooklyn	4,512	Attached	Masonry	2	Oil	Oil
S12.1*	Brooklyn	1,628	Attached	Masonry	1	Gas	Gas
S12.2*	Brooklyn	814	Attached	Masonry	1	Gas	Gas
S14	Brooklyn	2,483	Attached	Wood frame	1	Oil	Oil
S18	Brooklyn	2,811	Attached	Masonry	2	Oil	Electric
S19	Brooklyn	1,318	Detached	Wood frame	2	Oil	Oil
S21	Brooklyn	1,700	Detached	Wood frame	2	Gas	Gas
S23	Bronx	2,792	Detached	Wood frame	1	Oil	Oil
S25	Queens	1,870	Attached	Masonry	1	Gas	Gas
S31	Bellmore	2,625	Detached	Wood frame	1	Gas	Gas
S32	Yonkers	1,350	Detached	Wood frame	1	Oil	Oil
S35	Bronx	1,700	Detached	Frame/stucco	1	Oil	Oil
S39	Broad Chan.	1,387	Detached	Wood frame	1	Oil	Oil
S40	Bronx	750	Detached	Wood frame	1	Gas	Gas
S41	Dix Hills	3,000	Detached	Wood frame	1	Gas	Gas
S44	Queens	1,920	Detached	Wood frame	1	Gas	Gas
S45	Queens	3,600	Brownstone	Masonry	3	Oil	Oil/Gas
S46	Brooklyn	2,400	Detached	Masonry	1	Gas	Gas

* Site S12 had two apartments with separate dedicated space conditioning boilers.

Figure 1. Pictures of Each Site

2.2 Heat Pump System Description: Costs and Sizing

Table 2 summarizes the heat pumps installed at each site. The systems included one to five outdoor units with up to twelve indoor heads or sections. All but one system used wall-mounted ductless units (one also used ceiling cassettes for a portion of the indoor units). Equipment was predominantly Mitsubishi and Fujitsu with one Daikin and one American Standard (Trane) ducted system (with an air handler).

2.2.1 Costs

Table 3 lists the installed costs for each heat pump system (the envelope improvement costs are given separately in Table 5). The costs that are rounded to the nearest $1,000 were estimated by TLP staff. The other costs were taken from contractor invoices. Only one of the sites required an electrical upgrade for the heat pump system (i.e., a new electrical panel). At two other sites the electrical panel was already upgraded as part of a larger gut rehab renovation project at the house. Costs are also summarized per nominal cooling ton, per indoor head, and per square foot of floor area. Cost per ton ranged from $2,824 to $6,550, with an average of $4,483. Costs per indoor head ranged from $2,000 to $5,219, with an average of $3,593. Costs per square foot ranged from $4.5 to $16.0, with an average of $10.6. The plots in Figure 2 show the distribution of costs per installed nominal cooling ton, per indoor head, and per square foot of floor area.

2.2.2 Equipment Sizing

Heat pump sizing was determined based on the Manual J load calculation method from the Air Conditioning Contractors Association (ACCA). The Manual J load calculations were either directly created by the team or created by the contractor and then verified by the team. The sizing process aimed for a total equipment heating/cooling capacity greater or equal to the total heating/cooling load, while not exceeding 30 percent of the load. This applies to both the sizing for the outdoor unit and the sizing for each indoor unit based on loads of each individual room. All the project homes have cooling loads that were lower than heating loads. The attached homes have very close cooling and heating loads. Considering this, the sizing process was mainly focused on the heating capacity and the heating load. The sizing goal was achieved for more than half of the 20 sites, the rest sites were either undersized or oversized due to the following reasons:

- Small homes are challenging, especially those with many bedrooms. For example, the minimum available size of an indoor unit is 7,000 British thermal units per hour (Btu/hr), while the load of a small bedroom could be less than 3,000 Btu/hr. This will result in more than 100 percent oversizing in that room. And because outdoor units must be sized based on total connected indoor capacity, this resulted in some small homes with overall equipment capacity at design temperature about 150 to 200 percent of the heating load.
- A few sites where the heat pumps had been installed prior to the project team's involvement were slightly undersized (equipment size was about 79% to 98% of the load) or oversized (equipment capacity was 130% to 198% of the total load).
- In a few instances the owner opted to undersize the overall system because they chose not to condition a specific space for cost or other reasons.
- Heat pump sizing and equipment selection sometimes had to change because of preference of installers and homeowners. This resulted in suboptimal equipment sizing.

Table 4 compares the design heating loads calculated for each house to the capacity data for the installed ccASHPs from the North East Energy Partnerships (NEEP) cold climate heat pump database (available at https://neep.org/heating-electrification/ccashp-specification-product-list). The design temperature assumed for the New York metro region for this project was 15°F (instead of the ACCA-provided design conditions of 17°F). The AHRI rated heating capacities (from the AHRI certificates) are given at 47°F and 17°F. This table compares the rated heating capacity at 17°F to the NEEP-provided maximum heating capacities at 17°F and 5°F. The heating sizing ratio provides a metric to determine how well the heat pump heating output matches the heating load. For these sites the sizing ratio was determined using:

$$\textbf{Heating Sizing Ratio} = \frac{\textbf{Heating Capacity Available at Design Conditions}}{\textbf{Heating Load at Design Conditions}} \approx \frac{\textbf{QH17\_max}}{\textbf{BHL}}$$

The average heating sizing ratio was 129% (matching the target of 130% mentioned above). The average sizing ratio for the 12 sites where the boiler remained in place was 119%. For the eight sites where the boiler was removed the average sizing ratio was 145%.

Table 2. ccASHP Installation Details at Each Site

Site Number	City or Borough	HP Install Date	Boiler Status?	No of Apts	# of Sections Out / In	Total Installed Capacity (Tons)	Ratings HSPF / SEER	Outdoor Unit Make and Model	Indoor Heads Make and Model
S1	Brooklyn	?	In-Place	2	2 / 6	5	9.4 / 17.1	AOU24RLXFZH[2], AOU36RLXFZH	ASU12RLF, AUU12RLF, AUU7RLF, AUU9RLF
S3	Brooklyn	11/29/2017	In-Place	1	3 / 7	6.5	10.3 / 18.7	MXZ3C24NAHZ[1], MXZ3C30NAHZ	MSZFH06NA/ MSZFH09NA/ MSZFH12NA
S5	Brooklyn	2/14/2018	In-Place	1	4 / 10	8.5	10.3 / 18.8	MXZ3C24NAHZ[1], MXZ3C30NAHZ	MSZFH06NA, MSZFH09NA, MSZFH12NA
S10	Brooklyn	4/5/2018	In-Place	2	3 /10	8	11.1 / 18.4	MXZ3C30NAHZ[1], MXZ3C36NAHZ	MSZFH06NA, MSZFH09NA, MSZFH12NA
S12	Brooklyn	11/29/2017	In-Place	2	3 / 8	6	10.0 / 19.0	MXZ3C24NAHZ2[1]	MSZFH06NA, MSZFH09NA, MSZFH12NA, MSZFH15NA
S14	Brooklyn	7/12/2018	Removed	1	3 / 7	6	10.0 / 19.0	MXZ3C24NAHZ[1]	MSZFH06NA, MSZFH15NA
S18	Brooklyn	4/17/2019	Removed	2	4 / 10	8	10.0 / 19.0	2MXL18QMVJU[3], 3MXL24RMJU	FTXS09LVJU, FFQ09Q2VJU, CTXS07LVJU
S19	Brooklyn	2/9/2018	Removed	2	2 / 5	4.5	10.5 / 18.5	MXZ3C24NAHZ[1] MXZ3C30NAHZ	MSZFH06NA, MSZFH12NA
S21	Brooklyn	7/12/2018	In-Place	2	2 / 4	3.3	10.8 / 20.4	MXZ3C24NAHZ[1], MUFZKJ15NAHZ	MSZFH06NA, MSZFH09NA, MSZFH12NA, MSZFH15NA
S23	Bronx	5/8/2018	In-Place	1	2 / 7	6	11.3 / 19.1	AOU36RLXFZ1H[2]	ASU7RLF1, ASU15RLF1

Notes:

For boiler status the boiler was either left “In-Place” or “Removed.”

Manufacturers: 1—Mitsubishi, 2—Fujitsu, 3—Daikin

See appendix B for more details about the number and location of each indoor head.

Table 2. continued

Site Number	City of Borough	HP Install Date	Boiler Status?	No. of Apts	No. of Sections Out / In	Total Installed Capacity (tons)	Ratings HSPF/ SEER	Outdoor Unit Make and Model	Indoor Heads Make and Model
S25	Queens	5/17/2018	Broken / Removed	1	2 / 8	6	11.3 / 19.1	AOU36RLXFZH[2]	ASU7RLP1, ASU9RLP1
S31	Bellmore	10/3/2018	In Place	1	2 / 7	5	9.9 / 18.0	AOU24RLXFZH[2], AOU36RLXFZ1H	ASU7RLP1, ASU9RLP1, ASU12RLP1
S32	Yonkers	10/4/2018	Removed	1	1 / 4	3	9.4 / 16.0	AOU36RLXFZ1H[2]	ASU7RLP1, ASU12RLP1
S35	Bronx	6/18/2019	In Place	1	1 / 6	4	11.4 / 19.8	AOU48RLAVM[2]	ASUA4TLVA1, ASUA7TLVA1, ASUA12TLVA1
S39	Broad Channel	4/3/2018	In Place	1	1 / 4	3	9.4 / 16.0	AOU36RLXFZ1H[2]	ASU7RLP1, ASU18RLP1
S40	Bronx	12/7/2018	Removed	1	1 / 3	2	10.3 / 20.0	AOU24RLXFZH[2]	ASU7RLP1, ASU12RLP1
S41	Dix Hill	2/5/2019	In Place	1	1 / ducted	4	10.0 / 18.0	AccuComfort[4] Platinum 18	Ducted AHU
S44	Queens	11/7/2018	Removed	1	2 / 5	4	10.8 / 20.4	AOU24RLXFZH[2]	ASU7RLP1, ASU12RLP1, ASU18RLP1
S45	Queens	11/7/2018	Removed	3	5 / 12	8.5	11.0 / 22.2	AOU12RLS3H[2], AOU18RLXFZH, AOU24RLXFZH	ASU7RLP1, ASU9RLP1, ASU12RLP1
S46	Brooklyn	11/26/2018	In Place	1	2 / 8	7	11.4 / 19.0	MXZ4C36NAHZ[1], MXZ8C48NA	MSZFH06NA, MSZFH12NA, MSZFH15NA

Notes:

For boiler status the boiler was either left “In-Place” or “Removed.”

Manufacturers: 1—Mitsubishi, 2—Fujitsu, 4—American Standard/Trane.

Table 3. ccASHP Installation Costs Each Site

Site	City or Borough	Number of Sections Out/In	Total Installed Nominal Cooling Tons	Heated Area (sq ft)	Electrical Upgrade Required?	Total HP System Installed Cost ($)	System Cost ($ per nominal ton)	System Cost ($ per Indoor Head or Section)	System Cost ($ per sq ft)
S1	Brooklyn	2 / 6	5	1,600	No	$23,900	$4,780	$3,983	$14.9
S3	Brooklyn	3 / 7	6.5	4,650	No	$32,148	$4,946	$4,593	$6.9
S5	Brooklyn	4 / 10	8.5	3,370	Yes	$52,190	$6,140	$5,219	$15.5
S10	Brooklyn	3 /10	8	4,512	No	$35,783	$4,473	$3,578	$7.9
S12	Brooklyn	3 / 8	6	2,442	No	$37,130	$6,188	$4,641	$15.2
S14	Brooklyn	3 / 7	6	2,483	No	$23,030	$3,838	$3,290	$9.3
S18	Brooklyn	4 / 10	8	2,811	Gut Rehab	$25,083	$3,135	$2,508	$8.9
S19	Brooklyn	2 / 5	4.5	1,318	No	$20,000	$4,444	$4,000	$15.2
S21	Brooklyn	2 / 4	3.3	1,700	No	$17,874	$5,416	$4,469	$10.5
S23	Bronx	2 / 7	6	2,792	No	$21,576	$3,596	$3,082	$7.7
S25	Queens	2 / 8	6	1,870	No	$22,000	$3,667	$2,750	$11.8
S31	Bellmore	2 / 7	5	2,625	No	$23,000	$4,600	$3,286	$8.8
S32	Yonkers	1 / 4	3	1,350	Gut Rehab	$12,000	$4,000	$3,000	$8.9
S35	Bronx	1 / 6	4	1,700	No	$25,000	$6,250	$4,167	$14.7
S39	Broad Chan	1 / 4	3	1,387	No	$12,000	$4,000	$3,000	$8.7
S40	Bronx	1 / 3	2	750	No	$12,000	$6,000	$4,000	$16.0
S41	Dix Hills	1 / ducted	4	3,000	No	$13,444	$3,361		$4.5
S44	Queens	2 / 5	4	1,920	Unknown	$16,000	$4,000	$3,200	$8.3
S45	Queens	5 / 12	8.5	3,600	No	$24,000	$2,824	$2,000	$6.7
S46	Brooklyn	2 / 8	7	2,400	No	$28,000	$4,000	$3,500	$11.7

Notes: For electrical upgrade column, two homes had larger gut rehab renovation projects that resulted in a new electrical panel.

Figure 2. Distribution of Heat Pump Costs per Ton, per Indoor Section or Head, and per Square Feet

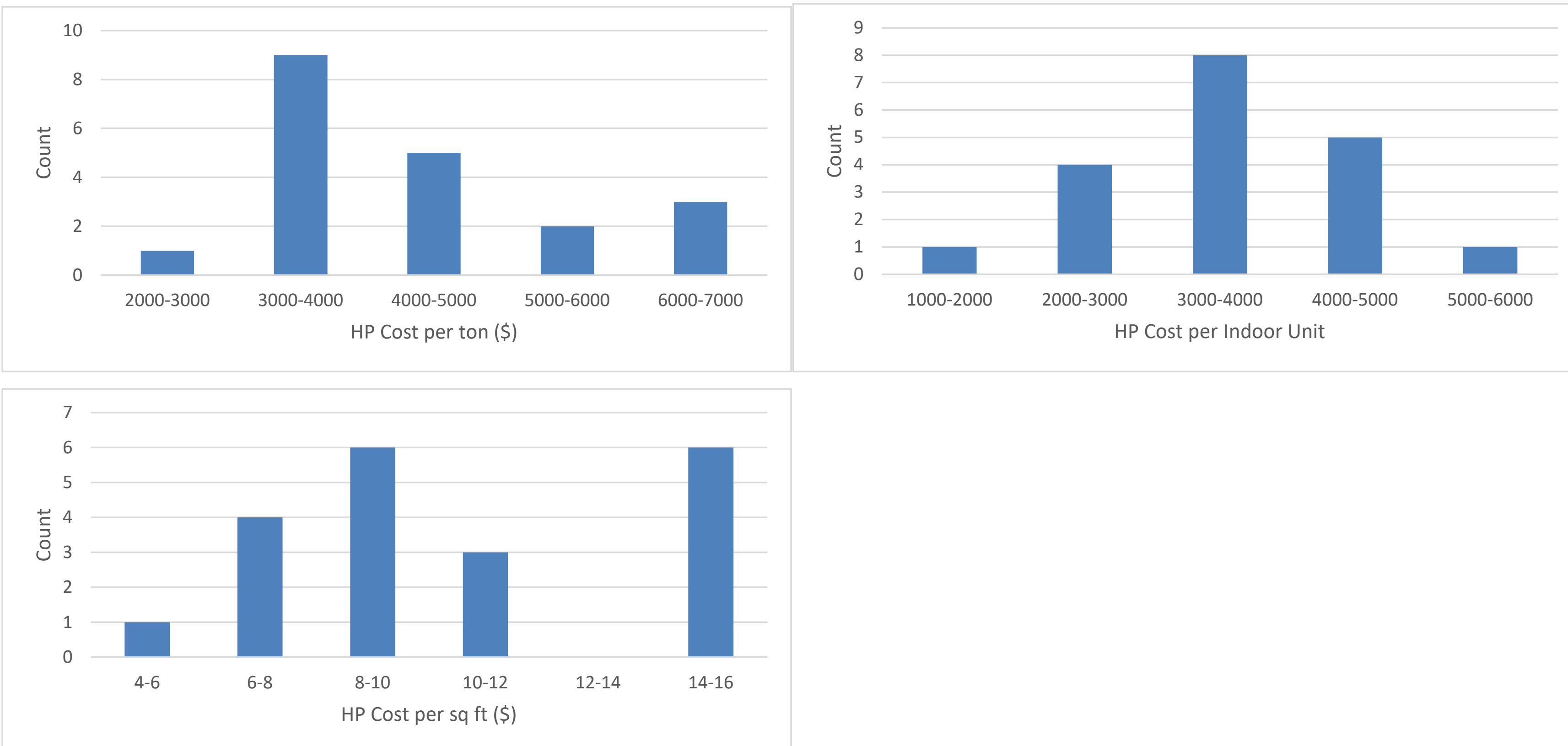


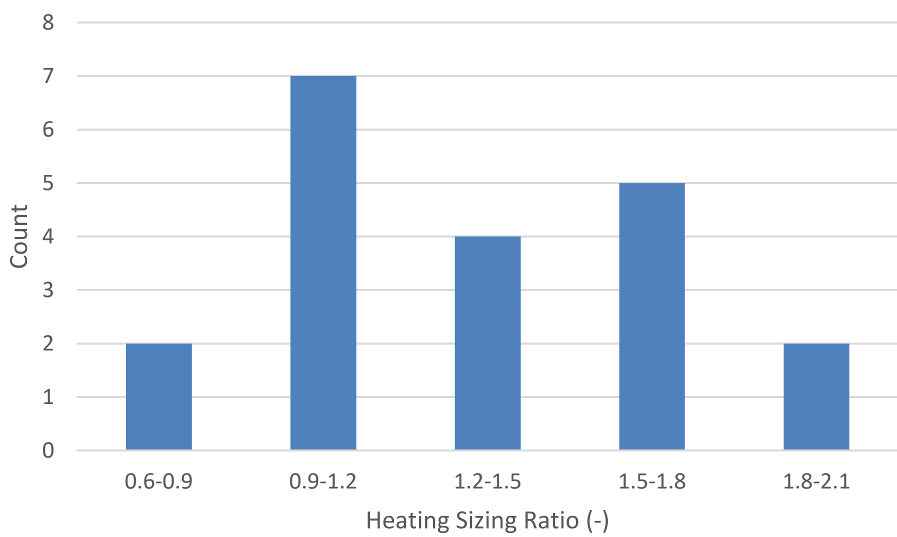
Table 4. Heating Capacities Compared to Design Loads for ccASHP

		QC	BHL	QH5_max	QH17_rated	QH17_max	QH17_max / BHL	QH5_max / QC
Site	City or Borough	Total Installed Nominal Cooling Tons	Design Heating Load at 15°F (Btu/h)	Max Heating Capacity at 5°F (Btu/h)	Rated Heating Capacity at 17°F (Btu/h)	Max Heating Capacity at 17°F (Btu/h)	Heating Sizing Ratio (%)	H-C Capacity Ratio (%)
S1	Brooklyn	5	42,998	61,907	36,800	65,341	152%	103%
S3	Brooklyn	6.5	99,462	78,600	46,000	78,600	79%	101%
S5	Brooklyn	8.5	80,226	103,600	60,000	103,600	129%	102%
S10	Brooklyn	8	110,633	102,200	70,000	102,200	92%	106%
S12	Brooklyn	6	74,167	75,000	42,000	75,000	101%	104%
S14	Brooklyn	6	76,224	75,000	42,000	75,000	98%	104%
S18	Brooklyn	8	51,660	81,060	55,660	100,520	195%	84%
S19	Brooklyn	4.5	53,612	53,600	32,000	53,600	100%	99%
S21	Brooklyn	3.3	43,095	43,000	28,400	45,000	104%	109%
S23	Bronx	6	54,411	72,814	42,800	78,682	145%	101%
S25	Queens	6	50,434	72,814	42,800	78,682	156%	101%
S31	Bellmore	5	41,397	61,907	36,800	65,341	158%	103%
S32	Yonkers	3	20,009	36,407	21,400	39,341	197%	101%
S35	Bronx	4	45,252	41,300	33,000	50,000	110%	86%
S39	Broad Chan	3	31,967	36,407	21,400	39,341	123%	101%
S40	Bronx	2	23,694	25,500	15,400	26,000	110%	106%
S41	Dix Hills	4	47,871	29,200	36,600	37,600	79%	61%
S44	Queens	4	37,926	51,000	30,800	52,000	137%	106%
S45	Queens	8.5	69,456	115,000	70,000	119,000	171%	113%
S46	Brooklyn	7	53,864	77,000	67,000	81,600	151%	92%

Notes: Heating design loads confirmed by independent Manual J calcs by TLP staff.
Capacity data for the ccASHP units taken from the NEEP database (circa 2019).

The NYS Clean Heat Program, which launched after these 20 projects were completed, now requires that the heating sizing ratio to be between 90 and 120% before eligibility in the Category 2: Full-Load Heating Incentives. Only 7 of the 20 sites met that program sizing criteria. Figure 3 shows the distribution of sizing ratios for this project.

Figure 3. Distribution of Heat Pump Sizing Ratio

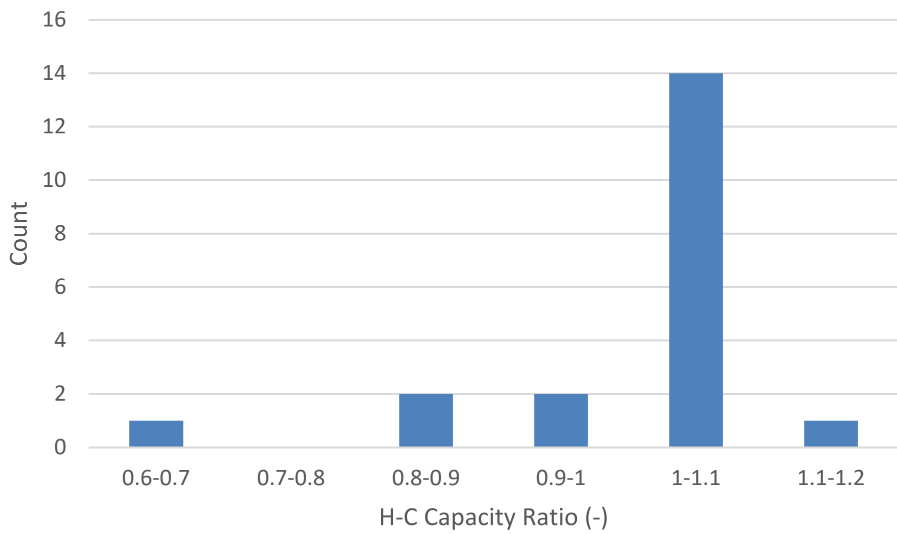


2.2.3 Equipment Capacity Ratios

Another important metric can help to understand how the available heating capacity compares to the nominal cooling capacity (or the size) of the ccASHP unit. In Table 4, the nominal cooling capacity at rated conditions (QC) is expressed in tons. The dimensionless heating-to-cooling capacity ratio divides the maximum heating capacity at 5°F (QH5_max) by QC. Figure 4 shows the distribution of the heating and cooling (H-C) capacity ratios. The ratios are very close to unity for all the ductless units, in part because the manufactures choose to reduce the rated capacity for cooling in a way that maximizes the SEER. The ducted unit (S41) reflects the more traditional approach, making the rated cooling capacity equal to the maximum possible cooling output. In this case, the H-C capacity ratio is 61%.

A detailed bin analysis using NEEP-listed data for all cold climate air source heat pumps in the white paper developed to support the NY Technical Resource Manual (Henderson 2020a) showed discrepancies between the rated Seasonal Energy Efficiency Rating (SEER)_ and the predicted seasonal cooling performance, due to how manufacturers choose to rate the cooling capacity for their units. Appendix F in the white paper describes that the very high SEER ratings of many ductless ccASHP do not actually translate into a higher seasonal-cooling efficiency to the degree the SEER rating would suggest. That analysis also links the H-C ratio to the especially optimistic SEER values.

Figure 4. Distribution of Heat Pump H-C Capacity Ratio (QH5_max per Nominal Cooling)



2.3 Weatherization Improvements

Table 5 describes the envelope improvements implemented at each site along with the energy savings estimated by the weatherization contractor. The energy savings associated with weatherization is important because the analysis factors that into the analysis to predict heat pump performance and impact. For many sites the weatherization contractor reported the fuel savings for insulation and envelope-air leakage reduction separately. For three sites (S40, S44, and S45), only the reduction in the Manual J peak heating load was reported by the contractor. In these cases, the analysis assumed the fuel reduction from weatherization was proportional to the reduction of the Manual J peak load.

The simple paybacks for the weatherization measures alone ranged from 5 to 140 years, with an average of 23 years and a median of 24 years.

Table 5. Summary of Envelope Improvements at Each Site

Site Numbers	City or Borough	Insulation Improvements	Infiltration Improvements	Envelope Savings	Infiltration Savings	Man J Load Reduction	Total Energy Savings	Total Installed Costs
S1	Brooklyn	None	8,885 to 7,500 cfm50		85 therms		85 therms	Unknown
S3	Brooklyn	Knee Wall & Rim joist	15,731 to 9,371 cfm50	19 gal	440 gal		459 gal	$5,500
S5	Brooklyn	Rim joist	14,923 to 5,594 cfm50	10 therms	688 therms		697 therms	$5,500
S10	Brooklyn	Attic and rim joist	20,019 to 14,313 cfm50	59 gal	342 gal		401 gal	$10,736
S12	Brooklyn	Various walls	5,979 to 4,710 cfm50	89 therms	90 therms		179 therms	$10,000
S14	Brooklyn	Gut Renovation	6,680 to 5,520 cfm50	308 gal	76 gal		384 gal	$28,431
S18	Brooklyn	Gut Renovation	12,684 to 8500 cfm50	168 gal	275 gal		443 gal	$26,500
S19	Brooklyn							
S21	Brooklyn	Rim Joist	5,670 to 4500 cfm50	28 therms	94 therms		12 therms	$5,500
S23	Bronx	Attic floor, walls, ceiling	2,373 to 1,750 cfm50	328 gal	23 gal		351 gal	$13,596
S25	Queens	Ceiling and Wall	4,711 to 4000 cfm50	85 therms	64 therms		149 therms	$7,350
S31	Bellmore							
S32	Yonkers	None	6,525 to 2,320 cfm50		244 gal		244 gal	$3,500
S35	Bronx							
S39	Broad Channel							
S40	Bronx	Roof cavity and crawl space	3,750 to 2,000 cfm50		150 therms	33%	287 therms	$9,750
S41	Dix Hill	Air Sealing, wall, attic, basement insulation					unknown	$14,357
S44	Queens	Extensive renovation				20%	234 therms	Unknown
S45	Queens	Wall, Attic, Windows				26%	149 therms	$10,000
S46	Brooklyn							

Notes: Sites with shaded rows had no weatherization improvements. cfm50 is the leakage airflow at 50 pascals.

2.4 Quality Assurance (QA) Efforts for ccASHP Installations

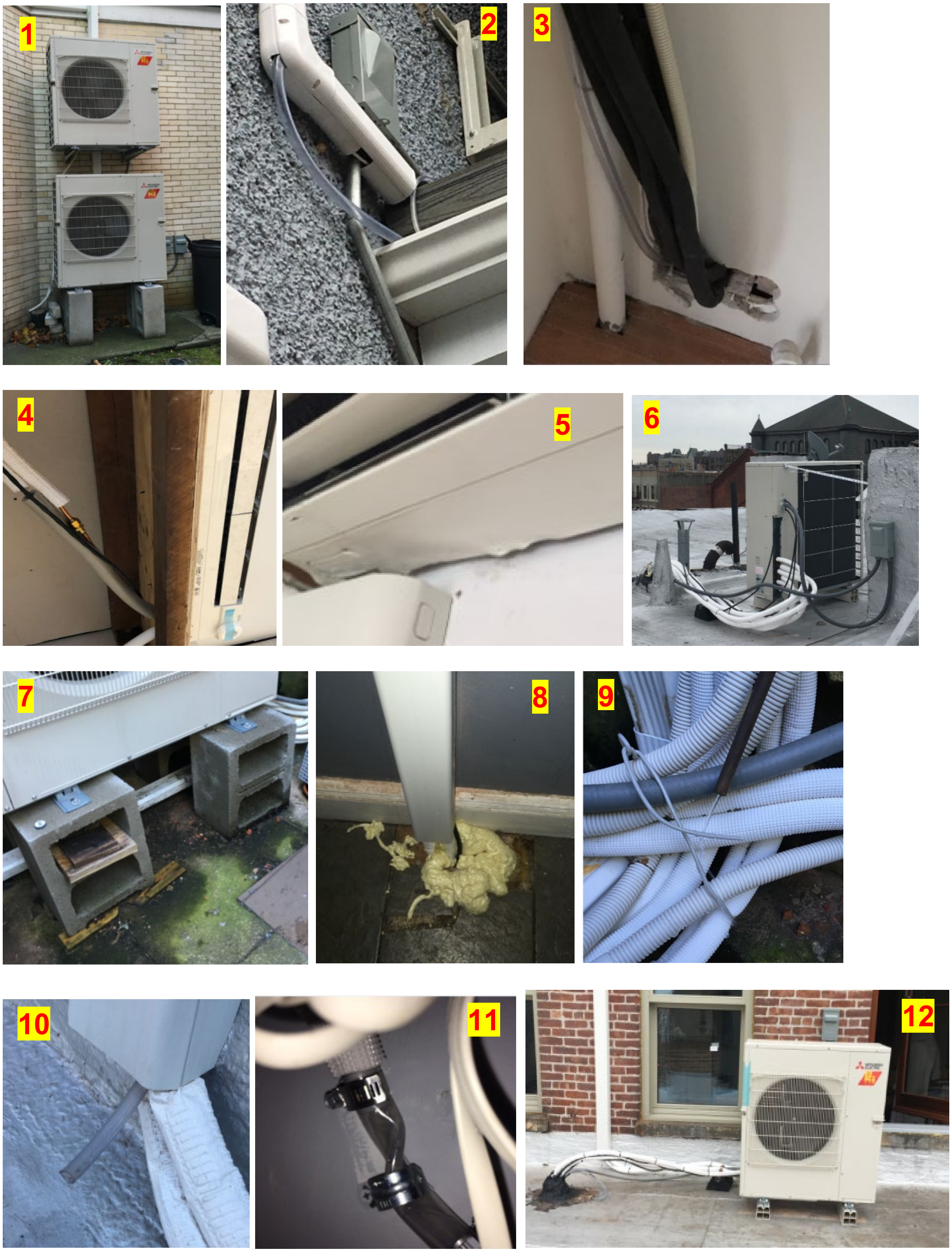
TLP staff provided feedback to the contractors during the design process as well as at the end of the installation process. Table 6 lists installation faults identified during inspections of completed projects. A number of these issues were found on multiple projects, chief among them were items relating to the installation of the outdoor unit and problems with condensate lines. Contractors were called back to correct all issues. Quality inspections of contractor installations are crucial to ensure problem-free results and as part of the education process for installers.

Table 6. List of Identified Installation Faults

Type of Defect (Numbers in parentheses correspond to photo number in Figure 5)		**Sites Affected (Site No.)**
Outdoor Unit	Incorrect placement of condensers (stacking) (1)	S3
	Incorrect support/fastening of condensers (blocks, scrap wood) (7, 12)	S3, S12, S21, S10
	Ground clearance of condensers (6, 12)	S5, S21, S10
Condensate	Condensate tube drains to improper location (2)	S12, S10
	Condensate leak at evaporator	S14, S10
	Condensate tubing—flex plastic instead of copper/PVC (2, 9, 10, 11)	S3, S21, S10
Refrigerant Lines	Inadequate sealing of wall/floor penetrations (3, 8)	S5
	Line cover (or portion) missing (3)	S12
	Inadequate or missing refrigerant pipe insulation (4)	S5, S14
Other	Refrigerant leak	S5, S3, S14, S35, S45
	Damage to evaporator/lubricant leakage (5)	S12
	Noisy outdoor unit	S10

Figure 5. Photos of Installation Faults

Numbers are aligned to descriptions in Table 6.



3 Results: Energy Impacts and Cost Savings

3.1 Monitoring Approach

A performance validation plan was written at the beginning of the project to arrive at a common understanding among the team concerning what measured data would be collected from each site and how it would be used to quantify the energy, emissions, and utility cost impacts as well as performance of each ccASHP site. The plan is given in appendix C.

The overall monitoring approach in this study was to use a pre- and post-retrofit comparison to quantify the impact of installing the ccASHP in the home. Inherent in this approach is the assumption that the occupants maintain similar set points and generally have similar behavior in the pre- and post-periods.

In the post-retrofit period, power metering was installed to measure ccASHP electric use. HOBO® battery-powered data loggers (http://www.onsetcomp.com/) were installed along with Wattnode® power meters (http://www.ctlsys.com/) to collect data at 15-minute intervals. The analysis determined daily ccASHP energy use and correlated it to daily outdoor temperature data from a nearby weather station. Similarly, fuel delivery logs and/or monthly utility fuel bills from before the ccASHP installation (pre-retrofit) were also correlated to outdoor temperatures from a nearby weather station. Typically, the analysis had to account for baseline fuel use by non-space-heating uses, such as domestic water heating. Then these pre- and post-retrofit trends were used with a temperature bin analysis using typical-year weather data for the same local weather station. From this bin analysis the team could determine:

- Pre-retrofit and post-retrofit fuel use for space heating in a typical year.
- ccASHP electric use for space heating (and cooling) in a typical year.
- Annual fuel savings.
- Annual cost savings.
- Reductions in greenhouse gas emissions.

For many of these sites, building envelope or weatherization improvements were also implemented at the same time as the ccASHP installation. This confounded our ability to discern heat pump impact separately from the envelope improvement impacts. Therefore, the analysis used the estimate of envelope energy savings provided by the weatherization contractor. Then the inferred annual fuel reduction associated with the heat pumps was defined as:

[Inferred HP fuel savings] = [MEASURED fuel savings] - [ESTIMATED fuel savings from envelope]

At some sites (S5 and S10) the team was able to complete a flip-flop test—where the homeowners switched back to using the boiler after the heat pumps were installed—to independently determine the impact that weatherization had on boiler fuel use. This provided a check on the savings estimated by the weatherization contractor, which is discussed further in section 3.

The inferred heat pump fuel savings could be used with heat pump electricity use to infer the seasonal average heating efficiency for the ccASHP system.

Table 7 summarizes the power measurements made at each home along with the boiler runtime. Boiler runtime measurements were most useful/meaningful for oil-fired systems. Typically, there was one power transducer per heat pump system, though at one site, two heat pump systems were measured with one transducer. The monitoring start date and the duration of monitoring is also given.

Table 7. Metered Electric End Uses at Each Home

Site	Monitoring Start Date	Months of Data	Closest Weather Station	Base Fuel	No. of HPs	No. of Power Measurements	Boiler Runtime Measurements
S1	8/15/2019	12.5	JFK	Gas	2	2	-
S3	12/18/2017	15	JFK	Oil	3	3	1
S5	4/11/2018	21	JFK	Gas	4	4	
S10	4/11/2018	28	JFK	Oil	3	3	1
S12	12/18/2017	15	JFK	Gas	3	3	
S14	8/16/2018	24	JFK	Oil	3	3	
S18	3/14/2019	10	JFK	Oil	4	4	
S19	4/11/2018	14	JFK	Oil	2	2	
S21	8/16/2018	23	JFK	Gas	2	1 (2 HPs)	1
S23	4/12/2018	13.5	LGA	Oil	2	2	1
S25	4/12/2018	15	LGA	Gas	2	2	
S31	8/23/2018	12.5	JFK	Gas	2	2	1
S32	8/23/2018	16	LGA	Oil	1	1	
S35	6/3/2019	12.5	JFK	Oil	1	1	1
S39	3/18/2018	17	JFK	Oil	1	1	1
S40	12/3/2018	20.5	LGA	Gas	1	1	
S41	12/20/2018	20	ISP	Gas	1	1	1
S44	8/15/2018	16	LGA	Gas	2	2	
S45	8/15/2018	16	LGA	Oil	5	5	
S46	12/4/2018	21	JFK	Gas	2	2	

For some of the power measurements, the team only measured power using a single CT (current transducer) on one leg of a 240-volt load—and then measured the voltage relative to neutral. This single CT approach requires a multiplier of two and relies on the voltages of the two 120-volt legs (L1 and L2) in the circuit panel that are very similar with no neutral current. On previous field monitoring projects, including the EFG (Energy Futures Group) field testing project in NYSERDA Report 22-08, the team found that the L1 and L2 voltages are typically within 1–2 volts of each other. As a result, there is very little error when using the single CT approach.

The team returned to the sites to manually collect data from the battery-powered HOBO® data loggers at approximately the six-month point, and then again at the last site visit. At the final visit all the power transducers were removed. HOBO® loggers installed to measure space conditions (temperature and humidity) were manually collected at the same times.

3.2 Weather Data and Utility Electric/Fuel Costs

The team associated each site with a nearby weather station (either John Fitzgerald Kennedy (JFK), LaGuardia (LGA) or Islip (ISP) airports). Local utility costs are listed in Table 8. These costs are from NYSERDA's Energy Analysis group and were used for the ASHP Proforma Tool (circa 2020) that is used to calculate cost savings for the purposes of determining a savings to investment ratio and subsequently loan approval.

Table 8. Utility Fuel Costs

Utility Region	Electric Cost ($/kWh)	Natural Gas Cost ($/therm)	Fuel Oil Cost ($/gal)
NYC	0.20	1.4032	2.4471

Note: The costs for NYC were also used for the Nassau and Westchester County homes as well.

3.3 Detailed Analysis Heating Results for Representative Sites

A detailed analysis of the data collected from each site is included in appendix D. The sections below highlight the analysis process for two example sites:

- S10, a home that installed three multi-head ccASHP units and had envelope improvements implemented at the same time. A flip-flop test allowed the team to confirm the estimated savings due to building envelope.
- S21, a home where the two heat pumps operated for the first few months of the first winter. Then homeowner switched back to mostly using the boiler.

3.3.1 **Analysis of Site S10** (Replacing Oil Heat)

This 4,512 sq ft two-family home originally used an oil boiler with conventional baseboard radiation. Three electric heat pumps with a total nominal capacity of 8 tons were added to the home in March 2018. The oil boiler remained in place to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on April 11, 2018, to collect data at 15-minute intervals. The house also had proposed weatherization improvements (air sealing, insulation) that were projected to save 401 gallons of oil per year.

Table 9 summarizes the energy use of the heat pumps across the period. Figure 6 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 7 shows daily energy use of all the heat pumps. Since the boiler was monitored, a plot for daily runtime is also provided.

Table 9. Summary of Monthly Heat Pump Energy Use and Boiler Runtime at S10

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	HP3 (kWh)	Boiler (hrs)
Apr-18	65%	709.4	314.1	299.8	95.5	-
May-18	100%	362.0	108.2	141.0	112.8	-
Jun-18	100%	557.5	267.7	148.0	141.8	-
Jul-18	100%	991.3	149.8	496.1	345.4	-
Aug-18	100%	993.8	121.4	486.2	386.2	-
Sep-18	100%	602.0	153.1	212.8	236.1	-
Oct-18	100%	1,143.7	401.8	512.1	229.8	-
Nov-18	100%	2,458.6	903.4	973.3	581.9	11.4
Dec-18	100%	2,849.1	949.6	1,264.3	635.3	28.4
Jan-19	100%	3,349.1	1,377.5	1,469.8	501.8	82.4
Feb-19	71%	1,930.7	688.6	955.1	287.0	35.8
Mar-19	100%	2,797.2	906.3	1,326.2	564.7	26.5
Apr-19	100%	1,346.7	317.4	760.3	269.0	-
May-19	100%	966.1	192.8	557.0	216.4	-
Jun-19	100%	465.2	128.6	150.6	186.0	-
Jul-19	100%	1,066.1	395.6	261.0	409.5	-
Aug-19	100%	969.1	261.8	356.2	351.2	-
Sep-19	100%	543.2	160.5	164.9	217.9	-
Oct-19	100%	745.7	269.3	283.6	192.8	1.2
Nov-19	100%	2,244.4	820.7	1,011.8	411.9	27.0
Dec-19	100%	2,422.2	973.9	1,168.8	279.5	67.2
Jan-20	100%	3,111.4	1,092.8	1,371.6	647.0	56.9
Feb-20	104%	2,845.0	968.0	1,310.0	567.0	46.6
Mar-20	100%	2,385.7	659.8	1,204.4	521.4	6.5
Apr-20	100%	2,109.4	642.4	1,068.1	398.9	-
May-20	100%	1,224.6	181.3	831.7	211.7	-
Jun-20	100%	624.7	207.1	117.9	299.8	-
Jul-20	100%	903.8	342.2	104.9	456.7	-
Aug-20	80%	524.6	193.8	83.3	247.4	-
Annual	100%	19,522.3	6,487.7	8,722.0	4,312.9	225.4
Summer (Jun-Sep)		3,043.6	946.5	932.7	1,164.6	-
Winter (Oct-May)		16,478.7	5,541.2	7,789.3	3,148.3	225.4

Figure 6. Plot of Power Use for All HPs at S10

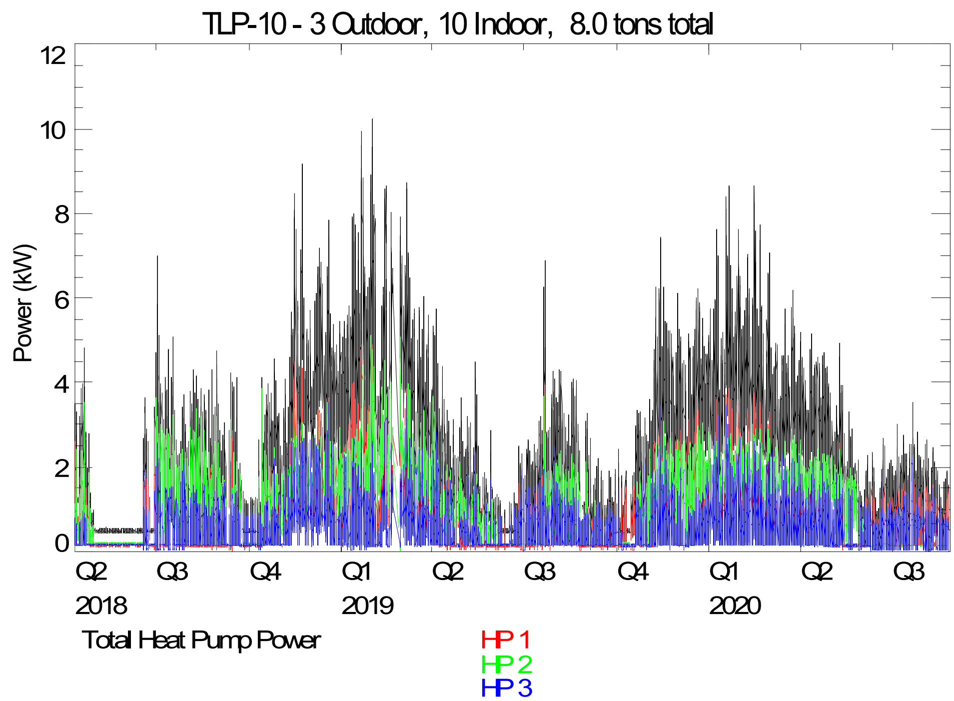


Figure 7. Plot of Daily Total HP Electric Use and Daily Boiler Operation at S10

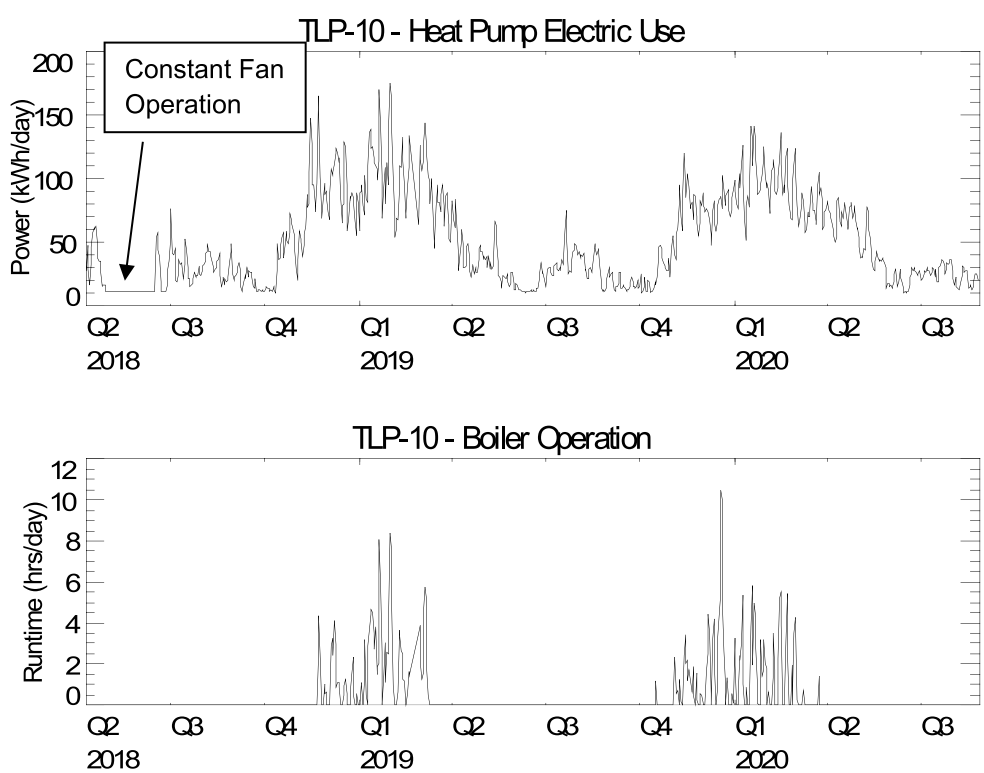


Figure 8 shows daily electric use for all the heat pumps versus the daily average ambient temperature using JFK Airportweather data. The data for each month are shown with different colors. Different symbol types are used for each year.

Figure 9 shows the correlation between daily boiler runtime and the daily average ambient temperature from JFK airport. The same colors and symbols were used to represent months and years as described above.

From February 20 to 28, 2019 the team conducted a flip-flop test where the heat pumps were turned off and the boiler picked up the house heating load. This flip-flop test allowed us to independently estimate the energy savings associated with the envelope improvements alone by comparing this period to the pre-retrofit heating oil consumption data. The days with higher boiler runtime during the flip-flop test are highlighted on Figure 9.

Figure 8. Daily HP Electric Use versus Outdoor Temperature at S10

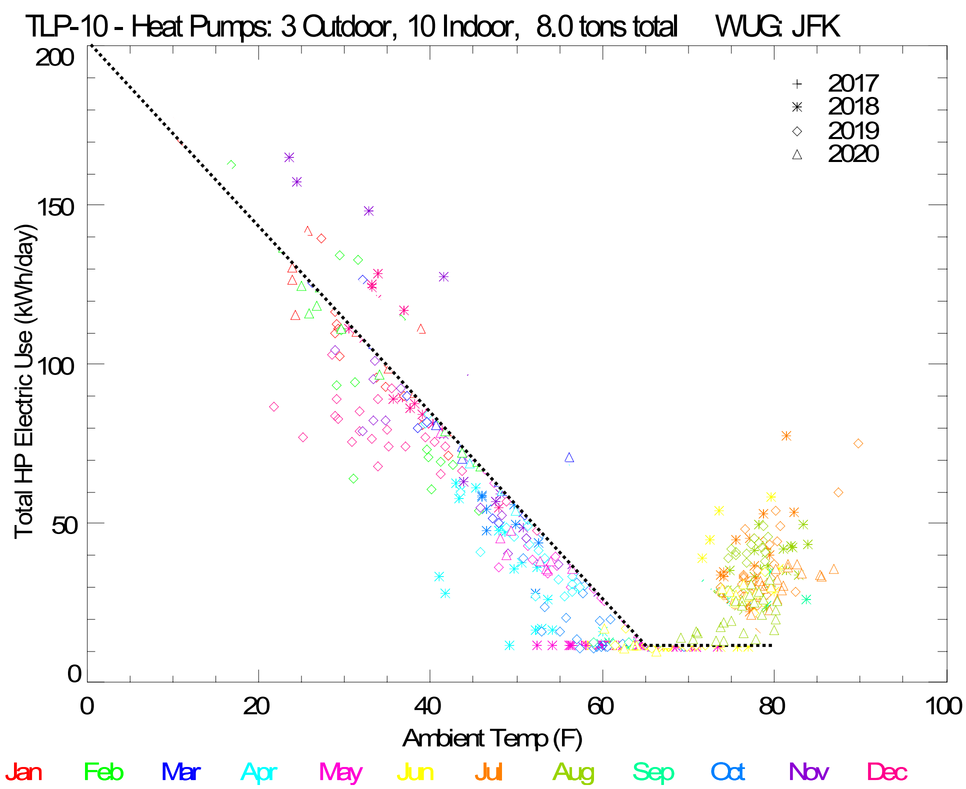


Figure 9. Daily Oil Use versus Outdoor Temperature at S10

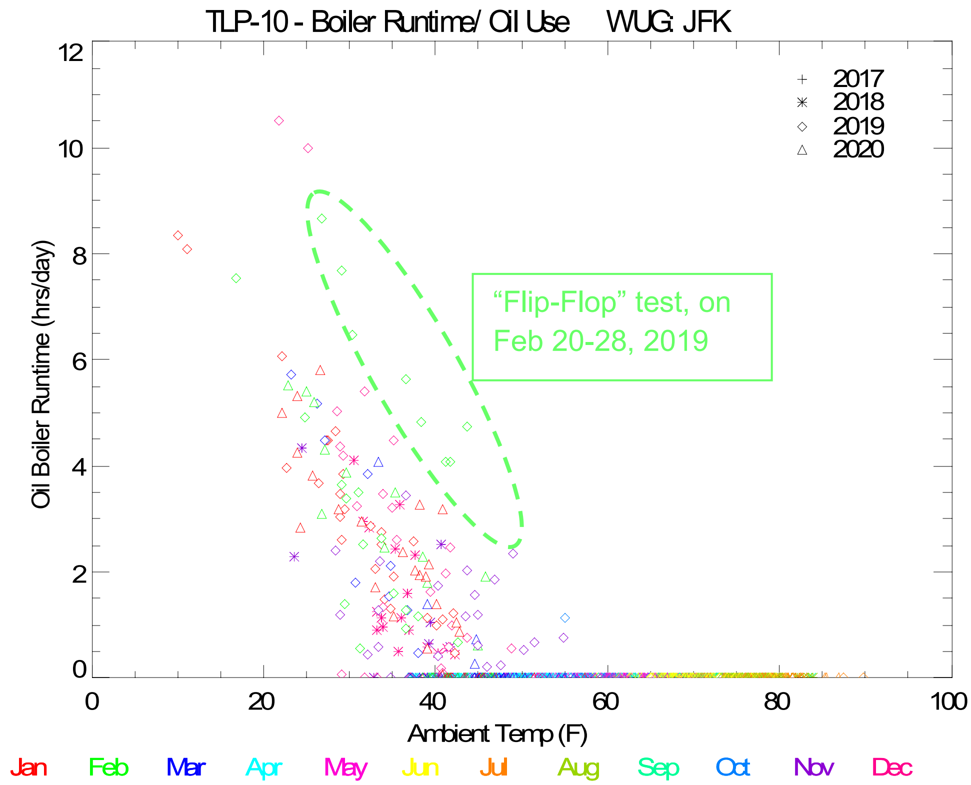
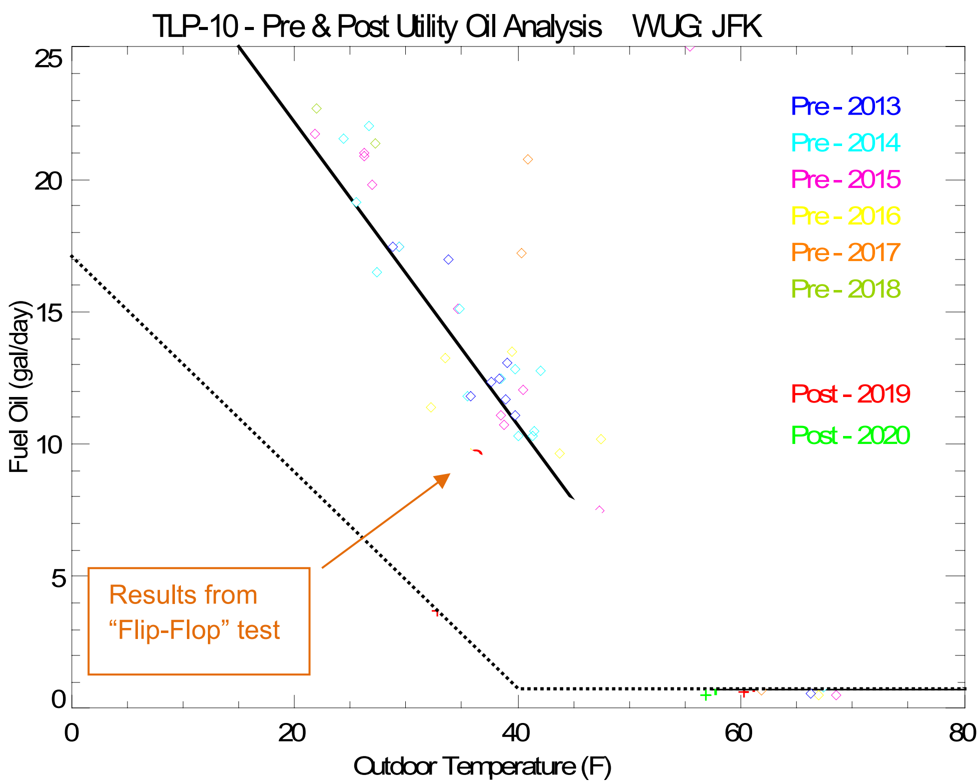


Figure 10 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. There are only three post-retrofit oil readings on the plot. The dotted line is the approximate best fit to those values while maintaining the same baseline summer use as in the pre-retrofit period.

The orange symbol on Figure 10 shows the results of the flip-flop test. The average oil consumption during the test was nine gallons/day and the average temperature over the eight-day period was 35.4°F. The results confirm a reduction in heating energy use relative to the black line (pre-retrofit), which would seem to be in line with the estimated envelope savings of 401 gallons per year (or a 29% reduction compared to pre-retrofit) from the weatherization proposal (shown in Table 5).

Figure 10. Trend of Oil Use with Outdoor Temperature, Using Fuel Delivery Logs from Pre- and Post-Retrofit Periods at S10



3.3.1.1 Annual Savings Analysis

The linear trends from the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Table 10 incorporates the linear trends versus outdoor temperature assumed for oil use in both pre- and post-retrofit periods (from Figure 10) as well as piecewise linear trend for post-retrofit electric use of the heat pumps (from Figure 8). The pre- and post-retrofit costs are expressed as dollars per day and shown for illustrative purposes.

Table 10. Bin Analysis of HP Savings Using TMY3 Weather for JFK Airport at S10

SITE: **TLP-10** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Oil** $ 2.447 per gal

Floor Area **4512**

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	49.3	28.3	282.4	28.3	2.2	120.5	125.8	
-22.5	0	46.4	26.3	267.8	26.3	2.2	113.5	117.9	
-17.5	0	43.5	24.3	253.2	24.3	2.2	106.6	110.0	
-12.5	0	40.7	22.2	238.5	22.2	2.3	99.6	102.1	
-7.5	0	37.8	20.2	223.9	20.2	2.3	92.6	94.1	
-2.5	0	35.0	18.1	209.3	18.1	2.4	85.6	86.2	
2.5	0	32.1	16.1	194.7	16.1	2.4	78.6	78.3	
7.5	20	29.3	14.0	180.1	14.0	2.5	71.6	70.4	
12.5	22	26.4	12.0	165.5	12.0	2.6	64.7	62.4	
17.5	101	23.6	9.9	150.8	9.9	2.6	57.7	54.5	
22.5	167	20.7	7.9	136.2	7.9	2.8	50.7	46.6	
27.5	247	17.9	5.9	121.6	5.9	2.9	43.7	38.7	
32.5	475	15.0	3.8	107.0	3.8	3.1	36.7	30.7	
37.5	855	12.2	1.8	92.4	1.8	3.3	29.8	22.8	
42.5	708	9.3	0.8	77.8	0.8	3.2	22.8	17.4	
47.5	608	6.5	0.8	63.2	0.8	2.6	15.8	14.5	
52.5	880	3.6	0.8	48.5	0.8	1.7	8.8	11.5	
57.5	750	0.8	0.8	33.9	0.8	0.0	1.8	8.6	
62.5	814	0.8	0.8	19.3	0.8	0.0	1.8	5.7	
67.5	723	0.8	0.8	12.0	0.8	0.0	1.8	4.2	
72.5	751	0.8	0.8	12.0	0.8	0.0	1.8	4.2	

Table 11 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 1,389 gallons per year for all improvements. The next step is to subtract the oil savings for the envelope improvements to determine that the fuel savings attributable to the heat pumps is 989 gallons per year. The heat pumps are estimated to use 13,110 kilowatts (kWh) per year, excluding the continuous indoor fan power (i.e., indoor fan power had to be excluded during the hours when the heat pump compressor was off to find a realistic value of COP. It is not clear why the occupants choose to operate the indoor fans continuously). From this, the analysis can estimate the implied coefficient of performance (COP) of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency for the existing oil-fired system) and dividing by the heat pump power input. In this case the implied COP is 2.2. The summary statistics show that the actual, measured heat pump power use was 26% greater than the estimated use from the bin analysis. This discrepancy was mostly attributable to the constant fan power when the unit was off—which was excluded in the bin analysis.

Table 11. Summary of Predicted Heating Season Impacts of the Heat Pumps at S10

Heating Only TLP-10	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	1,649	260	401	1,389	989
HP Electric (kWh/yr)		13,110		(13,110)	
Total Heating Costs	$ 4,035	$ 3,257	$ 980	$ 778	$ (202)
Implied Seasonal COP				3.1	2.2

Summary Statistics	
0.37	Htg gal per sq ft per year
42.7	Htg MBtu per sq ft per year
84%	Reduction in Htg Fuel Use
16,479	Measured HP Electric (kWh/yr)
126%	of typical year kWh

3.3.2 **Analysis of Site S21** (Change in Heat Pump Operation)

This 1,700 sq ft two-family home originally used a gas boiler with conventional baseboard radiation. Two electric heat pumps with a total capacity of 3.3 tons were added to the home in mid-2018. The gas boiler was also upgraded to a high-efficiency unit to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on August 16, 2018, to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, rim joist) implemented that were projected to save 122 therms per year.

Table 12 summarizes the energy use of the heat pumps across the period. Note that both heat pumps were measured as one power channel. Figure 11 shows the daily energy use of the all the heat pumps. Both Table 12 and Figure 11 show there was almost no heat pump use in the second winter. The occupants decided to switch back to primarily using the boiler for heating, because, according to the homeowners, their cat liked the warm floors with boiler operation.

Table 12. Summary of Monthly Heat Pump Energy Use and Boiler Runtime at S21

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	Boiler (hrs)
Aug-18	50%	278.1	278.1	4.8
Sep-18	100%	325.3	325.3	10.4
Oct-18	100%	455.1	455.1	14.2
Nov-18	100%	1,214.2	1,214.2	65.0
Dec-18	100%	1,412.0	1,412.0	373.8
Jan-19	100%	1,214.9	1,214.9	593.2
Feb-19	100%	1,022.2	1,022.2	522.2
Mar-19	100%	1,061.2	1,061.2	460.0
Apr-19	100%	345.5	345.5	181.8
May-19	100%	183.0	183.0	69.7
Jun-19	100%	299.4	299.4	12.6
Jul-19	100%	514.3	514.3	10.1
Aug-19	100%	332.6	332.6	10.7
Sep-19	100%	235.4	235.4	15.4
Oct-19	100%	198.6	198.6	47.0
Nov-19	100%	188.1	188.1	424.7
Dec-19	100%	238.0	238.0	581.1
Jan-20	100%	295.4	295.4	541.2
Feb-20	100%	194.6	194.6	491.2
Mar-20	100%	195.3	195.3	350.5
Apr-20	100%	184.9	184.9	287.2
May-20	100%	185.9	185.9	183.5
Jun-20	100%	386.8	386.8	162.1
Jul-20	100%	548.6	548.6	221.1
Aug-20	83%	511.5	511.5	204.1
Annual	100%	8,379.7	8,379.7	2,323.7
Summer (Jun-Sep)		1,471.6	1,471.6	43.8
Winter (Oct-May)		6,908.1	6,908.1	2,279.9

Figure 11. Plot of Daily Total Heat Pump Electric Use and Daily Boiler Operation at S21

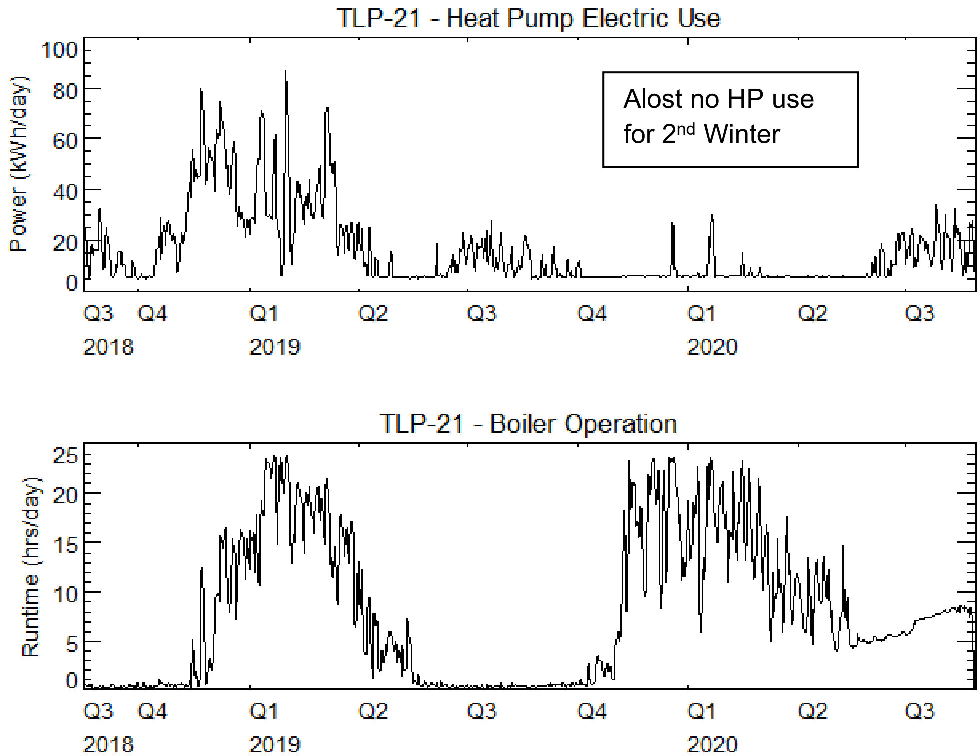


Figure 12 shows daily electric use for all the heat pumps versus the daily average ambient temperature from JFK. The data for each month are shown with different colors. Different symbol types are used for each year. The dotted line is fit to the data for the first winter of operation, when the HPs were used to meet the heating load. The electric use from subsequent winters shows much lower HP energy use.

Figure 12. Daily Heat Pump Electric Use versus Outdoor Temperature (from JFK) at S21

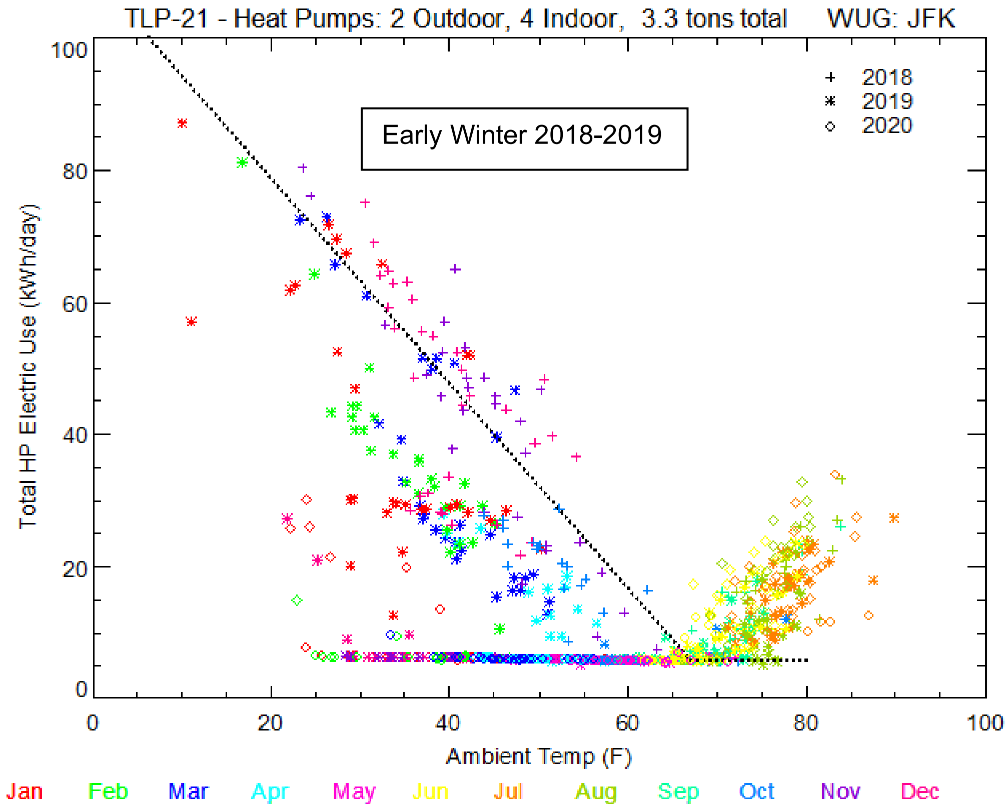
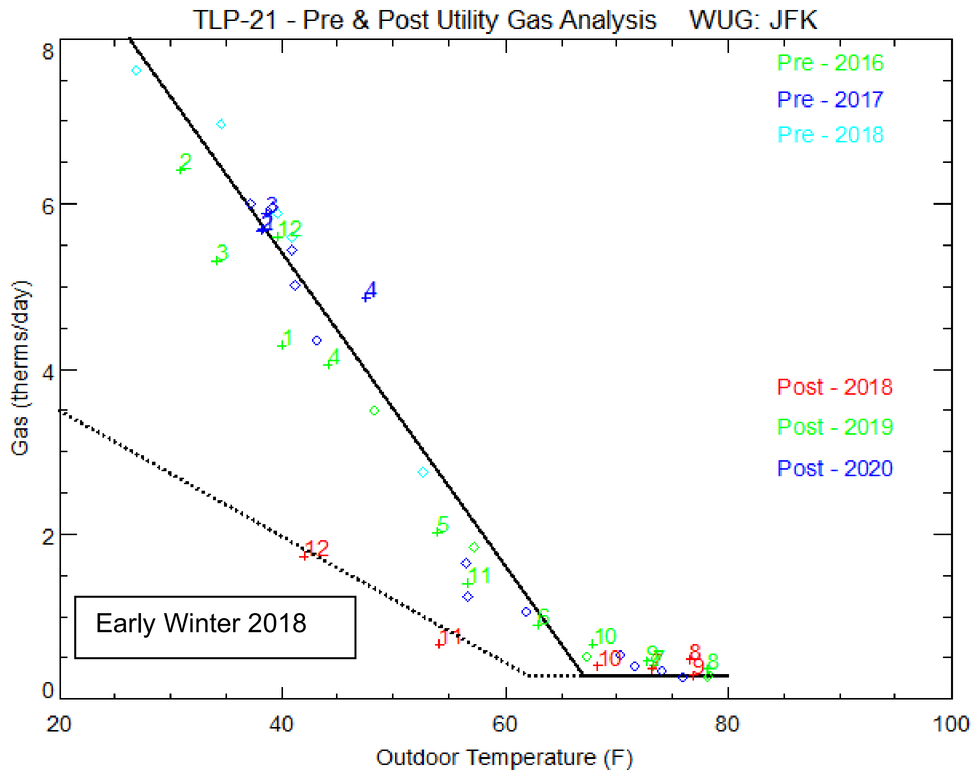


Figure 13 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. The dotted line is the best fit to the post-retrofit data from the first few months from the first winter of operation (November and December 2018).

Figure 13. Trend of Gas Use with Outdoor Temperature, Using Utility Bills from Pre- and Post-Retrofit Periods at S21



3.3.2.1 Annual Savings Analysis

The trends from the plots above (focused on early winter 2018) were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Table 13 incorporates the linear trends versus outdoor temperature assumed for gas use in both pre- and post-retrofit periods (from Figure 13) as well as piecewise linear trend for post-retrofit electric use of the heat pumps (from Figure 12). The pre- and post-retrofit costs in the table are expressed as dollars per day and shown for illustrative purposes.

Table 13. Bin Analysis of Heat Pump Savings Using TMY3 Weather for JFK Airport at S21

SITE:	TLP-21	WEATHER:	New_York	$ 0.20	per kWh
FUEL:	Gas			$ 1.403	per therm

Floor Are: 1700

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	18.2	7.1	152.7	7.1	2.0	25.5	40.5	
-22.5	0	17.2	6.7	144.9	6.7	2.0	24.2	38.4	
-17.5	0	16.3	6.4	137.2	6.4	2.0	22.9	36.4	
-12.5	0	15.4	6.0	129.4	6.0	2.0	21.5	34.3	
-7.5	0	14.4	5.6	121.6	5.6	2.0	20.2	32.2	
-2.5	0	13.5	5.2	113.9	5.2	2.0	18.9	30.1	
2.5	0	12.5	4.8	106.1	4.8	2.0	17.6	28.0	
7.5	11	11.6	4.5	98.4	4.5	2.0	16.2	25.9	
12.5	22	10.6	4.1	90.6	4.1	2.0	14.9	23.8	
17.5	101	9.7	3.7	82.8	3.7	2.0	13.6	21.7	
22.5	167	8.7	3.3	75.1	3.3	2.0	12.2	19.7	
27.5	247	7.8	2.9	67.3	2.9	2.0	10.9	17.6	
32.5	475	6.8	2.5	59.6	2.5	2.0	9.6	15.5	
37.5	855	5.9	2.2	51.8	2.2	2.0	8.3	13.4	
42.5	708	4.9	1.8	44.0	1.8	2.0	6.9	11.3	
47.5	608	4.0	1.4	36.3	1.4	2.0	5.6	9.2	
52.5	880	3.0	1.0	28.5	1.0	2.0	4.3	7.1	
57.5	750	2.1	0.6	20.7	0.6	2.0	2.9	5.1	
62.5	814	1.2	0.3	13.0	0.3	1.8	1.6	3.0	
67.5	723	0.3	0.3	6.0	0.3	0.0	0.4	1.6	
72.5	751	0.3	0.3	6.0	0.3	0.0	0.4	1.6	

Table 14 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 647 therms per year for all improvements. The next step is to subtract the gas savings from the envelope improvements to determine that the fuel savings attributable to the heat pumps, which is 525 therms per year. The heat pumps are estimated to use 7,658 kWh per year, excluding fan power for heat pumps. From this, the analysis estimated the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency of the existing boilers) and dividing by the heat pump power input. In this case, the implied COP is 1.9 and the total heating cost increases by $795 per year.

Table 14. Summary of Predicted Heating Season Impacts of the Air Source Heat Pumps

Exlcude HP Fan Power

Heating Only TLP-21	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Gas (therms/yr)	934	288	122	647	525
HP Electric (kWh/yr)		7,658		(7,658)	
Total Heating Costs	$ 1,311	$ 1,935	$ 171	$ (624)	$ (795)
Implied Seasonal COP				2.3	1.9

Summary Statistics

0.55	Htg therms per sq ft per year
43.4	Htg MBtu per sq ft per year
69%	Reduction in Htg Fuel Use
6,908	Measured HP Electric (kWh/yr)
90%	of typical year kWh

3.4 Summary of Heating Results for All Sites

The analysis shown in the previous section for two sites was repeated for all twenty test sites. The per-site analysis is given for each site in appendix D. The tables below summarize the results for all twenty sites.

3.4.1 Measured Fuel and Electric Use

Table 15 summarizes the measured heat pump electric use at all the sites. The boiler runtime is also given when it was measured. The winter (heating) energy use is from October through May and the summer (or cooling period) is defined as June through September. The table also gives the measured heat pump energy use per square foot of house area. The average and median values are given at the bottom of the table. The average heat pump use is 6,796 kWh in the winter and 1,494 kWh in the summer. On average 18% of annual heat pump energy is for summer cooling. The normalized average use is 3.3 kWh per sq ft in the winter and 0.76 kWh per sq ft in the summer.

Table 15. Summary of Post-Retrofit Heat Pump Electricity Use at Each Site

		All Heat Pumps						
Site	Available Data	Total (kWh)	Winter (kWh)	Summer (kWh)	Summer Percent	Boiler (hrs)	HP Heating (kWh/sq ft)	HP Cooling (kWh/sq ft)
S1	99%	3,214	2,108	1,106	34%		1.3	0.69
S3	100%	15,193	13,593	1,601	11%	465	2.9	0.34
S5	96%	12,441	10,623	1,818	15%		3.2	0.54
S10	100%	19,522	16,479	3,044	16%	225	3.7	0.67
S12.1	100%	4,856	3,240	1,616	33%		2.0	0.99
S12.2	100%	3,263	2,708	555	17%		3.3	0.68
S14	100%	11,773	11,438	335	3%		4.6	0.13
S18	77%	2,690	2,608	82	3%		0.9	0.03
S19	100%	18,891	16,136	2,755	15%		12.2	2.09
S21	100%	8,380	6,908	1,472	18%	2,280	4.1	0.87
S23	100%	6,793	4,831	1,962	29%	64	1.7	0.70
S25	100%	10,170	8,607	1,564	15%		4.6	0.84
S31	98%	6,532	5,445	1,087	17%	833	2.1	0.41
S32	100%	5,211	4,256	955	18%		3.2	0.71
S35	100%	5,338	3,977	1,362	26%	533	2.3	0.80
S39	100%	6,726	5,222	1,504	22%	118	3.8	1.08
S40	100%	4,327	3,179	1,148	27%		4.2	1.53
S41	100%	1,939	1,328	611	32%	1,739	0.4	0.20
S44	100%	5,564	4,918	646	12%	646	2.6	0.34
S45	100%	9,883	7,750	2,133	22%	2,133	2.2	0.59
S46	100%	11,379	7,358	4,021	35%	3,956	3.1	1.68
Average		8,290	6,796	1,494	20%	1,181	3.3	0.76
Median		6,726	5,222	1,472	18%	646	3.1	0.69

3.4.2 Summary of Bin-Analysis Results for Heating

Table 16 summarizes the overall results from the bin analysis for all sites in terms of fuel savings, heat pump energy use, implied heating efficiency and cost savings. The normalized heating loads per square foot were determined from the predicted pre-retrofit fuel use, assuming a combustion efficiency appropriate for the fuel. The normalized heat pump electric use for heating is divided by the nominal cooling capacity of the unit in tons. Space heating fuel reduction compares the pre- and post-retrofit consumption, excluding baseline fuel use for water heating. The implied COP is the seasonal average heating efficiency after excluding estimated fuel savings for the envelope improvements. The % of HSPF compares the seasonal efficiency to the rated HSPF (i.e., the measured COP x 3.412 and divided by HSPF). Cost savings are based on utility costs from Table 8.

Table 16. Summary of Heating Results for All Sites from Bin Analysis

Site	City or Borough	Floor Area (sq ft)	No. of Apts	Pre-Retrofit Fuel	ASHP (out/in/tons}	Annual Heating Load (MBtu per sq ft)	ASHP (kWh/ton)	Space Heating Fuel Reduction	Implied COP	% of Rated HSPF	ASHP Cost Savings per ton
S1	Brooklyn	1600	2	Gas	2 / 6 / 5	31.9	561	81%	3.5	128%	$10
S3	Brooklyn	4650	1	Oil	3 / 7 / 6.5	48.1	2,286	80%	2.0	65%	-$55
S5	Brooklyn	3370	1	Gas	4 / 10 / 8.5	54.8	1,274	82%	2.6	88%	-$54
S10	Brooklyn	4512	2	Oil	3 / 10 / 8	42.7	1,639	84%	2.2	68%	-$25
S12.1	Brooklyn	1628	1	Gas	2 / 5 / 4	14.5	376	74%	1.5	51%	-$40
S12.2	Brooklyn	814	1	Gas	1 / 3 / 2	30.9	1,093	84%	2.1	72%	-$73
S14	Brooklyn	2483	1	Oil	3 / 7 / 6	80.6	1,743	100%	2.8	97%	$109
S18	Brooklyn	2811	2	Oil	4 / 10 / 8	31.2	343	100%	4.0	137%	$37
S19	Brooklyn	1318	2	Oil	2 / 5 / 4.5	42.7	3,409	100%	2.7	88%	$30
S21	Brooklyn	1700	2	Gas	2 / 4 / 3.3	43.4	2,321	69%	1.9	60%	-$241
S23	Bronx	2792	1	Oil	2 / 7 / 6	27.0	781	100%	1.8	54%	-$36
S25	Queens	1870	1	Gas	2 / 8 / 6	37.2	1,178	100%	2.3	69%	-$65
S31	Bellmore	2625	1	Gas	2 / 7 / 5	19.3	1,059	68%	2.3	79%	-$90
S32	Yonkers	1350	1	Oil	1 / 4 / 3	47.4	1,246	100%	2.8	101%	-$1
S35	Bronx	1700	1	Oil	1 / 6 / 4	60.9	1,755	66%	2.9	85%	$7
S39	Broad Chan	1387	1	Oil	1 / 4 / 3	16.2	2,080	100%	1.1	38%	-$259
S40	Bronx	750	1	Gas	1 / 3 / 2	90.9	2,336	100%	2.9	95%	-$63
S41	Dix Hill	3000	1	Gas	1 / Ducted / 4	31.9	239	-18%			
S44	Queens	1920	1	Gas	2 / 5 / 4	47.1	1,199	100%	4.4	139%	$79
S45	Queens	3600	3	Oil	5 / 12 / 8.5	18.6	914	100%	1.9	58%	-$61
S46	Brooklyn	2400	1	Gas	2 / 8 / 7	25.3	959	37%	1.0	30%	-$134
Notes:	Out = no. of outdoor units/in = no. of indoor heads / tons = nominal cooling capacity				MIN	14.5	239	37%	1.0	30%	-$259
					AVG	40.1	1,371	86%	2.4	80%	-$46
					MEDIAN	37.2	1,199	92%	2.3	76%	-$47
					MAX	90.9	3,409	100%	4.4	139%	$109

Table 17 lists any special circumstances from each site and relates these issues to the measured results. S41 had negative fuel savings and therefore it was not possible to determine the other calculated quantities. This surprising result appears to have been due to a behavioral change (different set points) between the pre- and post- periods. Similarly, other sites had very low COPs (near 1) that were due to set-point changes between the pre- and post- periods (S46) or due to limited pre-retrofit fuel use data (S39).

Table 18 seeks to classify the various issues identified in Table 17. At four sites with unexpectedly high COPs (S1, S18, S32 and S44), the results imply the envelope improvements were more extensive than predicted by the original design report from the weatherization contractor. The implied COPs in these cases ranged from 2.8 to 4.4.

For at least five sites the occupants initially used the HPs, but then chose to switch back to using the boilers to meet more of the heating load. The various reasons from occupants are given in Table 18. In other cases: (1) the heat pump had refrigerant charge issues (S35), (2) the occupant was frequently out of the house (S14), or (3) the homeowners switched back to the boiler to use up the oil remaining in their tank (S39). Note that all bin analysis results extended the initial, or best case, trend of heat pump use to predict annual performance—so these behavioral issues are not fully reflected in the results in Table 16.

Eight of the sites removed their boilers when the heat pumps were installed. For three of these sites, the house temperatures dropped below 50°F at some point in the winter (see section 3.6). For two of these sites, the drop may have been caused by a deep setback or temporary vacancy (S14 and S40). At the other site (S19), the occupants experienced a significant temperature drop in a bedroom, which is discussed in section 3.6 below.

Table 19 breaks out the results by pre-retrofit fuel type. There were no significant differences between sites that used natural gas or fuel oil, except, of course, for cost savings. The average annual heating cost savings per installed ton were -$67 per ton for the natural gas sites and -$25 per ton for the oil sites.

Table 17. Notable Findings and Analysis Issues at Each Site

Site	Monitoring Start Date	Notes on Each Site
S1	8/15/2019	The envelope savings of 85 therms were likely underestimated for this extensive renovation project. This resulted in a high COP (3.5).
S3	12/18/2017	Heat pump operation varied considerably across the year. One occupant left after initial period and the remaining occupant was cold with HP operation. Bin analysis based on best-case performance.
S5	4/11/2018	A flip-flop test did not corroborate the estimated savings from weatherization contractor (see the S5 analysis section in appendix D).
S10	4/11/2018	A flip-flop testing corroborated the savings estimated by the weatherization contractor.
S12	12/18/2017	Each apartment had its own gas meter, so these units were independently analyzed.
S14	8/16/2018	HPs were off for eight weeks in June-July 2019 as well as four weeks around January 2020, presumably when the house was unoccupied.
S18	3/14/2019	Scope of the multi-year envelope retrofit is uncertain relative to initial design report (savings 443 gallons), which may explain the high COP (4.0).
S19	4/11/2018	Two affordable housing units. Some evidence that space temperatures dropped in 1st floor bedroom in this house without a boiler backup.
S21	8/16/2018	Only used the heat pumps in the first few months, then switched back to the boiler (because the cat liked the warm floors). Bin analysis based on best-case performance.
S23	4/12/2018	
S25	4/12/2018	
S31	8/23/2018	
S32	8/23/2018	Savings from insulation improvements uncertain, estimate from initial design report is 244 gallons. The result may explain higher COP (2.8).
S35	6/3/2019	The heat pump was down for two periods for several weeks due to a refrigerant leak and the boiler had to meet the heating load (November-December, 2019 and January-February, 2020). Bin analysis based on proper operation.
S39	3/18/2018	Limited pre-retrofit oil use data available (May 2016 to May 2017). This may explain lower than expected COP (1.1). The heat pump did not operate March to May 2020 because owner wanted to use up remaining oil in oil tank.
S40	12/3/2018	Initial period from December 2018 to February 2019 showed more heat pump use. The bin analysis was conducted on this period. Heat pump energy use was lower after the initial period because the home was unoccupied.
S41	12/20/2018	There were negative fuel savings at this site. The ducted heat pump was only used in the swing season. They had a child just after the HPs were installed; switched back to boiler.
S44	8/15/2018	The envelope savings of 234 therms estimated from the 20% reduction in Manual J loads may underestimate the energy impact of the extensive house renovations. The owners also used new electric heaters in the bathroom and laundry to meet some of the load. Taken together these may explain why the implied COP is 4.4.
S45	8/15/2018	This house had extensive renovations that increased the floor area and added insulation. The savings of 149 therms was estimated using the reported change in Manual J loads. HPs installed in multiple phases over 3 years.
S46	12/4/2018	Heat pumps used more energy in the first winter than in the second year. Gas data seems valid but inferred COP is near 1. Significant change in heating set points between pre- and post- periods may have caused the poor COP.

Table 18. Classification of Performance, Behavioral, and Analysis Issues at each Site

Site	Boiler Status	Envelope Improvement Savings	Change in HP Use	Temperatures Always Maintained above 50°F
S1	In-Place	Underestimated? (COP=3.5)		
S3	In-Place		Behavioral, only used HPs at first.	
S5	In-Place	Overestimated per FFT (COP=2.6)		
S10	In-Place	Confirmed by FFT (COP=2.2)		
S12	In-Place			
S14	Removed		HPs off for 8 weeks, perhaps due to vacation.	No. Space temps dropped in office. Appeared to be intentionally set back.
S18	Removed	Underestimated? (COP=4.0)	HP4 in garden level apt never used.	
S19	Removed			No. Space temps dropped in bedroom. See Section 3.6.
S21	New boiler with HPs		Behavioral, only used HPs at first (switched back to boilers because cat liked floors warm).	
S23	In-Place			
S25	Broken			
S31	In Place (new Boiler)			
S32	Removed	Underestimated? (COP=2.8)		
S35	In Place		HPs not used in Nov 2019 to Feb 2020. Refrigerant charge issue with HPs.	
S39	In Place		HP off March to May 2020. Owner wanted to use up remaining oil.	
S40	Removed		Behavioral, only used HPs at first. Change in HP use because home is frequently unoccupied.	No. Space temps dropped in living room. Appears to have been intentional setback. See Section 3.6.
S41	In Place		Ducted HP only used in swing season. Reported that gas was cheaper. Also had baby part way through post period.	
S44	Removed	Underestimated? (COP=4.4)	Some electric heat use in bathroom and laundry may also explain high COPs.	
S45	Removed			
S46	In Place (new Boiler)		Behavioral, only used HPs at first. Occupants had a baby when the HPs were installed and reportedly had higher set points (which may explain low COP of 1).	

Notes: FFT – Flip-Flop Test

Table 19. Summary of Average Results by Fuel Type

Fuel	No. of Sites	Heating Load (MBtu per sq ft per year)	Space Heating Fuel Reduction[1]	Implied COP	Percent of Rated HSPF	ASHP Cost (Savings per ton per year)
Gas	10	39.5	88%	2.4	81%	-$67
Oil	10	41.5	93%	2.4	79%	-$25
All	20	40.1	86%	2.4	80%	-$46

Note: Negative fuel reduction at S18 excluded.

One question is whether heat pump sizing ratios can explain the differences in the space heating fuel displacement, or whether behavior is the dominant cause. Figure 14 shows that many of the sites had the expected 100% fuel use reduction also had sizing ratios near or above 100%. However, ten sites did not displace all the space heating fuel use. Four of these ten sites were sized above the 110% sizing ratio yet did not displace all the fuel use (S1, S5, S25 and S46, which are circled on the graph).

Figure 14. Impact of HP Sizing Ratio on the Space Heating Fuel Reduction

The allowable design range is 90–120% for NYS Clean Heat Program. Site with negative fuel reduction not shown.

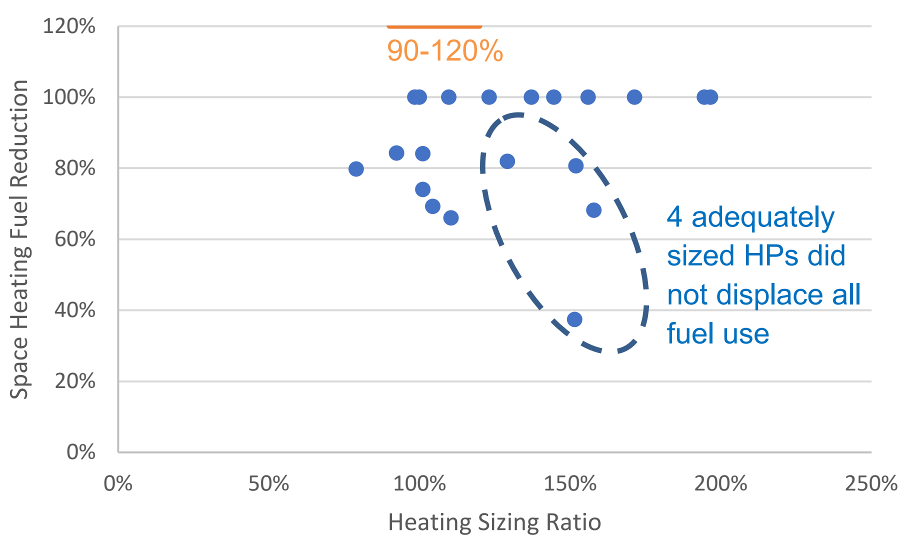


Table 20 shows the impact of assuming higher and lower costs for fuel and electric. Table entries with positive savings are as shaded green. For natural gas, the savings are not greater than zero until both electric is 20% lower and fuel is 20% higher. The savings for fuel oil are greater than zero if either the fuel is 20% more expensive or electric is 20% less expensive. In the best case, the savings for oil increases to $99 per ton and savings for gas increase to $19 per ton.

Table 20. Sensitivity of Annual Cost Savings to Fuel Cost and Electric Costs

$ per installed ton

		Electric Cost		
		-20%	**0**	**+20%**
Gas Cost	**-20%**	-53	-103	-152
	0	-17	**-67**	-116
	+20%	19	-31	

		Electric Cost		
		-20%	**0**	**+20%**
Oil Cost	**-20%**	-20	-85	-151
	0	40	**-25**	-90
	+20%	99	34	-30

3.4.3 Cost Savings and Economics for Heating

Table 21 shows the fuel savings, heat pump electric use, and cost savings for each site. The costs savings were determined using the fuel and electric costs from Table 8. The cost savings were calculated for the total project (envelope improvements and heat pump installation combined) as well as for the heat pumps alone. In cases where the envelope improvements were not implemented the weatherization costs are shown as a gray cell. For three of the sites, envelope improvements were completed but the implementation costs were unknown.

Table 21. Summary of Cost Savings at each Site

Site	Fuel Type	Total Fuel Savings (therms or gal)	HP Fuel Savings (therms or gal)	HP Use (kWh)	Total Cost Savings	HP Cost Savings	Weather-zation Installed Costs	HP Install Costs
S1	Gas	522	437	2,804	$171	$52	unknown	$23,900
S3	Oil	1528	1069	14,859	$767	$(355)	$5,500	$32,148
S5	Gas	1914	1217	10,830	$520	$(459)	$5,500	$52,190
S10	Oil	1389	989	13,110	$778	$(202)	$10,736	$35,783
S12.1	Gas	221	101	1,503	$9	$(158)	$6,667	$24,733
S12.2	Gas	267	208	2,185	$(62)	$(145)	$3,333	$12,397
S14	Oil	1507	1123	10,460	$1,597	$656	$28,431	$23,030
S18	Oil	788	346	2,741	$1,381	$298	$26,500	$25,083
S19	Oil	1309	1309	15,339	$137	$137		$20,000
S21	Gas	647	525	7,658	$(624)	$(795)	$5,500	$17,874
S23	Oil	646	295	4,685	$645	$(214)	$13,596	$21,576
S25	Gas	880	731	7,065	$(178)	$(387)	$7,350	$22,000
S31	Gas	436	436	5,297	$(448)	$(448)		$23,000
S32	Oil	548	304	3,739	$594	$(3)	$3,500	$12,000
S35	Oil	586	586	7,019	$29	$29		$25,000
S39	Oil	192	192	6,241	$(778)	$(778)		$12,000
S40	Gas	863	576	4,672	$277	$(126)	$9,750	$12,000
S41	Gas	-82	-82	956	$(306)	$(306)	$14,357	$13,444
S44	Gas	1144	910	4,794	$647	$318	unknown	$16,000
S45	Oil	573	424	7,771	$(151)	$(517)	$10,000	$24,000
S46	Gas	288	288	6,712	$(939)	$(939)		$28,000

Notes: "Total" indicates combined project with weatherization/envelope and HP. Gray cells indicate sites with no envelope improvement. Electric and fuel costs were $0.20 per kWh, $1.4032 per therm, and $2.4471 per gallon.

3.4.4 Greenhouse Gas Savings from Heating

The measured energy savings were used to predict the reduction in greenhouse gas (GHG) emissions for the cASHP systems. The eGrid 2018 data for NYC/Westchester was used to determine the GHG emission factor for electric generation in the region.[1] EPA's eGrid publishes the overall average emission factor for the region as well as the non-baseload emissions factor. For NYC/Westchester, the overall average factor is 0.598 lb of CO_2 equivalent for each kWh. The non-baseload factor is 1.069 lb of CO_2 equivalent per kWh. GHG CO_2 equivalent factors for the fossil fuels are 11.7 lb/therm for natural gas and 22.4 lb/gal for fuel oil.

Generally, for GHG analyses of building efficiency technologies, the EPA recommends using the non-baseload emissions factors to reflect the impact of incremental or marginal changes in energy use. However, from the perspective of wholesale electrification to eliminate all fossil fuel heating, it might be more appropriate to use the average emissions factor. Table 22 shows the analysis using the non-baseload emissions factor for electricity while Table 23 shows the analysis using average emissions factor. The average GHG reduction for the 19 sites (excluding S41) is 3,155 lb of CO_2 equivalent per year (or 592 lb per year per installed ton) using the non-baseload emissions factor. Using the average emissions factor, the average GHG reductions for the 19 sites is 6,440 lbs of CO_2 equivalent per year (or 1,265 lb per year per installed ton).

Table 22. Summary of Annual Greenhouse Gas Savings for Each Site

non-baseload eGrid factor

Site	Fuel Type	Total Fuel Savings (therms or gal)	HP Fuel Savings (therms or gal)	HP Use (kWh)	Total GHG Savings (lb/yr)	HP GHG Savings (lb/yr)	Total GHG per Investment (lb/$1000)	HP GHG per Investment (lb/$1000)
S1	Gas	522	437	2,804	3,105	2,114		88
S3	Oil	1,528	1,069	14,859	18,341	8,069	487	251
S5	Gas	1,914	1,217	10,830	10,819	2,658	188	51
S10	Oil	1,389	989	13,110	17,110	8,136	368	227
S12.1	Gas	221	101	1,503	974	(420)	31	(17)
S12.2	Gas	267	208	2,185	793	96	50	8
S14	Oil	1,507	1,123	10,460	22,586	13,976	439	607
S18	Oil	788	346	2,741	14,730	4,816		192
S19	Oil	1,309	1,309	15,339	12,935	12,935	647	647
S21	Gas	647	525	7,658	(622)	(2,044)	(27)	(114)
S23	Oil	646	295	4,685	9,471	1,609	269	75
S25	Gas	880	731	7,065	2,748	1,001	94	46
S31	Gas	436	436	5,297	(563)	(563)	(24)	(24)
S32	Oil	548	304	3,739	8,283	2,818	534	235
S35	Oil	586	586	7,019	5,612	5,612	224	224
S39	Oil	192	192	6,241	(2,364)	(2,364)	(197)	(197)
S40	Gas	863	576	4,672	5,102	1,744	235	145
S41	Gas	(82)	(82)	956	(1,977)	(1,977)	(71)	(147)
S44	Gas	1,144	910	4,794	8,262	5,521		345
S45	Oil	573	424	7,771	4,536	1,187	133	49
S46	Gas	288	288	6,712	(3,808)	(3,808)	(136)	(136)
Minimum		(82)	(82)	956	(3,808)	(3,808)	(197)	(82)
Maximum		1,914	1,309	15,339	22,586	13,976	647	1,914
Average		770	571	6,688	6,480	2,910	180	770

Notes: The non-baseload emission rate is 1.069 lb of CO_2 equivalent per kWh for NYC/Westchester per eGrid. GHG CO_2 equivalent factors for the fossil fuels are 11.7 lb/therm for natural gas, and 22.4 lb/gal for fuel oil.

Table 23. Summary of Greenhouse Gas Savings for Each Site

average eGrid factor

Site	Fuel Type	Total Fuel Savings (therms or gal)	HP Fuel Savings (therms or gal)	HP Use (kWh)	Total GHG Savings (lb/yr)	HP GHG Savings (lb/yr)	Total GHG per Investment (lb/$1000)	HP GHG per Investment (lb/$1000)
S1	Gas	522	437	2,804	4,425	3,434		144
S3	Oil	1,528	1,069	14,859	25,340	15,068	673	469
S5	Gas	1,914	1,217	10,830	15,920	7,759	276	149
S10	Oil	1,389	989	13,110	23,285	14,311	501	400
S12.1	Gas	221	101	1,503	1,682	288	54	12
S12.2	Gas	267	208	2,185	1,822	1,126	116	91
S14	Oil	1,507	1,123	10,460	27,513	18,903	535	821
S18	Oil	788	346	2,741	16,021	6,107		243
S19	Oil	1,309	1,309	15,339	20,160	20,160	1,008	1,008
S21	Gas	647	525	7,658	2,985	1,563	128	87
S23	Oil	646	295	4,685	11,678	3,816	332	177
S25	Gas	880	731	7,065	6,076	4,329	207	197
S31	Gas	436	436	5,297	1,932	1,932	84	84
S32	Oil	548	304	3,739	10,044	4,579	648	382
S35	Oil	586	586	7,019	8,918	8,918	357	357
S39	Oil	192	192	6,241	575	575	48	48
S40	Gas	863	576	4,672	7,303	3,944	336	329
S41	Gas	(82)	(82)	956	(1,526)	(1,526)	(55)	(114)
S44	Gas	1,144	910	4,794	10,520	7,779		486
S45	Oil	573	424	7,771	8,196	4,847	241	202
S46	Gas	288	288	6,712	(646)	(646)	(23)	(23)
Minimum		(82)	(82)	956	(1,526)	(1,526)	(55)	(114)
Maximum		1,914	1,309	15,339	22,586	13,976	647	647
Average		770	571	6,688	6,480	2,910	180	122

Notes: The average emission rate is 0.598 lb of CO2 equivalent per kWh for NYC/Westchester per eGrid.
GHG CO_2 equivalent factors for the fossil fuels are 11.7 lb/therm for natural gas, and 22.4 lb/gal for fuel oil.

3.5 Impact on Cooling

The savings from cooling could not be determined using the same pre-post analysis method that was used for heating in this report. The companion EFG report (NYSERDA Report 22-08) showed that even when total house electric bills are available to complete the cooling analysis, the energy savings were essentially zero. Very little savings were expected since the SEER rating for ccASHP units often overstates the efficiency of these units. Appendix F of Henderson (2020a) as well as Harley (2020) provide a detailed explanation of how and why SEER values in some cases overstate actual seasonal cooling efficiency.

Table 24 summarizes the magnitude of the cooling energy use at each site. The electric use for June through September was stipulated as the cooling energy use. Cooling energy use varied considerably from site to site because occupant choice of desired cooling setpoints, as well as occupants' decisions of when (and if) to open windows at mild conditions. Heat pump cooling use at the homes ranged from 82 to 4,021 kWh in the summer for cooling, with a median of 1,472 kWh. Summer electric use ranged from 3 to 34% of the annual use, with a median value of 18%. Cooling energy use normalized by floor area ranged from 0.03 to 2.09 kWh per sq ft per yr, with a median value of 0.69 kWh per sq ft per yr.

Table 24. Cooling Energy Use by Heat Pumps at Each Site (June–September)

Site	Summer (kWh)	Summer (% of total)	Summer (% of Heating)	HP Cooling (kWh/sq ft)
S1	1,106	34%	52%	0.69
S3	1,601	11%	12%	0.34
S5	1,818	15%	17%	0.54
S10	3,044	16%	18%	0.67
S12.1	1,616	33%	50%	0.99
S12.2	555	17%	21%	0.68
S14	335	3%	3%	0.13
S18	82	3%	3%	0.03
S19	2,755	15%	17%	2.09
S21	1,472	18%	21%	0.87
S23	1,962	29%	41%	0.70
S25	1,564	15%	18%	0.84
S31	1,087	17%	20%	0.41
S32	955	18%	22%	0.71
S35	1,362	26%	34%	0.80
S39	1,504	22%	29%	1.08
S40	1,148	27%	36%	1.53
S41	611	32%	46%	0.20
S44	646	12%	13%	0.34
S45	2,133	22%	28%	0.59
S46	4,021	35%	55%	1.68
Minimum	82	0.03	0.03	0.03
Maximum	4021	0.35	0.55	2.09
Average	1,494	20%	26%	0.76
Median	1,472	18%	21%	0.69

3.6 Observed Space Temperatures

The following tables summarize the measured space temperatures in the winter (Table 25) and summer (Table 26) seasons for the living areas, bedrooms, and other areas. Appendix D provides plots of the space temperature data for each site. The standard deviation of the space temperature in each period are also given in the tables. The tables also include the number of hours below 50°F in the heating season (Table 25) and the hours above 85°F in the cooling season (Table 26). This metric provides an indication if loads were ever unmet in the period, however because setpoints were not recorded occupant choices cannot be ruled out as the cause of these fluctuations. In most cases, temperatures were within expectations and any variations were presumably driven by occupant preference.

Table 25. Measured Space Temperatures and Standard Deviation in Heating Season (November through March)

	Living Area (Living Kitchen, Family)			Bedrooms			Other Spaces (Offices, Basement)		
Site	Avg (F)	Std Dev (F)	Hours under 50°F	Avg (F)	Std Dev (F)	Hours under 50°F	Avg (F)	Std Dev (F)	Hours under 50°F
S1	66.7	2.6	0	68.6	2.3	0			
S3	67.2	5.3	10	71.5	2.0	0			
S5	70.0	2.7	0						
S10	76.3	4.0	0	72.2	2.1	0			
S12.1	64.3	2.4	0						
S12.2	69.5	2.8	0						
S14	70.1	6.0	1				63.9	5.7	111
S18	71.9	2.6	0						
S19	73.7	3.9	0	63.9	6.6	101			
S21	73.1	1.5	0	70.7	2.8	3			
S23	67.8	2.2	0	71.4	2.1	0			
S25	71.0	2.2	0	66.5	2.8	0			
S31	71.8	1.4	0	74.3	1.6	0	64.5	2.0	0
S32	74.5	2.1	0	74.3	3.3	0			
S35	0.0	0.0	0	75.3	3.4	0			
S39				68.5	2.8	0			
S40	66.9	4.3	12	70.9	1.2	0			
S41	60.6	7.3	646	65.4	2.4	0			
S44	71.5	2.5	0	68.6	1.7	0	67.8	3.0	0
S45	68.4	2.1	0	74.5	2.4	0			
S46	71.5	2.6	0						

Sites with shaded rows do NOT have boiler for backup

Table 26. Measured Space Temperatures and Standard Deviation in Cooling Season (June through August)

	Living Area (Living Kitchen, Family)			Bedrooms			Other Spaces (Offices, Basement)		
Site	Avg (F)	Std Dev (F)	Hours over 85F	Avg (F)	Std Dev (F)	Hours over 85°F	Avg (F)	Std Dev (F)	Hours over 85°F
S1	76.1	2.1	22	74.2	2.8	22			
S3	76.0	3.1	21	73.5	2.5	21			
S5	79.0	4.4	23	81.0	4.7	23			
S10	77.5	3.3	23	80.2	2.7	22			
S12.1	82.8	3.1	26						
S12.2	80.0	2.7	22						
S14	75.2	2.7	23				77.4	3.5	22
S18	77.4	2.9	21						
S19	70.8	3.7	20	74.9	2.8	20			
S21	80.3	3.4	24	79.4	3.2	22			
S23	73.3	2.2	21	75.6	3.4	21			
S25	75.9	1.7	20	79.1	4.6	25			
S31	75.8	2.3	21	77.5	1.8	22	73.4	1.7	22
S32	75.3	2.4	21	70.4	2.4	20			
S35				81.7	2.5	22			
S39				73.0	3.4	21			
S40	75.6	5.0	23						
S41	76.0	3.4	22	75.6	2.6	22			
S44	76.0	2.3	21	79.5	3.2	22	79.6	3.3	23
S45	85.1	3.1	23	75.8	2.2	22			
S46	76.1	2.2	21						

The shaded rows in Table 25 indicate where the boiler had been removed. At a few of these sites, there was evidence that the space temperatures dropped below 50°F in the heating season. For S14 and S40, in Figure 15 and Figure 16, the periods when the space temperature dropped below 50°F seem to correspond more to occupant choice and/or setpoint selection. At S14 (Figure 15), the temperature dropped slightly in the office while temperatures were maintained in the living area. The outdoor temperature during the temperature dip was modest. At S40 (Figure 16), temperatures dropped just slightly below 50°F on relatively cold days. A few days later the homeowners seemed to raise the setpoint—presumably correcting for their selection of too low a temperature target.

Figure 15. Period When Space Temperatures Dipped Below 50°F in the Heating Season at S14

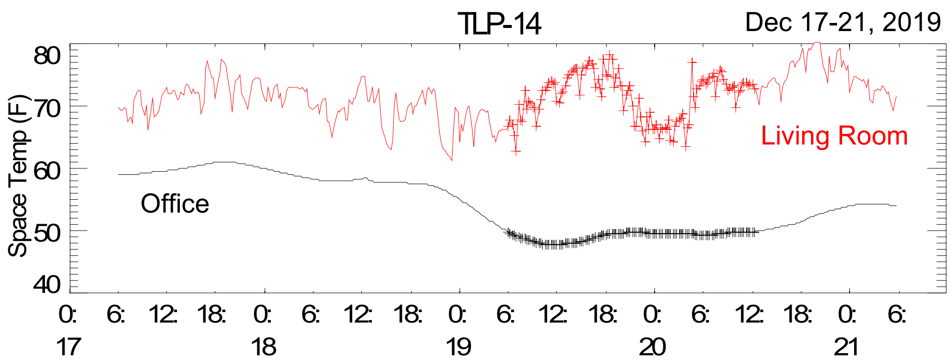


Figure 16. Period When Space Temperatures Dipped Below 50°F in the Heating Season at S40

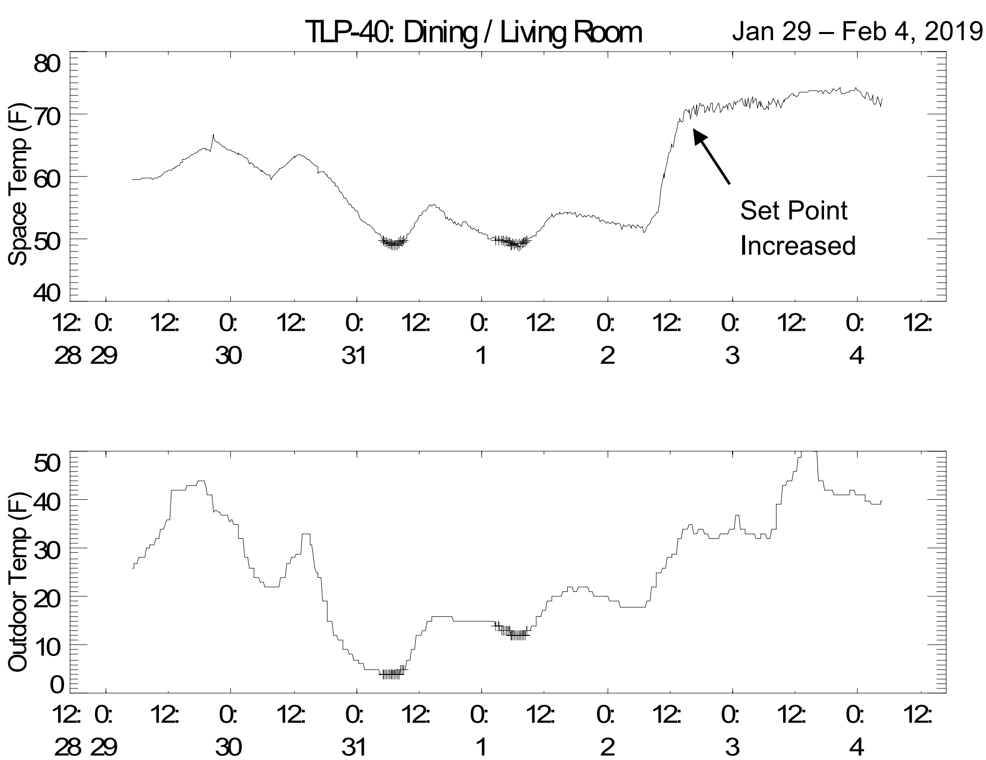
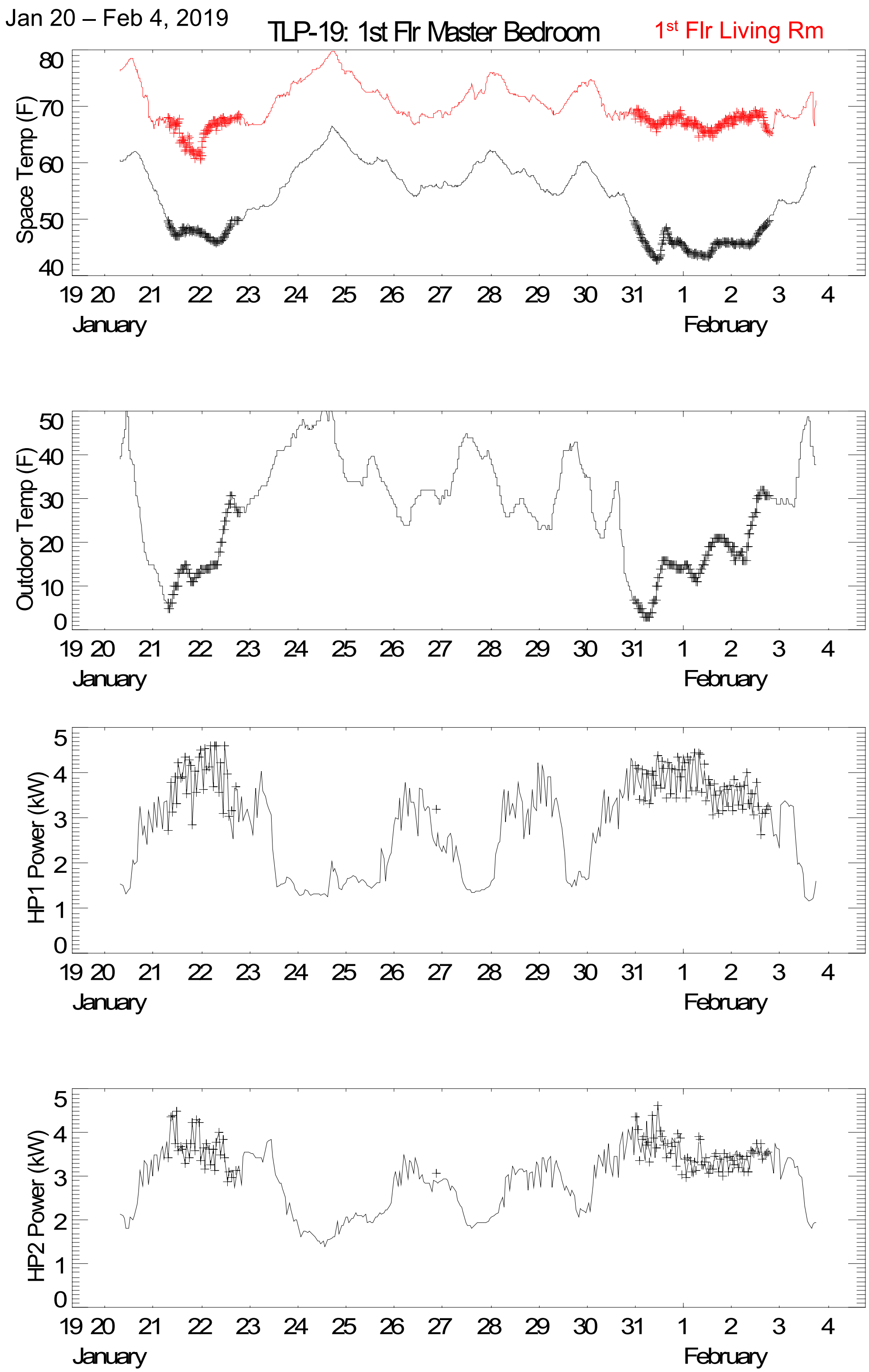


Figure 17 shows the temperature profile for two rooms at S19, a two-family home with renters as occupants. The black line shows the first floor master bedroom temperature while the red line shows the first floor living room temperature. In this first floor apartment, the temperature in the bedroom dropped significantly below 50°F at the coldest hours of the year and then recovered to more normal temperatures when outdoor temperatures moderated. The power graphs at the bottom of the figure show that both heat pumps at the site were fully on for these cold periods. This trend seems to imply that the heat pump's indoor head in this bedroom was fully on but not able to maintain the desired temperature set point. However, the indoor head in the living room (on same heat pump system, and with the same capacity as the bedroom indoor unit) was able to maintain the space temperature. This could mean that the HP for this apartment, or the indoor head, were possibly undersized for the application. However, the overall heating sizing ratio is 100% for this site (see Table 4) and each apartment heat pump was reportedly also sized close to 100%. Another possible explanation is that something happened to change the heating load in that bedroom. In fact, the owner did report that the building's exterior was being retrofitted with new insulation and siding during this time Therefore, it seems likely that the heating load was increased when the siding and insulation were removed for a few days in this process. The occupants at this site did not take the second survey (in section 4), so the team did not receive explicit feedback from them.

Figure 17. Periods When Space Temperatures Dipped Below 50°F in the Heating Season at S19



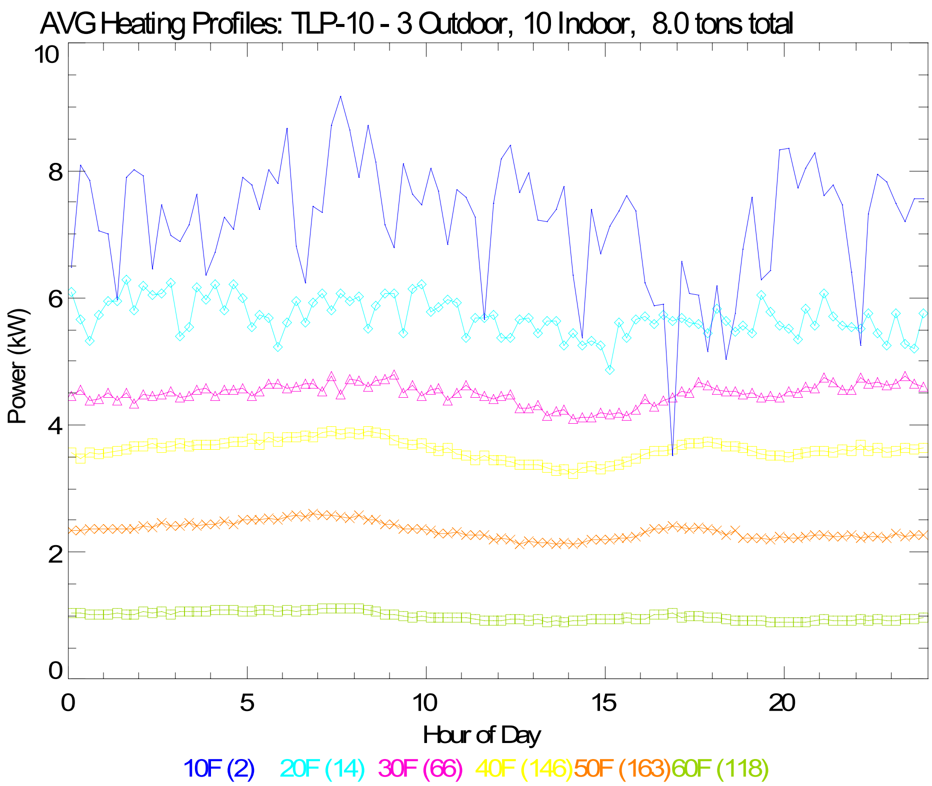
3.7 Electric Demand Profiles for Heating and Cooling

The average demand profiles for all the heat pumps at S10 are shown in Figure 18. The daily profiles shown on the plot correspond to days with similar outdoor temperature that were grouped together and averaged. For the heating plot at the top of Figure 18, the blue line corresponds to a temperature of 10°F and includes days where the average outdoor temperature was between 5°F and 15°F (±5°F). As shown at the bottom of the plot, there were two days that met this criterion and were averaged together. Similarly, there were 14 days that were averaged together to make the average profile at 20°F.

Normalizing the demand profiles by dividing by the installed tons (i.e., the nominal rated cooling capacity), allows them to be combined and compared with the average demand profiles from all the sites. Figure 19 shows demand profiles from all the sites that correspond to 10°F. For each site, the electric demand (kW) is divided by the installed tonnage to determine the normalized demand. Note that for S41, the ducted unit, the heat pump power also includes some electric resistance heat. The daily profile for each site is based on a different number of days and shown by a colored line. The thick black line is average normalized demand for all the sites at daily average temperatures of 10°F (or between 5°F and 15°F). The average profile is weighted based on the number of days associated with each site. A total of 44 days from all the sites were used to make this weighted-average profile of the normalized demand at 10°F. Note that S41 chose not to run the HP on these cold days. S19, a site with no backup boiler, had a much higher demand.

Figure 20 similarly shows the normalized demand profiles for each site at 80°F (or between 75°F and 85°F). The weighted average, shown as the thick black line, in this case is based on 1,735 days when the daily average temperature criteria was met.

Figure 18. Average Demand Profiles for S10, Days Grouped with Similar Outdoor Temperatures



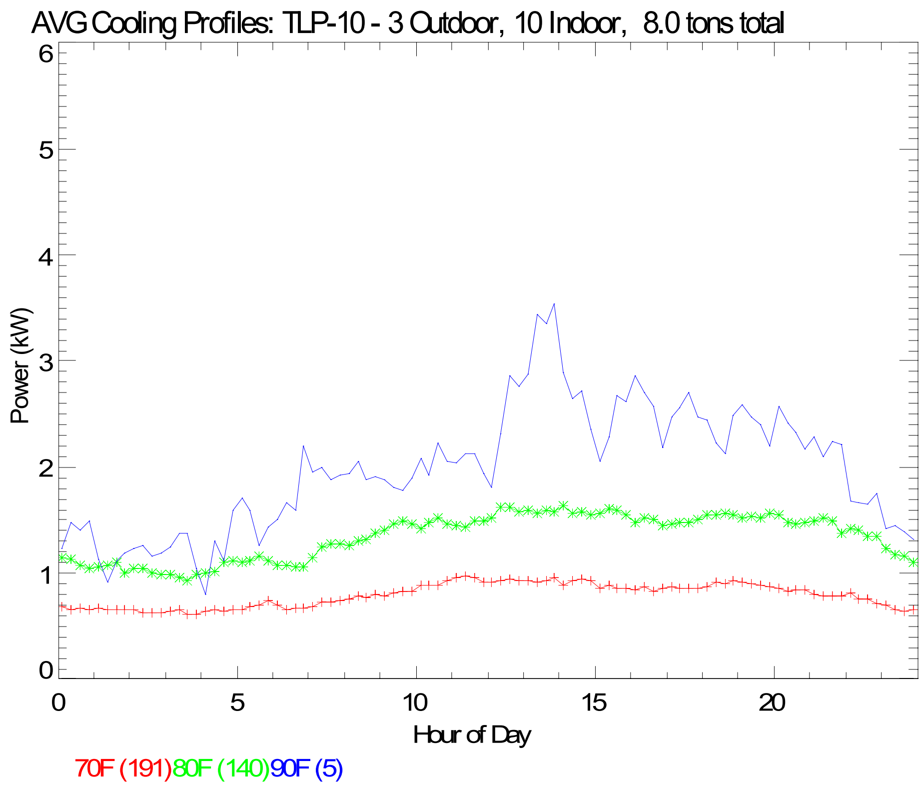


Figure 19. Normalized Demand Profiles for all Sites Combined at an Outdoor Temperature of 10°F

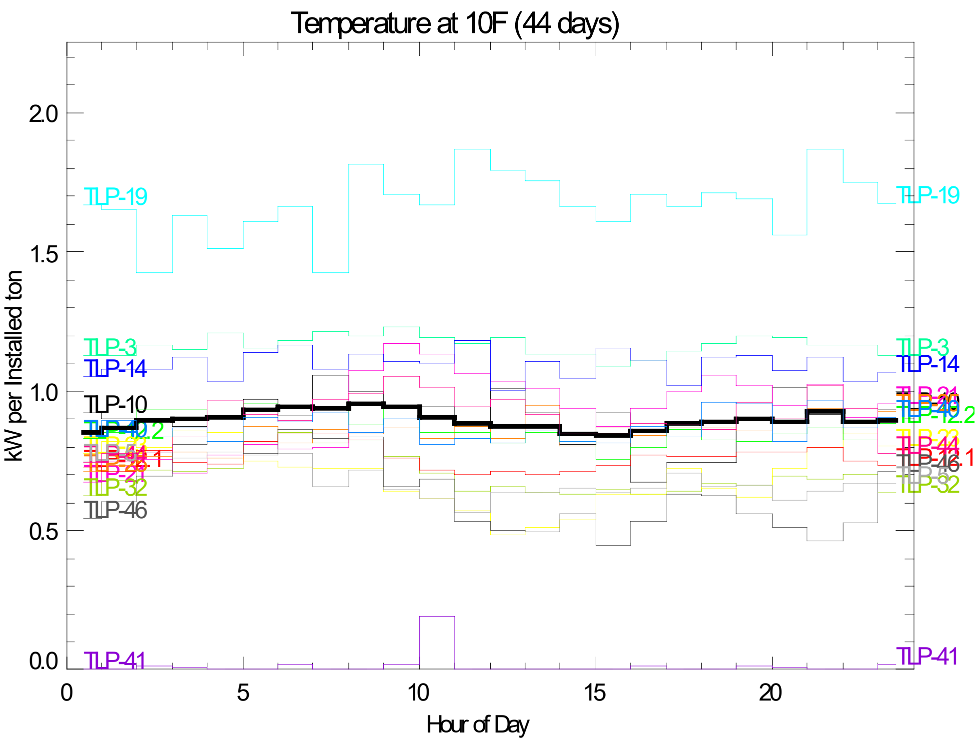


Figure 20. Normalized Demand Profiles for all Sites Combined at an Outdoor Temperature of 80°F

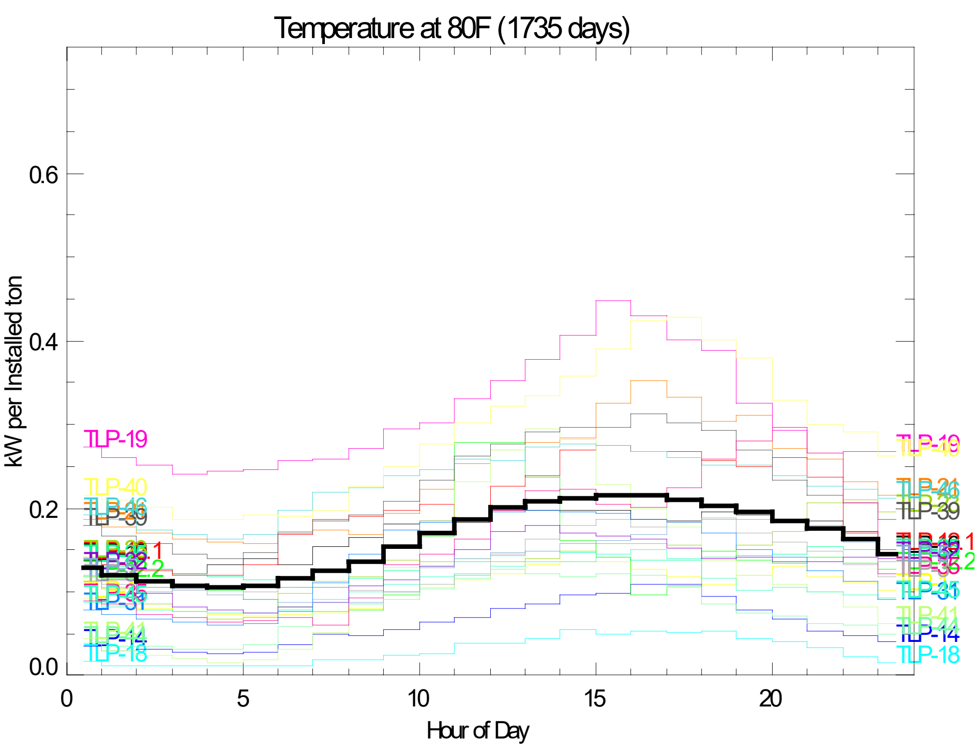


Figure 21 repeats the process above for each winter daily temperature condition and shows the average normalized demand at each temperature range. Table 27 shows the 24 normalized demand values for each hour of the day at each temperature. The normalized demand profile shows that the demand is higher at lower temperatures with highest demand values for days at 10°F.

Figure 21. Normalized Demand Profiles for all Sites at Various Winter Temperatures

Number of days and number of sites given in parentheses.

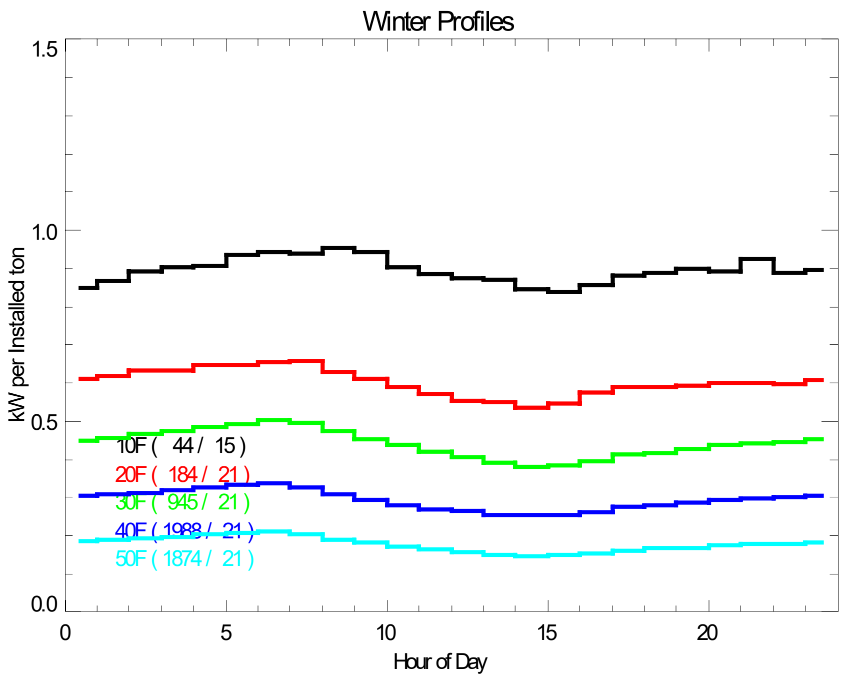


Table 27. Normalized Demand Profiles for Heating

Data from Figure 21

Temp (F)	Average Normalized Demand for Each Hour: 1 to 24 (kW per nominal ton)
10	0.85 0.87 0.89 0.90 0.91 0.94 0.94 0.94 0.95 0.94 0.90 0.89 0.87 0.87 0.85 0.84 0.86 0.88 0.89 0.90 0.89 0.93 0.89 0.89
20	0.61 0.62 0.63 0.63 0.65 0.65 0.65 0.66 0.63 0.61 0.59 0.57 0.55 0.55 0.54 0.55 0.57 0.59 0.59 0.59 0.60 0.60 0.60 0.61
30	0.45 0.46 0.47 0.48 0.48 0.49 0.50 0.49 0.47 0.45 0.44 0.42 0.41 0.39 0.38 0.39 0.39 0.41 0.42 0.43 0.44 0.44 0.45 0.45
40	0.30 0.31 0.31 0.32 0.33 0.33 0.34 0.33 0.31 0.29 0.28 0.27 0.26 0.26 0.25 0.26 0.26 0.27 0.28 0.29 0.29 0.30 0.30 0.30
50	0.19 0.19 0.19 0.20 0.20 0.21 0.21 0.20 0.19 0.18 0.17 0.16 0.16 0.15 0.15 0.15 0.15 0.16 0.17 0.17 0.17 0.18 0.18 0.18

Figure 22 repeats the process above for each summer temperature bin and shows the average normalized demand at each temperature. Table 28 shows the 24 demand values for each hour of the day at each temperature. The shape of the 60°F demand profile, with an early morning peak, implies it is more driven by heating operation than cooling.

Figure 22. Normalized Demand Profiles for all Sites at Various Summer Temperatures

Number of days and number of sites given in parentheses.

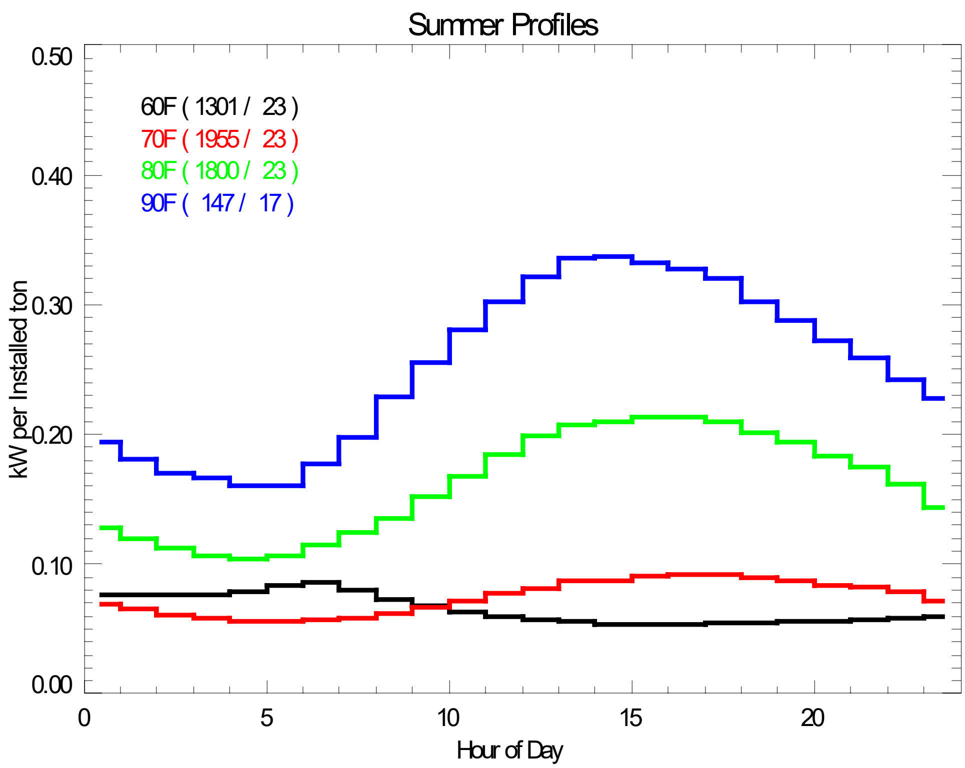


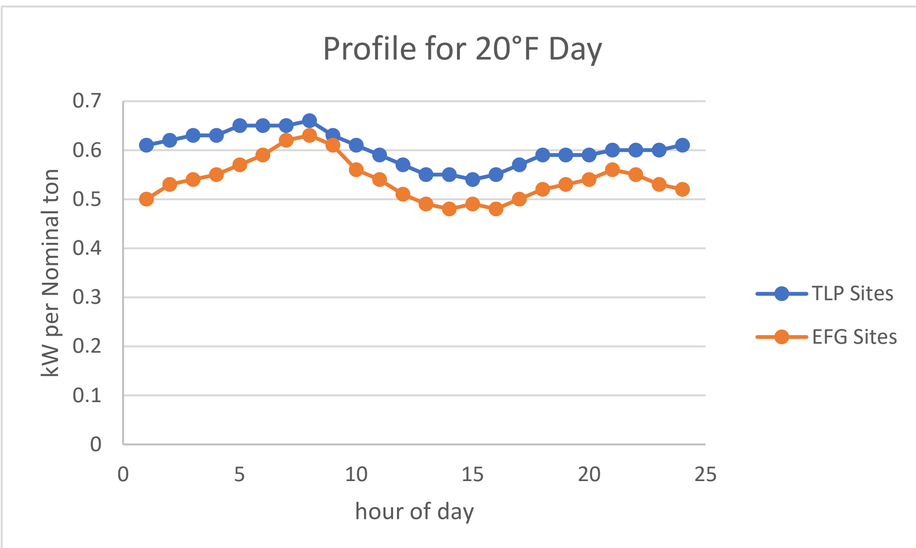
Table 28. Normalized Demand Profiles for Heating

Data from Figure 22.

Temp (F)	Average Normalized Demand for Each Hour: 1 to 24 (kW per nominal ton)
60	0.08 0.08 0.08 0.08 0.08 0.08 0.09 0.08 0.07 0.07 0.06 0.06 0.06 0.06 0.05 0.05 0.05 0.06 0.06 0.06 0.06 0.06 0.06 0.06
70	0.07 0.07 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.07 0.07 0.08 0.08 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.08 0.08 0.08 0.07
80	0.13 0.12 0.11 0.11 0.11 0.11 0.12 0.13 0.14 0.15 0.17 0.19 0.20 0.21 0.21 0.21 0.22 0.21 0.20 0.20 0.19 0.18 0.16 0.15
90	0.20 0.18 0.17 0.17 0.16 0.16 0.18 0.20 0.23 0.26 0.28 0.31 0.32 0.34 0.34 0.34 0.33 0.32 0.31 0.29 0.27 0.26 0.25 0.23

This same analysis for the TLP sites was also completed for the 20 Hudson Valley sites in the Energy Futures Group (EFG) field test project (NYSERDA Report 22-08). The plots in Figure 23 compare the average normalized demand profiles from the EFG and TLP studies for winter days at the same temperature. The profiles for the TLP sites generally show a higher normalized demand than the EFG sites in the heating mode –especially for the 10°F profiles. This difference may be due to the TLP sites being sized to meet all the heating load while the EFG sites were only partial displacement systems meant to meet part of the heating load. This might imply less heat pump capacity is available and running at the coldest conditions at the EFG sites.

Figure 23. Comparing Demand Profiles for TLP and EFG Sites for the Winter



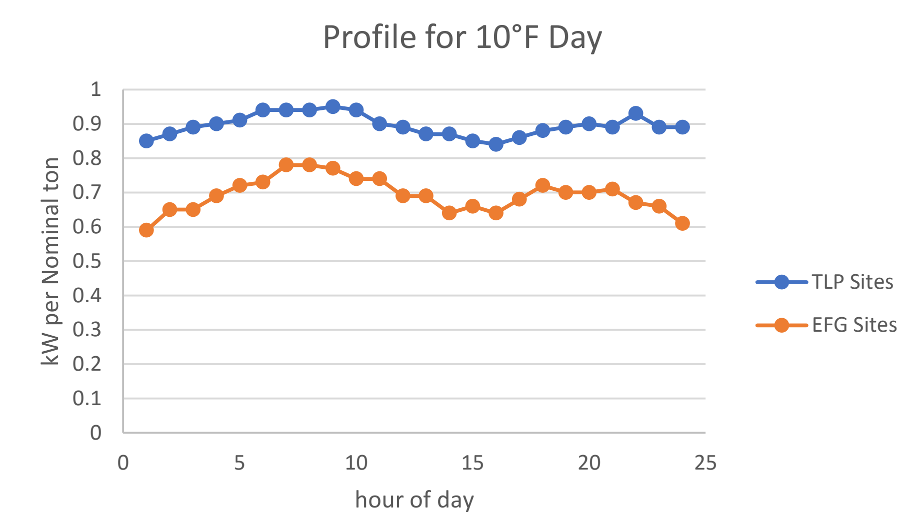
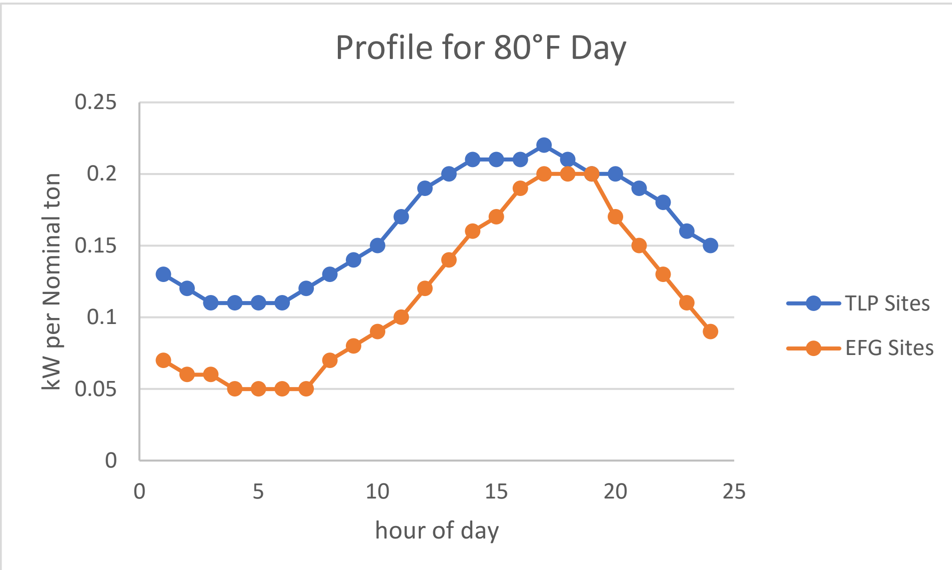
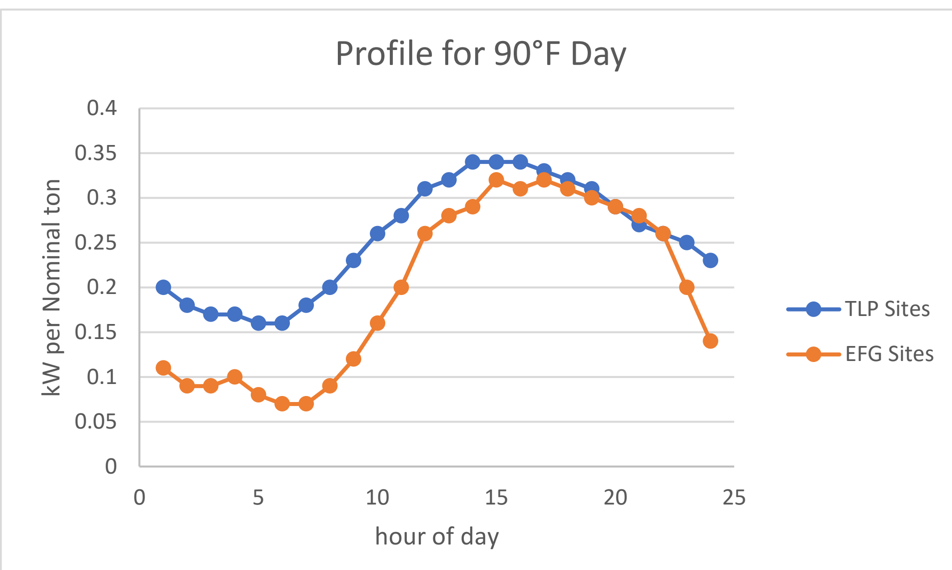


Figure 24 compares the normalized average profiles for the summer days with the same temperature. The summer days have similar peaks for both locations but drop to lower values at night in the Hudson Valley. This might be due to the upstate locations having wider temperature variations or diurnal swings for days with the same average temperature.

Figure 24. Comparing Demand Profiles for TLP and EFG Sites for Summer





3.8 Determining Building Equivalent Full-Load Hours

Many sections of the TRM use the concept of building equivalent full-load hours (BEFLH), which is the annual building load divided by the design load determined by the ACCA Manual J. BEFLH values for heating were theoretically determined by a white paper related to the development of the GSHP measure section in the TRM (Henderson 2020b).

For these sites both the Manual J design heating loads used for sizing the heat pumps as well as the annual heating load for the building (after the weatherization improvements were implemented) were available. Table 29 uses these values to calculate the BEFLH for heating. The average BEFLH is 1,360 and the median is 1,269.

Table 29. Using Design Load and Annual Load to Determine BEFLH

	Design Heating Load (Btu/h)	Annual Space Heating Load (MMBtu)	Heating BEFLH
S1	42,998	44.4	1,032
S3	99,462	170.0	1,709
S5	80,226	129.5	1,614
S10	110,633	145.8	1,318
S12.1	74,167	14.1	466
S12.2		20.4	
S14	76,224	131.1	1,720
S18	51,660	40.4	782
S19	53,612	145.8	2,719
S21	43,095	64.2	1,490
S23	54,411	34.5	634
S25	50,434	57.8	1,145
S31	41,397	50.5	1,221
S32	20,009	35.5	1,775
S35	45,252	103.5	2,287
S39	31,967	22.5	702
S40	23,694	45.5	1,920
S41	47,871	44.4	927
S44	37,926	71.9	1,895
S45	69,456	49.5	713
S46	53,864	60.7	1,127

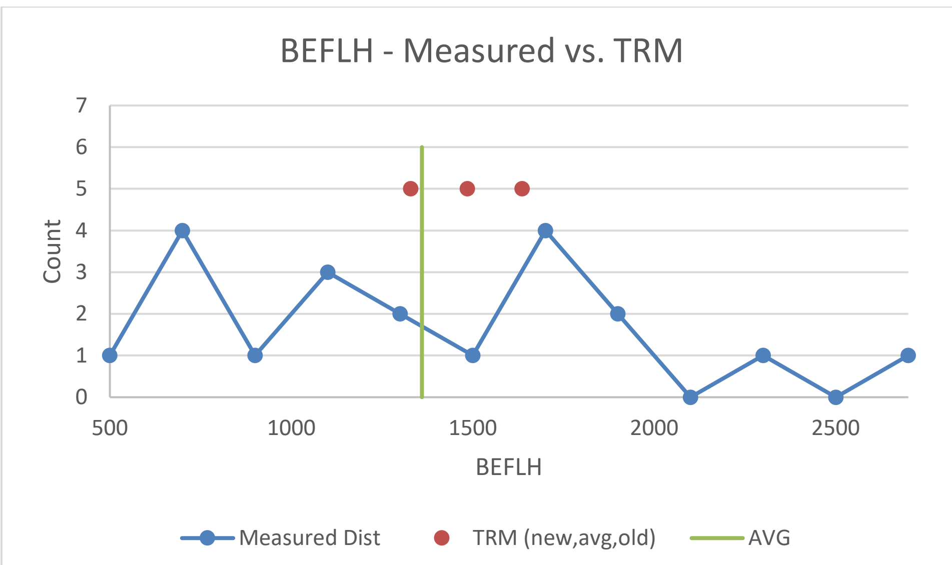
Notes: Both Design Load and Annual Load correspond to the house after weatherization has been implemented.
S19 has a high heating load; it is a fully exposed (unattached) poorly insulated frame structure, that did not receive any weatherization.

Figure 25 shows the distribution of the measured BEFLH values. The vertical line shown on the graph is the average of 1,360. The three circles on the plot are the theoretical BEFLH values from the TRM (Henderson 2020b). The TRM BEFLH values are 1,329, 1,485, and 1,636 corresponding to new construction, average construction, and old buildings, respectively.

While this is a wide distribution—perhaps in part due to the uncertainty surrounding the heating savings associated with weatherization—the average for the twenty sites is 92% of the TRM value for average construction. After weatherization was completed in these older homes, it is reasonable to assume the condition of these homes corresponded to "average" construction.

Figure 25. Distribution of BEFLH

Round dots are from the TRM; vertical line is average of the 20 sites**.**



4 Results: Customer Surveys

This section presents the results from the customer surveys completed by Frontier Energy (FE).

4.1 Survey Approach

FE administered a two-part survey of participating residents using SurveyMonkey®. A web survey was first given around the time of installation of the ccASHPs (Web Survey 1) and then again ~12 months later (Web Survey 2). At some of these sites the team also followed up by phone with additional questions. Not all respondents were asked all questions—those pertaining to quality of work, cost, and motivations to proceed with the installation were only asked of homeowners. The survey instrument used for this effort are given in appendix C.

The survey results are presented below. FE received twenty responses on the Web Survey 1, and eighteen on Web Survey 2. Specific survey response results are provided in Table 30.

Table 30. Responses to the Surveys at Various Stages

	Responses	Out of	Completion
Web Survey 1	20	20	100%
Phone Survey 1	9	10	90%
Web Survey 2	18	20	90%
Phone Survey 2	6	10	60%

Notes: S19 and S35 did not complete Web Survey 2.

The remainder of this section provides a summary of the findings that FE obtained through Web Survey 1 and Web Survey 2. Web Survey 1 occurred around the time of installation of the heat pumps and Web Survey 2 occurred after the heat pumps had been installed for at least one year. In all graphs, the number of responses is shown on the bars in each chart.

Survey questions focused on seven key areas:

- Customer's decision process to install an air source heat pump (and consideration/decision to install solar).
- Customer's satisfaction with the contractor and installation process.
- Customer's experience with heating/cooling equipment maintenance.
- Customer's perceived comfort with heating/cooling equipment.

- Customer's experience operating the heat pump(s).
- Customer's satisfaction with the heating/cooling equipment.
- Other feedback.

4.2 Decision to Install

Participants were asked how important ("very," "somewhat," "not at all") a variety of factors were in their decision-making process to install an air source heat pump system. The fourteen factors respondents had to choose from can be broadly grouped as follows: two related to climate change, four related to financial savings, six related to health/comfort, one related to feeling comfortable making the investment "recommended by someone I trust" and one related to status image, or "modern, trendy technology."

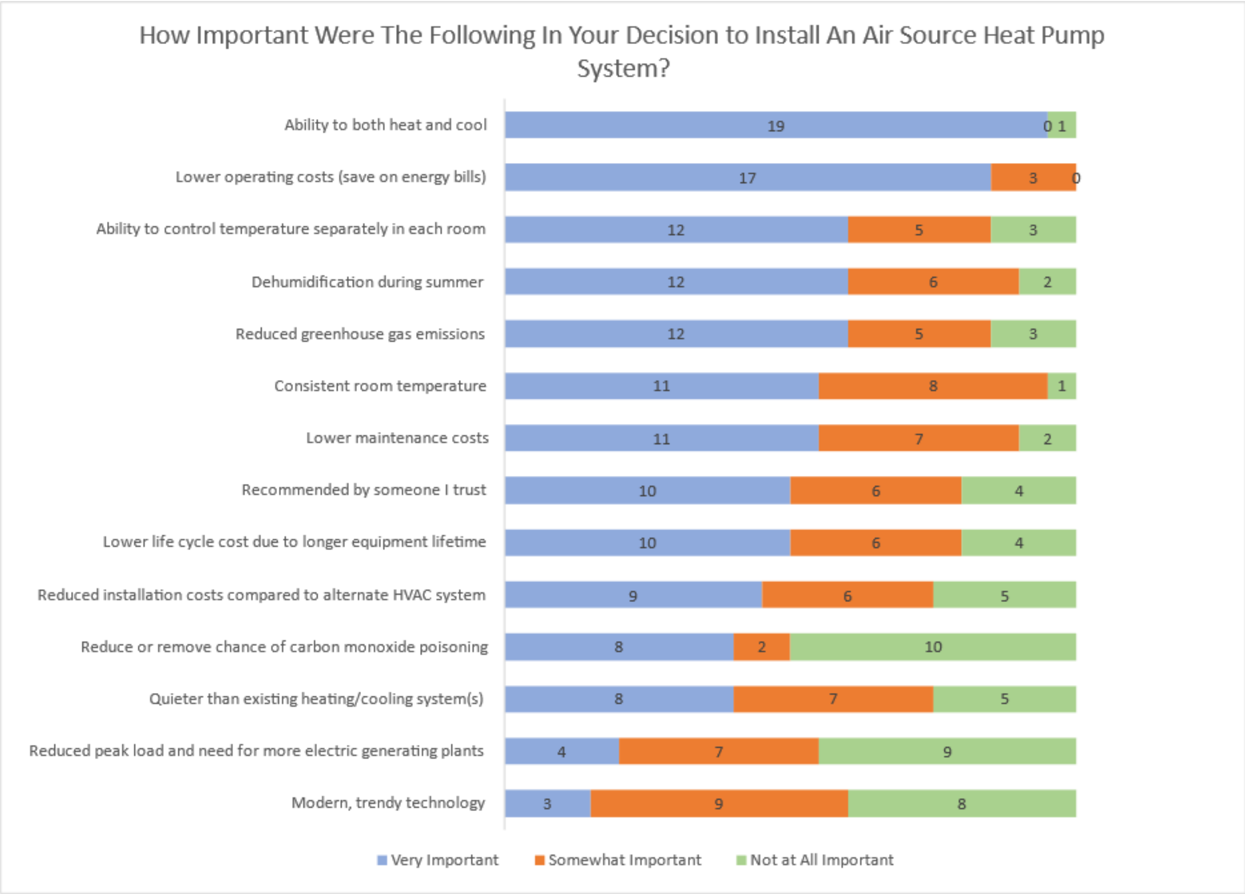
As shown in Figure 26, "ability to both heat and cool" and "lower operating costs" received the most "very important" responses at 19 of 20 and 17 of 20, respectively.

The other factor that could also be considered to relate to climate change ("reduced peak load and need for more electric generating plants") only received 20% (four total) of respondents selecting these factors as "very important." This difference may be due to many homeowners being unaware of the role peak demand plays in greenhouse gas emissions.

Comfort was also very important with 60% of respondents indicating "ability to control temperature separately in each room" and "dehumidification during summer" being very important. Having a system that is a "modern, trendy technology" was not at all important to eight respondents (40%), somewhat important to only nine (45%) and very important to only three respondents (15%).

Figure 26. Importance of Factors in Decision to Install an ASHP System

Numbers represent the number of respondents who selected each option.



Separate from the surveys discussed above, the following additional comments regarding motivation to participate were recorded (these comments occurred during phone calls made with participants to obtain their fuel records for data analysis purposes):

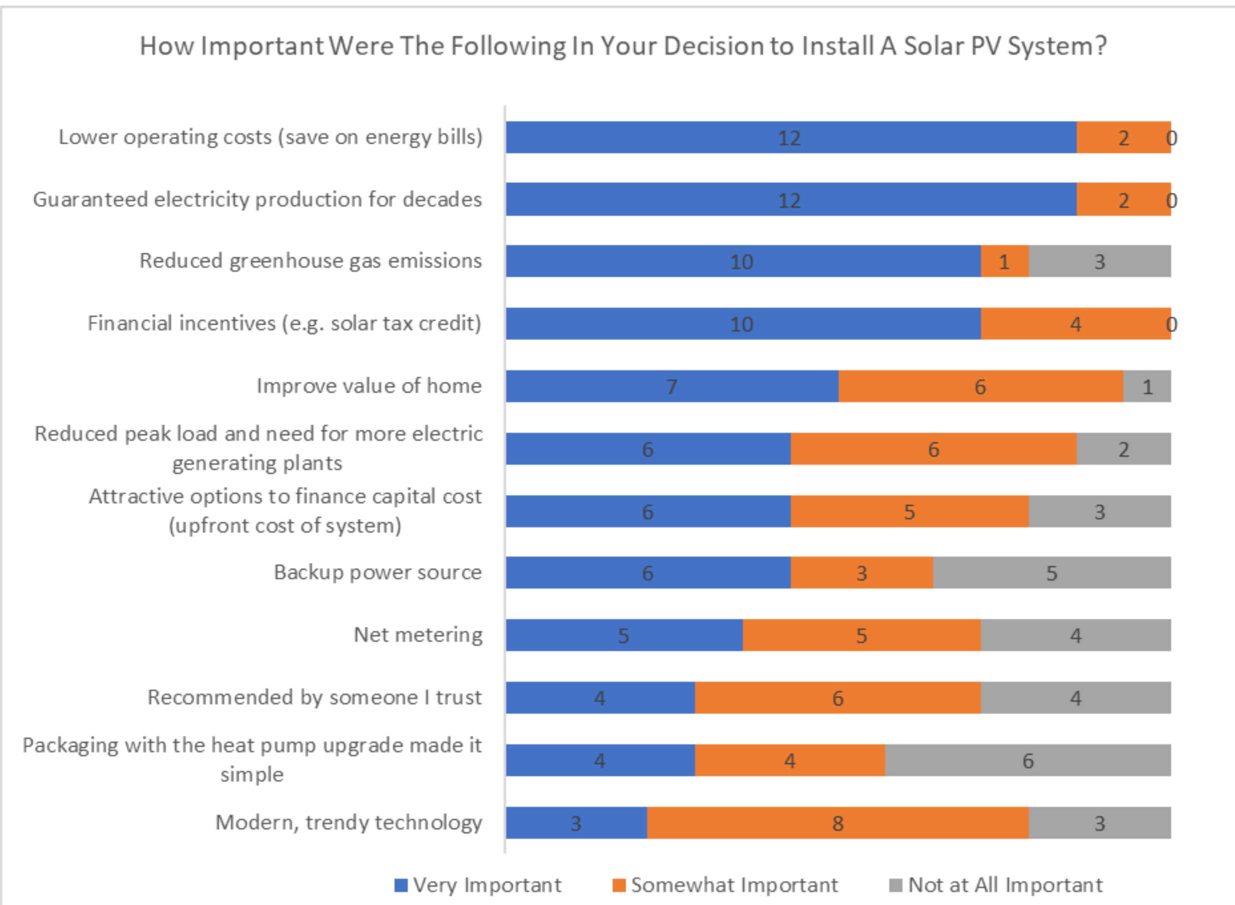
- "The boiler that came with the house is at least 15 years old, so do I want to spend money to upgrade the old boiler, or move to a new technology."
- "The radiant floor could not keep comfortable temperatures when there were prolonged periods of extremely cold weather. ASHPs are the easiest answer to providing additional heat for us and our tenant space."
- "Frees up floor space from bulky radiators."

After a year or more experience with the heat pump, phone calls were again made to obtain fuel records. The following anecdotal feedback was recorded:

- "I cannot think of a single disadvantage of having the system. I am very comfortable in both heating and cooling."

Customers were also asked whether they had considered installing solar and if so, why. Fifteen out of twenty customer participants had considered installing solar, with guaranteed electricity production and reduced costs playing the most important roles in that consideration. Figure 27 shows the role different factors have in participants considering solar (the numbers represent the number of respondents who selected each option). While the question asked, "How important were the following in your decision to install a solar PV system?" and fifteen participants answered positively, ultimately, only three sites had solar, all of which had been installed prior to participating in the program. Additionally, pairing heat pump installations with solar installations was not considered important by most.

Figure 27. Importance of Factors in Decision to Install a Solar PV System

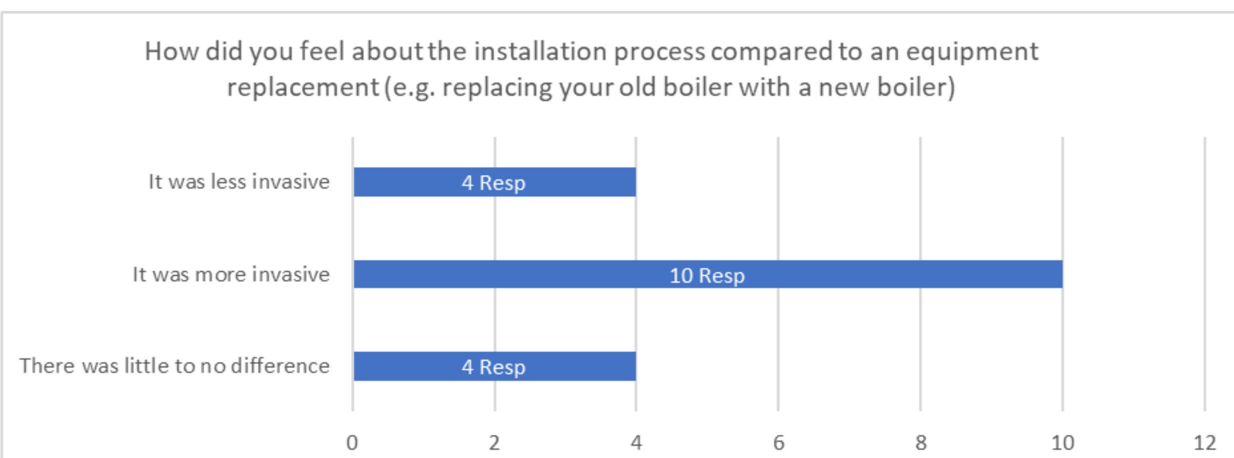


4.3 Installation Experience

Customers were asked how satisfied they were with the work carried out by the heat pump contractor, and how they felt about the installation process compared to an equipment replacement (e.g., replacing an old boiler with a new boiler). As shown in Figure 28, homeowners were generally very satisfied with the work carried out by the contractor, with no homeowner being dissatisfied. Assessing how invasive the installation process was in comparison to replacing the existing heating system varied, however, more than half of the respondents agreed it was more invasive (Figure 29).[2]

Figure 28. Customer Satisfaction with Work Carried Out by a Heat Pump Contractor

Figure 29. Customer Experience with the Installation Process



4.4 Maintenance Experience

Customers were asked about maintenance from three perspectives. First, the expected level of effort to maintain the heat pumps in comparison to their original heating and cooling systems in Web Survey 1. Second, how much effort it took them to maintain their original heating and cooling systems prior to the heat pump installation, also asked in Web Survey 1. Third, in Web Survey 2 after they had at least a year of experience with the heat pumps, how much effort it took them to maintain the new heat pumps.

As shown in Figure 30, participants experienced a greater improvement in the ease of maintenance of their ccASHP system when compared to their prior heating and cooling systems. Thirty percent of the participants expected heat pumps would be slightly more or much more difficult to maintain than their original heating and cooling systems, followed by 55% expecting them to be slightly or much easier and the remaining 15% expecting the maintenance to be about the same. After a year or more of experience with the ccASHP pump system, 78% stated it was slightly to much easier, with four stating it was “about the same” Not one respondent stated that it was slightly or much more difficult than their original systems.

Figure 30. Expected and Experienced Level of Effort to Maintain ccASHP in Comparison with Prior Heating and Cooling System

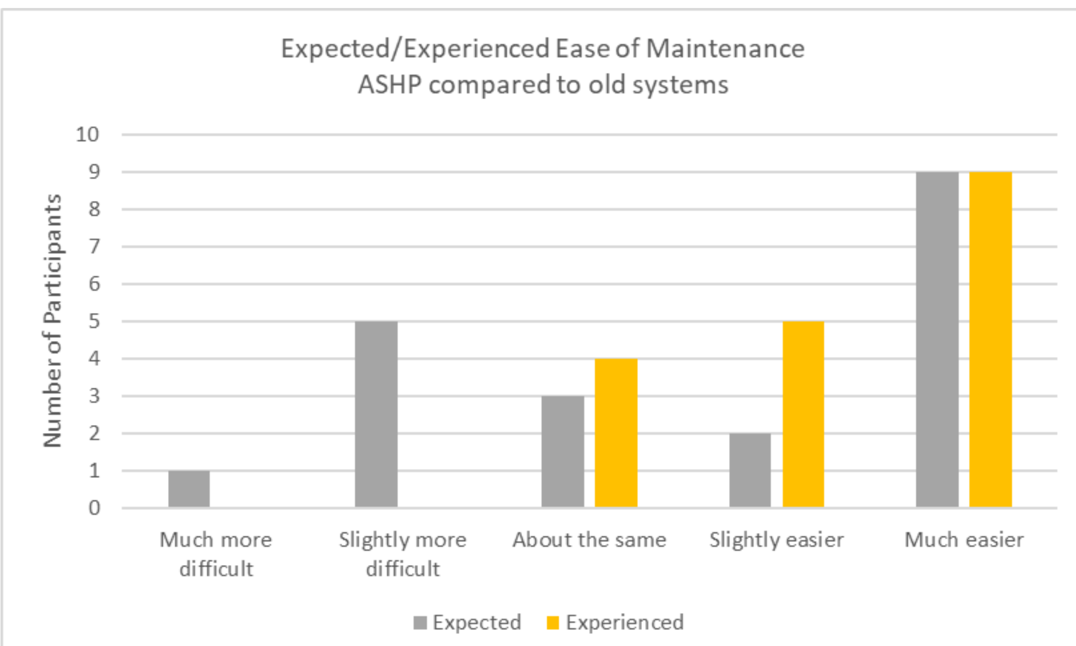
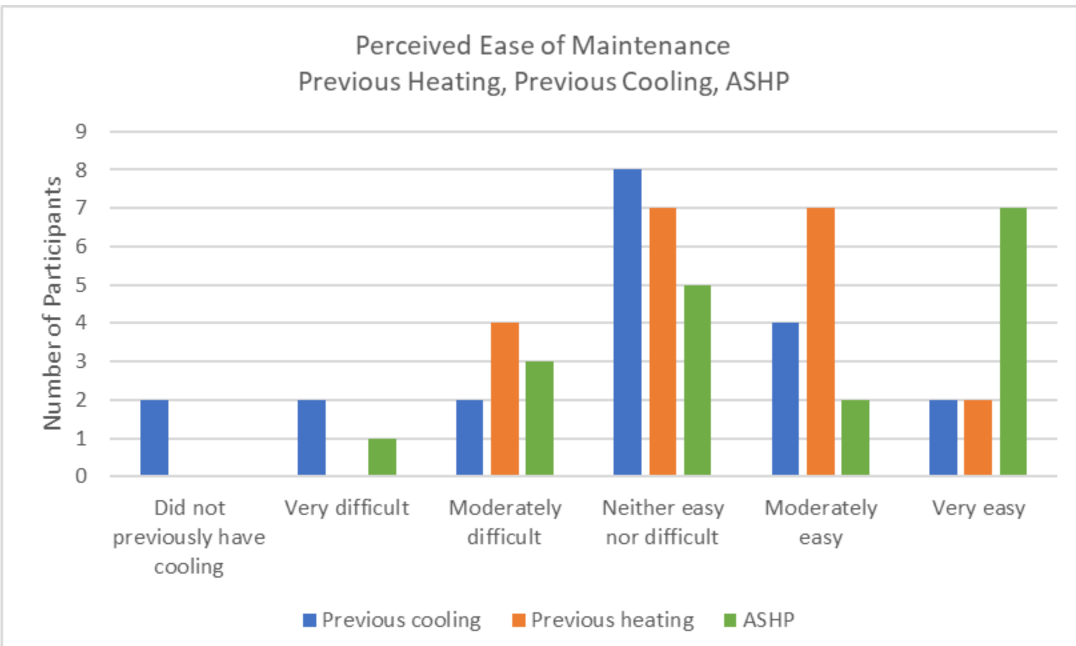


Figure 31 supports this finding, with participants overall finding the ccASHP system easier to maintain than both the previous heating and cooling systems. Generally, customers felt that the level of effort needed to maintain their original heating and cooling equipment was moderately to very easy, as shown in Figure 31. Forty-five percent reported that maintenance of the original heating system was moderately to very easy and 30% had the same response for their original cooling system. Nine respondents felt that maintaining their heat pump was "very easy" or "moderately easy," and four of the respondents felt that maintaining their heat pump was "moderately difficult" or "very difficult." The other five respondents indicated that maintenance was "neither easy nor difficult."

Figure 31. Perceived Levels of Effort to Maintain Previous Heating System, Previous Cooling System, and ASHP System



These results show that the participants felt that generally, maintenance was either easier or comparable to their conventional systems.

When asked in the final survey about their satisfaction of the ASHP system, one respondent who answered somewhat satisfied had the following to say:

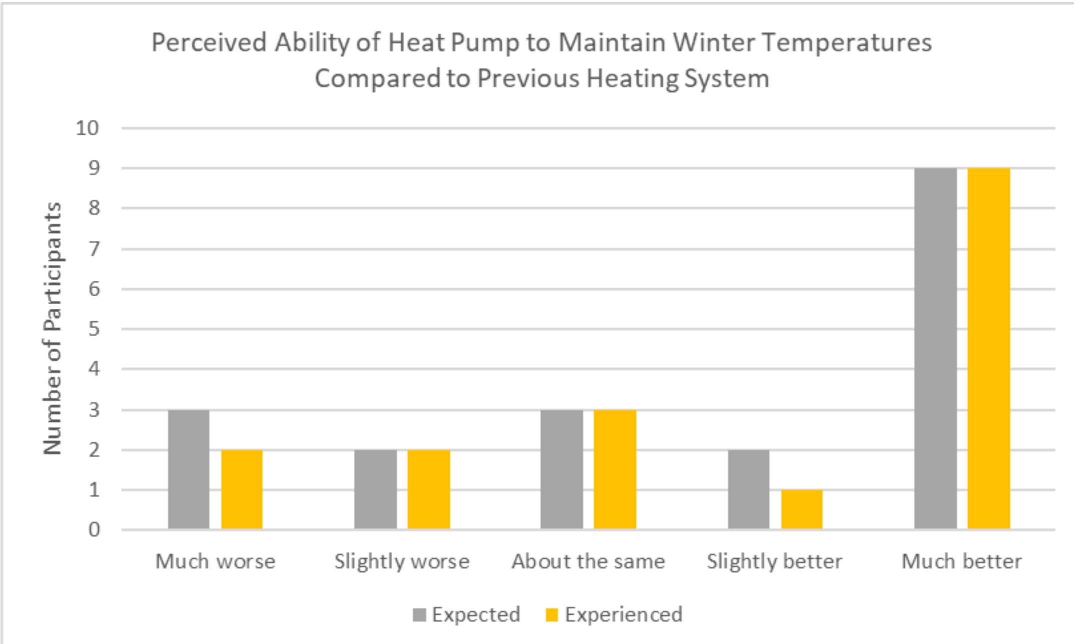
“I am unhappy that there are not more companies that can service the units and do routine maintenance. I have to call the contractor that installed the units each time when the ASHPs need service, and if they are busy, I cannot find anyone else. Vacuuming out the indoor units is difficult due to the height of the ceilings”

4.5 Perceived Comfort

Customers were asked a series of questions related to comfort. Web Survey 1 asked whether their desired temperature was reached with their original heating/cooling system prior to the heat pump being installed. Web Survey 1 also asked what their expectations were in terms of the heat pump system providing them with their desired temperatures for both heating and cooling. Web Survey 2 asked how the heat pump performed during winter and how this compared to their original heating system, and how the heat pump performed during summer and how this compared to their original cooling system. Finally, participants were asked whether they had noticed any temperature change in their basements.

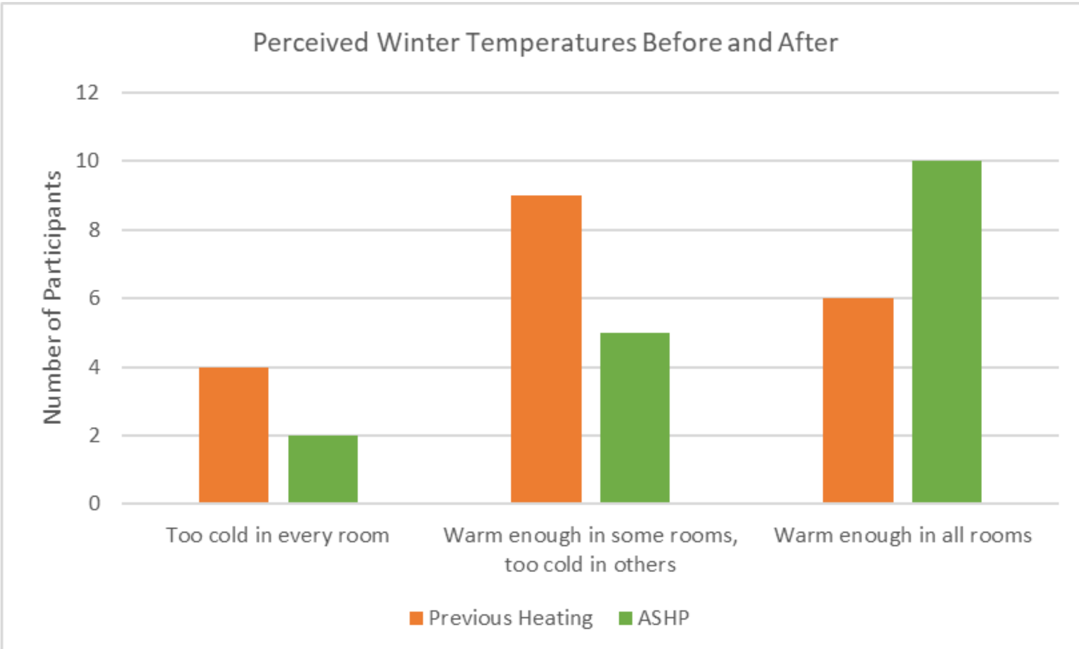
Overall, most participants found that their heat pumps maintained winter temperatures about as expected, though some did feel that it was worse (S3 & S12 much worse; S14 & S39 slightly worse). As Figure 32 shows, 58% of the participants expected the heat pumps to maintain their desired heating temperature slightly or much better than their original heating system, with three respondents (16%) expecting it to be about the same.

Figure 32. Perceived Ability of Heat Pump to Maintain Desired Winter Temperatures Compared to Previous Heating System



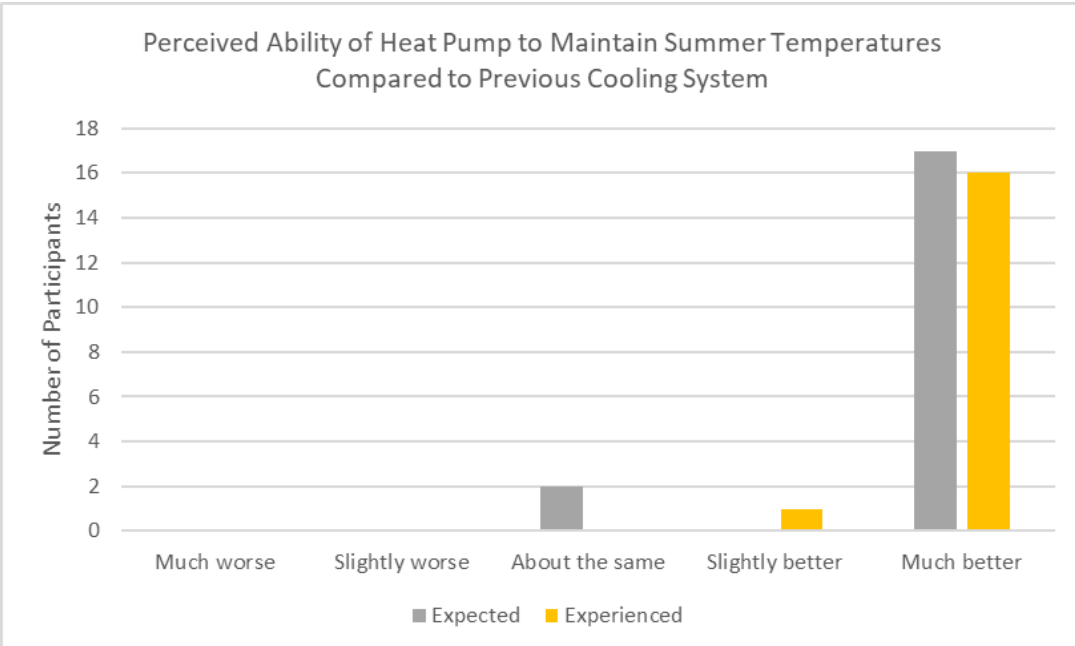
Participants reported an improvement in the distribution of temperatures throughout the home, as seen in Figure 33. Prior to the installation of the heat pump system, most participants felt that their original heating equipment maintained their desired temperatures in some rooms but not others (47%, or nine out of nineteen respondents). Six of the respondents felt that their desired temperature during the heating season was achieved in all rooms, and four felt that their desired temperature was never achieved. After the ccASHP system was installed ten out of the seventeen (59%) participants indicated all rooms were warm enough with only two participants (12%) reporting that all rooms were too cold in winter (S1 and S3). For S1 the heat pump was sized at 150% of the heating load, so it may have been a distribution issues that caused some rooms to be too cold. For S3 the heat pumps were sized at only 79% of the load, which could have explained the cold rooms. S3 was also one of the sites that switched back to using the boiler after a few months. Both of these sites also identified as "somewhat dissatisfied" in Figure 38.

Figure 33. Perceived Distribution of Comfort throughout Home during Winter for Previous Heating System and ccASHP



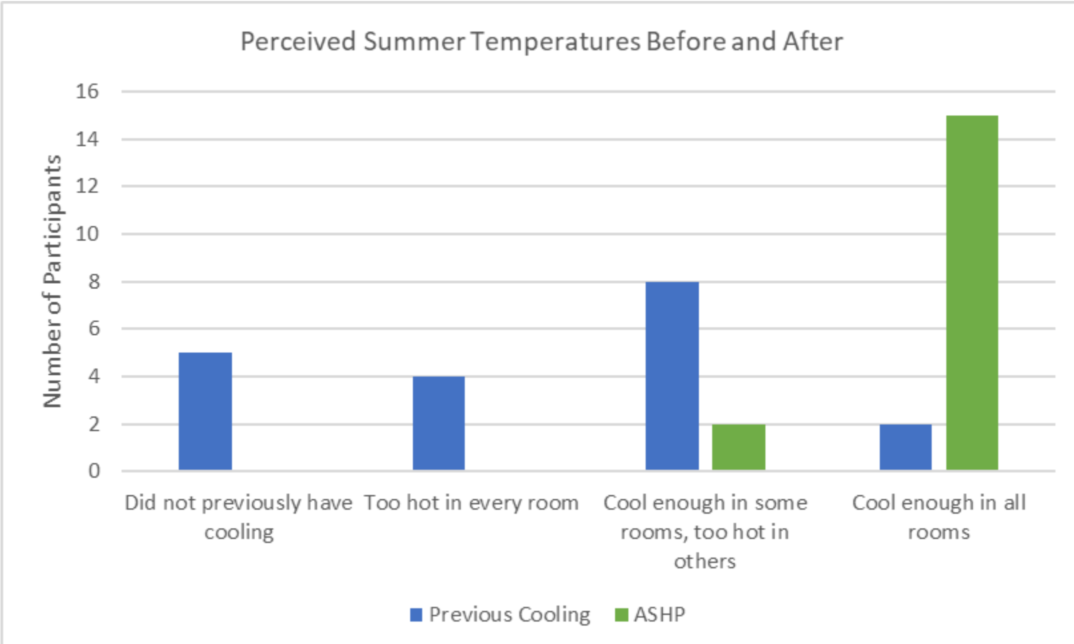
Participant responses for summer temperatures also indicate an improvement in the ability for the heat pump to maintain cool enough temperatures for comfort. For cooling, 94% expected their heat pumps to maintain their desired cooling temperature much better than their original system. Two respondents expected it to be about the same.

Figure 34. Perceived Ability of Heat Pump to Maintain Desired Summer Temperatures Compared to Previous Cooling System



Only two respondents (12%) felt their original cooling system kept all rooms of their home maintained at their desired temperature throughout the cooling season (Figure 35). Eight respondents said some but not all the rooms maintained their desired cooling temperature and four said nowhere in their home was their desired temperature met. Many more participants (15 compared to 2) reported that all rooms were able to achieve their desired temperature with the ccASHP and only 2 participants felt that some rooms were still too hot. The general trend is towards higher comfort with the ccASHP installation.

Figure 35. Perceived Distribution of Comfort throughout Home during Summer for Previous Cooling System and ccASHP

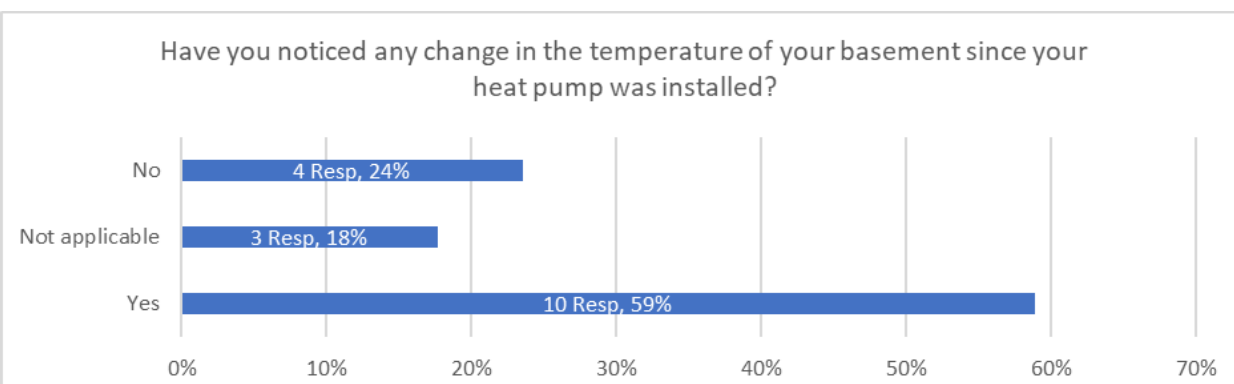


It must be noted that reasons for results are not necessarily explained by the simple survey responses. In the final survey, one participant elaborated:

- "Cooling is amazing much better than the window units we have. Feels like central air."

With regards to the final question pertaining to comfort, more than half of the respondents had noticed a change (i.e., reduction) in basement temperature, as shown in Figure 36.

Figure 36. Perceived Distribution of Comfort in Basement



4.6 Operation

Of the eighteen responders to the final survey, nine reported that it was "very easy" to operate their heat pump, and eight reported that it was "easy," one did not answer the question.

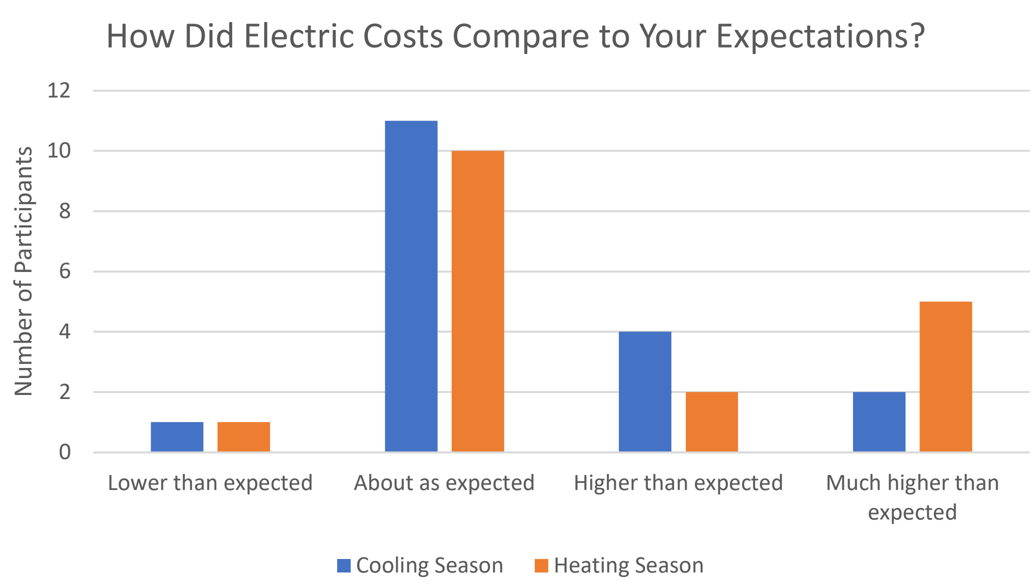
An additional comment from a participant regarding operation are:

- "Very easy to operate, no issues. I like the zoning capability so my parents can have their area at a different temperature than the rest of the house."

4.7 Perception of Electric Costs

Perceptions about operating costs and electric bills were also addressed in the survey. Figure 37 summarizes those perceptions. About seven of the twenty sites felt their electric costs for heating were higher or much higher than expected. Six sites felt the same way about electric costs for cooling.

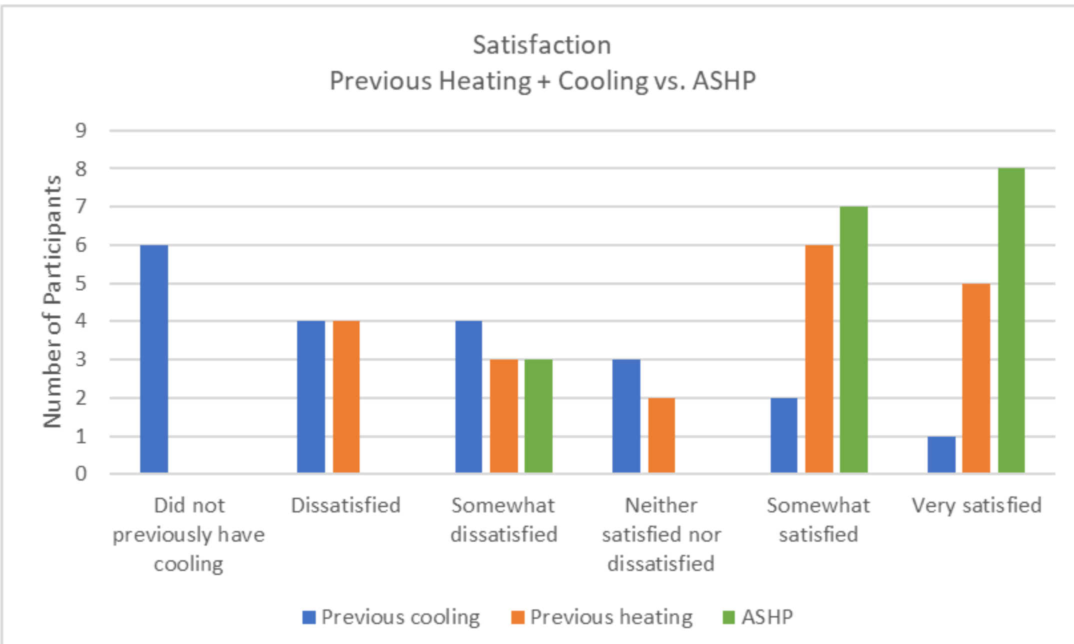
Figure 37. Perception of Electric Costs Relative to Initial Expectations



4.8 Satisfaction

Web Survey 1 asked customers about their satisfaction level with their previous heating and cooling system(s). Web Survey 2 asked those who had experienced their heat pumps for a year, about their satisfaction level with their heat pumps in both the heating and cooling seasons. As shown in Figure 38, satisfaction levels with the previous heating systems varied, but many participants were satisfied or very satisfied prior to the ccASHP system. Participants were typically less satisfied with their previous cooling system and six answered that they did not have a previous cooling system. Fifteen out of eighteen responses to the final survey have reported that they are "very satisfied" or "somewhat satisfied" with their ccASHP system, the level of effort they put into the project was worth the achieved benefits, and if cost and effort were not involved, they still would not switch back to their old heating and cooling systems. No respondents are dissatisfied with their air source heat pump system, however, three respondents (S1, S3, and S5) answered they were "somewhat dissatisfied."

Figure 38. Participant Satisfaction with Previous and ccASHP Cooling and Heating Systems



4.9 Other Feedback

Between the various surveys (web and phone, pre- and post-retrofit), along with other participant conversations (for example, to obtain fuel records), homeowners provided several other comments that did not necessarily fit within a specific survey question. Below are some additional comments given by the participants:

After one-year of ccASHP Operation—Positives/Benefits:

- "I really appreciate the heat pump installation, the whole process was easy and my comfort level at home as well as my family has drastically improved."
- "We felt that the oil boiler and steam system was a serious fire hazard, ugly and hard to maintain, in addition to being environmentally harmful. Glad to see it go."
- "I love the cleanness of the system and the amount of floor space regained but I was disappointed that there was not the cost savings I had expected."
- "Air filtration during the winter time - we switched to a MERV 16 filter during the Covid19 pandemic and psychologically feel safer."
- "The area is much more comfortable in both winter and summer months and such a difference. Love it!!"

After one-year of ccASHP Operation—Concerns/Issues

- "Placement of tenant's compressor is facing door so blows hot air to person exiting from door in summer. Really didn't think electric bills would be so high."
- "There is no heat pump in the bathroom. It's OK in winter because we have floor heating. But in summer it's really hot and there is no way to control that without wasting energy."
- "There is no way to automatically control the temperature to change at different times of day. With a regular heating system, you can set a night temperature and specify at what hours it should be specific temperatures. With the heat pump, you have to remember to go to every room and turn down the temperature at night. This is a HUGE waste of energy. For example, I may think I'm going to go back and work in my office after dinner to I leave the heat or AC on. Then I decide not to but forget to turn down the temp and that pump is on all night."[3]
- "The air is dryer than expected when heating"

Overall, three occupants flagged the fact the electric bills were higher than their expectations (S12, S14, and S46). Two homeowners indicated they had refrigerant charge issues (S14 and S45). And two homeowners reported problems with the condensate disposal systems on their indoor units (S10 and S14).

4.10 Summary of Customer Survey Findings

Based on participants responses it is apparent that homeowners were driven to install heat pumps to lower space conditioning costs and increase comfort. Concerning the installation, most homeowners were very satisfied with their contractor even though more than half thought the installation process was more invasive than installing a traditional boiler replacement. Almost all thought the heat pumps were very easy to maintain and operate, more so than their original systems, though some felt there should be a service available to conduct regular maintenance such as a service contract.

Participants had a range of satisfaction levels with their original heating and (if applicable) cooling equipment. Most expected the heat pumps to maintain temperatures better (especially in cooling) when compared to their previous system, which was achieved in cooling for all but two out of seventeen respondents. In heating, expectations were not met by all participants with just under a third indicating some of the rooms in their home were too cold. When conducting these surveys, it is apparent that indoor unit placement and sizing are key and failure to do this greatly impacts comfort. Only two respondents indicated they were too cold in every room with the heat pumps installed. In the end, overall satisfaction with the heat pumps system was achieved with only three out of seventeen respondents being somewhat dissatisfied and none being dissatisfied.

After speaking with participants both over the phone and in-person during the installation of the monitoring equipment, it was found that if there was dissatisfaction, it had to do with distribution in heating or cost to heat the home in comparison to their original natural gas system. This may point towards the need to better communicate to the customer that wall mounted heat pumps are not central heating and cooling systems that have multiple registers in defined spaces, but rather address conditioning needs for specific spaces. Centrally ducted (or a mix of ductless and compact ducted) systems may be required to meet customer expectations for proper thermal distribution. Additionally, savings estimators/calculators provided to homeowners should be as realistic as possible and communicate the possibility of negative savings if gas prices are low at the time of installation, especially if an efficient boiler system is already in place.

5 Technology Transfer

Throughout the project, the team presented preliminary results at conferences and meetings, including presentation at the 2018 and 2019 Building Energy NY conference, the 2019 NY-GEO conference and other special presentations to special audiences. A final presentation slide deck was provided to NYSERDA and is posted on The Levy Partnership website[4]. In addition to presentation slides, three case studies highlighting three of the demonstration sites were prepared and are included in appendix E. The technology transfer plan also included briefings to industry groups conducted in late 2021. These groups included the New York City Office of Climate and Environmental Justice and Energy Smart Homes Westchester campaign run by Sustainable Westchester.

6 Lessons Learned

This section summarizes the key lessons and findings that resulted from this project.

6.1 Lessons from Measured Performance Data

The analysis approach used to separate heat pump impacts out from combined improvements including both heat pump and envelope measures was largely found to be successful, on average, in this study. By using the estimated energy savings reported by the weatherization contractor, the analysis was able to determine the implied COP. The implied COP for these 20 sites averages 2.4. A flip-flop test for one site confirmed that the estimated weatherization savings were consistent with measured savings.

On average the measured seasonal heating efficiency is 80% of the efficiency indicated by the rated HSPF of the installed systems. In contrast the TRM calculation procedure implies the seasonal efficiency for NY sites should be about 90–100% of the rated HSPF.

The cost savings for natural gas were always less than zero given the assumed regional costs of $0.20/kWh and $1.40 per therm. The EFG study in the Hudson Valley (NYSERDA Report 22-08) also showed negative cost savings for all natural gas sites with the regional electric and gas costs there. Cost savings per installed ton were also less than zero for the oil sites using assumed costs of $2.45 per gallon. In contrast the EFG study (which used different costs for that region) showed positive cost savings of $23 per ton for oil sites.

The fossil fuel savings were typically lower than expected. For the sites in this study, where all systems were sized to meet the entire heating load and displace nearly all boiler operation, the displaced fossil fuel use for space heating was only 86% on average for the 19 sites with savings, even though the average sizing ratio for heating was 129%.

Five sites used the heat pumps initially but then switched back to relying more on boiler operation. For at least three of the five sites, they relied more on boiler operation due to comfort concerns with heat pump operation in colder weather—even though the heat pumps at these sites were properly sized to meet the heating load.

The average annual pre-retrofit space heating load in the 20 sites was 40 MBtu per square foot per year. In contrast the sites in the EFG study (NYSERDA Report 22-08) averaged 30 MBtu per square foot per year, even though the climate was colder. This finding implies that the homes in TLP study, which were generally pre-war or early 20th century vintage, had less upgraded insulation and were leakier envelopes on average compared to the detached, single-family, somewhat-newer suburban homes in the Hudson Valley.

One lesson from this study for future measurement and verification efforts like this is the need to add a survey question about temperature set points in the pre-retrofit period. A key analysis assumption was that occupant behavior and set points would remain the same before and after the new heat pumps were installed. While space temperatures were measured in the post-retrofit period, no measurements were possible before the heat pumps were installed. Occupant-reported information regarding set points before heat pump installation would have been helpful in confirming this key analysis assumption.

6.2 Design and Distribution

The biggest design challenge for heat pump retrofits such as in this project relates to distribution and equipment sizing. The demonstration homes have significant loads because they are older and the thermal envelopes are below current codes, but there are often many spaces within them with small heating loads, well below the minimum capacities available in ductless indoor heat pump units. These are typically spaces with limited exposure to ambient conditions (sometimes because the building is attached to another on one or both sides). Ideally, smaller indoor heat pump heads would be available to serve these spaces; however, other approaches are available.

One solution for these rooms is to substitute a single ceiling-mounted slim (or compact) ducted indoor unit in place of two or three ducted indoor units, which would also reduce the length of refrigerant lines needed. It would require, however, the construction of ductwork, and additional interior work to drop a ceiling and relocate trim and lighting that may be installed in the ceiling, as well as possibly lowering interior doorways. It also requires sufficient ceiling height and owners may dislike the lower ceilings. This cost tradeoff will be site-dependent but worth considering.

For smaller, well insulated, and air-sealed rooms where cooling is not important, or for interior spaces with minimal ambient exposure like bathrooms, small electric resistance heaters can take the place of an indoor head, if the heaters have reliable controls to ensure they are not inadvertently left on unnecessarily.

6.3 Barriers

This demonstration project sought to identify and suggest solutions to overcome barriers to electrification of one to four family homes using cold climate heat pumps. The barriers identified include:

- Cost: Installation cost is high. Retrofits require substantial labor by skilled technicians, which can add thousands of dollars to project costs. Running and connecting refrigerant lines is a large component of the labor cost, and these connections are subject to quality problems as well. Many of the installation defects in these projects were related to either refrigerant leaks or condensate drainage issues, both of which stem from installing the line-sets. Simpler, more foolproof line connection methods and/or unitary (packaged) systems with the same performance as mini-split heat pumps could help overcome this barrier.
- Quality: A significant number of installation defects were discovered in the course of this work. The field of cold climate heat pump retrofits is still young, with few experienced installers and technicians relative to the potential demand. These growing pains will continue and point to the need for a robust third-party QA/QC process.
- Service: Heat pumps, like most space conditioning systems require occasional service. Filters and coils should be cleaned, and condensate drain lines checked periodically. This service is relatively minor, but important. Because of the limited scope of work, high demand, and limited availability of skilled technicians, homeowners may have difficulty retaining regular service at reasonable costs.
- Design: Preparing accurate load calculations can be time consuming and requires technical knowledge. It therefore adds time and cost to projects, and some installers are not willing or competent to do them accurately. Load calculations also require significant judgements especially for retrofit projects when the composition and thermal properties of building assemblies and components such as windows is unknown. Infiltration is also unknown if a blower door test is not conducted; and if air sealing work is included in the scope, then post-retrofit infiltration is also unknown (unless blower door-directed air sealing is conducted to a specific target).
- Savings/payback: Because electricity is more costly per unit of energy than natural gas in the New York City region, electrification often results in higher utility bills for space heating, even when heat pumps are operating efficiently. Increasing the emphasis on insulation and air sealing can reduce the perceived impact of electrification by reducing overall heat demand. Restructuring of utility prices, to reduce electric rates for cold climate heat pump customers or future higher natural gas rates may also change this balance.
- Awareness/education: Homeowner awareness and understanding of heat pumps is limited. Most of these projects converted hydronic or steam systems to warm air heating. This resulted in perceived and sometimes actual differences in comfort (both positive and negative), as seen in the homeowner survey responses. In some cases, the lack of understanding can lead to heat pump hesitancy, but further exposure to successful heat pump retrofits can counteract and eventually overcome this reluctance.

6.4 Homeowner Perceptions and Motivations

One underlying motivation for homeowners was the need to improve the comfort of their home. Allowing and encouraging homeowners to talk about rooms and spots that are uncomfortable (cold, drafty, etc.) can build their commitment to the retrofit. It may also inform the design—locations for air handlers and need for envelope measures to address the biggest complaints. Targeted insulation and air sealing is underappreciated because the work can be invasive, dirty, and when complete, not visible. However, it can make a large difference in comfort—more so in a home with heat pumps than with a boiler because of the differences in the heat delivery system.

Homeowners are also concerned about the aesthetics and cleanliness of their home after the work is completed. Contractors should clearly describe how the work area will be restored to acceptable condition at the agreed budget. For example, is painting included? Will refrigerant and condensate lines be surface mounted or recessed or covered? Surface-mounted refrigerant lines are less expensive than recessed lines; and recessed lines may not be possible in some cases. However, if lines are surface mounted, make sure the homeowner has a clear understanding of their planned location and how the resulting installation will appear. Use realistic photos of previous installations and bring samples of line covers to eliminate any possibility of misunderstanding. This holds true for both interior and exterior surface mounted lines.

Similarly, contractor should communicate the planned location of all components (indoor and outdoor units as well as condensate pumps, if any) in writing and/or with sketches, as well as marking the locations on walls with painter's tape so both the client and installers know where they go. Overall, contractors and homeowners should expect surprises and budget for a few hours of problem solving. Offer solutions to solve roadblocks, not demands for more money. Finger-pointing diminishes client's confidence.

For many clients, heat pumps are a new technology, and very different from boilers and radiators because significant new work in the living space is required. Conducting a thorough training with the homeowners will save time by avoiding calls later. Upon completion of the installation, contractors should walk them through the controls, showing the various operation modes for all zones. A tutorial for proper heating usage should counsel residents to minimize thermostat adjustments and large setbacks. Heat pumps operate most efficiently and will have fewer problems if left to run at continuous low to moderate speeds, rather than ramping up and down constantly. Emphasize the importance of maintenance—for filters and outdoor coils. Consider offering a service plan for these tasks and call back seasonally to schedule service.

7 References and Bibliography

Canadian Standards Association. 2019. Standard EXP07:19 Load-based and climate specific testing and rating procedures for heat pumps and air conditioners.

Harley, B. 2020. EXP07:19 Load-Based and Climate-Specific Testing and Rating Procedures for Heat Pumps and Air Conditioners: Interim Lab Testing and Rating Results. Report prepared for NEEA, BC Hydro and National Resources Canada. July 7.

Henderson, H.I., 2020a. Savings Calculations for Residential Air Source Heat Pumps: The Basis for Modifying EFLH and Seasonal Efficiency Factors for “Whole House” and “Displacement” Applications. Prepared for the New York State Energy Research and Development Authority (NYSERDA) and the New York State Department of Public Service. June.

Henderson, H.I., 2020b. Savings Calculations for Residential Ground Source Heat Pumps: The Basis for Equivalent Full Load Hours (EFLH) and Seasonal Efficiency Factors. Prepared for the New York State Energy Research and Development Authority (NYSERDA) and the New York State Department of Public Service. June.

New York State Energy Research and Development Authority (NYSERDA). 2022. “Hudson Valley Heat Pump Pilot (HVHPP) Program: Demonstrating the Emerging Technology of Cold Climate Air Source Heat Pumps,” NYSERDA Report Number 22-08. Prepared by Energy Futures Group, Owahgena Consulting, Frontier Energy, Bruce Harley Energy Consulting, and Integral Building and Design. nyserda.ny.gov/publications

Technical Resource Manual (TRM). New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs - Residential, Multi-Family, and Commercial/Industrial. Version 9 filed on October 27, 2021 with the New York Department of Public Service. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/NYS%20TRM%20V9.pdf

Appendix A. Program Documents that TLP Used to Recruit and Evaluate Sites

This appendix includes:

- The sample site agreement used for each site.
- The NYSERDA commissioning check list that was provided contractors and used for quality assurance purposes.

Site Agreement: Replacing Fossil Fuel Heat with Mini-Split Heat Pumps in Urban Housing Stock (Under NYSERDA Agreement # 104080)

Parties: ___________________________________ (CITY, NY) (Site Owner) and The Levy Partnership, Inc. (New York, NY)

The New York State Energy Research and Development Authority (NYSERDA) is sponsoring an Emerging Technologies Program to demonstrate replacing fossil fuel heat with mini-split heat pumps in 20 small residential buildings. The goal of the retrofits is to provide satisfactory space heating and cooling service at a lower cost than with traditional steam or hydronic heat and window air conditioners.

The Levy Partnership, Inc. (TLP) is under contract to NYSERDA to coordinate this project and work with site owners, an implementation contractor and a measurement and verification (M&V) contractor hired by NYSERDA to install the equipment and evaluate its performance. This MOU outlines the responsibilities of the Site Owner and TLP under this project. This obligation commences on the date this Agreement is executed and shall continue for 14 months after the retrofit system becomes operational.

Effective as of the date of this memorandum, Site Owner and TLP enter into this MOU agreeing to work jointly as follows:

Responsibilities of The Levy Partnership, Inc.:

The Levy Partnership, Inc. in collaboration with subcontractor Centsible House agrees to undertake the following tasks with respect to the project:

1. **Project management and planning:** Coordinating with NYSERDA including reporting, preparing project plans and securing NYSERDA approvals.
2. **Site selection:** Site recruitment, preparing site recommendation report and obtaining site approval from NYSERDA.
3. **Design:** Preparing site design and obtaining NYSERDA design approval.
4. **Financing:** Provide funds from NYSERDA Agreement #104080 to reduce implementation cost to Site Owner in the amount of $5,250. Half ($2,625) to be provided after installation and commissioning of the heat pumps, and the balance upon successful completion of the 12-month data collection. In addition, solicit equipment/material discounts from manufacturer/supplier partners.
5. **Installation:** Prepare and submit site installation report to NYSERDA.
6. **Measurement and verification:** Facilitate access to sites for M&V contractor and provide support to M&V contractor.
7. **Technology transfer:** Conduct technology transfer activities such as technical article(s), newsletter article(s), technical presentation(s), open house(s), website/blog.

Key TLP contacts

Jordan Dentz, The Levy Partnership, Inc., Vice President

Julie Liu, Centsible House

Responsibilities of Site Owner

Site Owner agrees to contribute the following to the Project:

1. **Provide access.** Provide access to all spaces in the building including mechanical spaces for TLP, NYSERDA and/or its agents/guests for inspections, data collection, documentation, and installing and retrieving monitoring equipment.
2. **Contract retrofit.** Enter into an agreement with the project Implementation Contractor to conduct the retrofit according to design approved by NYSERDA. The retrofit scope may include, but is not limited to, some or all of the following items:
    - Attic, wall and/or rim joist insulation
    - Air sealing
    - Inverter-driven, air source heat pump(s)
    - Existing heating systems shall remain in place (assuming they are serviceable) as backup systems.
    - Ventilation/exhaust fan(s)
3. **Conduct retrofit.** Authorize and facilitate the retrofit in full by the project Implementation Contractor and its subcontractor(s) according to design approved by NYSERDA. Site Owner is responsible for costs other than that provided by TLP as described above and any additional funding provided by other State or Utility programs.
4. **Operation and maintenance.** Operate the retrofitted heating, cooling and ventilation (if present) equipment as intended by the design and in keeping with manufacturer's instructions. Because no pre-retrofit utility data is available for this site, operate heat pumps and boiler space heating during alternating periods of approximately two weeks each over the course of the first winter of operation (at least two such periods for each heating system). Do not operate boiler space heat during heat pump periods and do not operate heat pumps during boiler heating periods. Maintain equipment in good working order; notify the Implementation Contractor should any problems occur with the newly installed equipment or materials and facilitate repair/correction by Implementation Contractor or its subcontractor.
5. **Provide utility data.** Provide to TLP energy bills (electricity, natural gas, propane, oil, etc.) for the building for a minimum period of one year following the retrofit. Also, when separately metered, facilitate collection by TLP of tenant utility account data for same period. To simplify access to these data, permit TLP to enroll all utility accounts in the building in WegoHome from Wegowise (or similar utility tracking service), including providing utility account numbers and sharing password(s) with TLP. WegoHome (or similar) account will be turned over to Site Owner upon conclusion of the data collection period. Allow the temporary installation of sensors and data loggers on heating, cooling, electrical and ventilation equipment. It is understood that aggregated data will be published in reports produced by TLP and/or NYSERDA and individual site data will only be published with express permission of the site owner.
6. **Facilitate occupant survey.** Facilitate and participate in occupant surveys or interviews to be conducted by TLP or its subcontractor prior to, and following the retrofit.

7. **Publicity.** Take part in publicity activities organized by TLP and its subcontractor, including but not limited to permitting publication of project information in case studies and various electronic and printed media.

Key Site Owner contact(s):

Name:

Name:

Site Address:

Title to equipment and disposition of data

Title to all retrofit measures including heating and cooling equipment, ventilation equipment, insulation and air sealing materials installed under this project shall rest with the building owner.

Title to all M&V equipment such as sensors, data loggers, communication devices and other equipment temporarily installed to gather, record and transmit data on system and home operation shall rest with the M&V contractor and shall be removed by the M&V contractor or their designee at the conclusion of the project period.

All data collected from the above equipment as well as data collected from observation and interviews with building occupants during the monitoring period shall be the property of NYSERDA and its contractors. The use, public performance, reproduction, distribution, or modification of any materials does not and will not violate the rights of any third parties, including, but not limited to, copyrights, trademarks, service marks, publicity, or privacy.

Limitations of responsibility

As part of Site Owner's participation in this demonstration, the equipment and service being provided by The Levy Partnership, Inc. and its subcontractors and the M&V contractor and its subcontractors is funded, in part, by the New York State Energy Research and Development Authority (NYSERDA). The participant agrees to hold harmless NYSERDA, its agents and employees against loss or expense, including legal fees, from any and all claims, demands, losses, causes of action, damage, lawsuits and judgments, including attorney fees and costs arising out of or in consequence of this agreement.

None of the parties to this MOU shall incur any legal obligations under this MOU. Neither this MOU nor TLP's actions in the conduct of this project imply responsibility for the work of any project suppliers or contractors.

The above is agreed and accepted to:

Print Name:	Jordan Dentz
Print Title:	The Levy Partnership, Inc.
Date: ______________________, 2018	Date: ______________________, 2018

PARTICIPATING INSTALLER FIELD INSPECTION & COMMISSIONING CHECKLISTS

NEW YORK STATE OF OPPORTUNITY | NYSERDA

Air-Source Heat Pump Program

NYSERDA maintains the integrity of the Air-Source Heat Pump (ASHP) Program through an independent standards and quality assurance team, which manages the quality assurance (QA) system for the ASHP program. The QA system includes verifying compliance with program and installation standards using comprehensive field inspections and a commissioning checklist. QA field inspections and review of completed commissioning checklists are conducted by a qualified independent third-party competitively selected by NYSERDA and will use these checklists as their guides. Participating Installers are required to submit proof of all corrective action taken when a specific installation requirement has not been met and is deemed to be a major or critical system failure.

The checklists contained in this document represent an abbreviated form of the inspector's field inspection checklist used by the ASHP program as well as the required commissioning checklist. Participating installers should reference these checklists for each ASHP installation to serve as a verification that each pertinent requirement has been met and that each required commissioning action has been completed and documented.

Field Definitions

Installation Category — The Category field represents the highest level of the inspection checklist hierarchy and may include one or more measures.

Installation Element — The Measure field falls under a Category and represents a specific component that is open for inspection.

Installation Requirement — The Installation Requirement field falls under a Measure and represent the specific inspection checkpoints that an inspector would score for a given component

Code/Program Manual (PM) Reference — Each installation requirement that is tied back to either the ASHP Program Manual (PM), code reference, or Manufacturer instructions. Both the New York State (NYS) Energy Conservation Construction Code and the New York City (NYC) Energy Conservation Code are based on the 2015 International Energy Conservation Code (IECC), with supplements. Citations of the IECC include the supplements. Both New York State and New York City adopted the versions of the National Electric Code (NEC) and the International Mechanical Code (IMC). New York State adopted the International Residential Code (IRC) and International Building Code (IBC), although New York City's residential citations are in the NYC Building Code (NYCBC) which is substantially based on the International Building Code (IBC).

Rating
Fail (F) — The identified installation requirement has not been met.

Pass (P) — The identified installation requirement has been met.

N/A — The identified installation requirement is not applicable to this installation or was not able to be inspected.

Deficiency Category — Each task requirement is assigned a deficiency category of either incidental, minor, major or critical. Refer to the deficiency category descriptions below for additional detail. NYSERDA will require a participating installer to document through pictures and/or notes verification of resolution of all major and critical deficiencies. Minor and Incidental deficiencies need to be corrected but NYSERDA will not be verifying resolution.

Incidental — Not expected, on its own, to pose a substantial risk of system failure or hazard.

Minor — Require re-wiring to address but are not expected to pose a substantial risk of system failure or hazard.

Major — Present an increased risk of system failure or hazard but are not determined to be in imminent danger of failure or hazard.

Critical — Present an imminent hazard and/or probability of system failure.

ASHP Field Inspection Requirements

Installation Category	Installation Element	System Size - Applies to Single- Family, Multifamily or Both	Installation Requirement	Code/ Program Manual (PM) Reference	Deficiency Category	Rating		
						F	P	N/A
Ducts	Insulation	Both	Where ducts in unconditioned spaces are used by the installed system, ducts are sealed and insulated to code (generally to R-8), including register boots sealed to drywall or other interior surface penetration.	IECC sections R403.3.1, R403.3.2, and R402.4.1.1	Minor	F	P	N/A
Electrical	Access	Both	Adequate access has been provided around electric panels, including disconnects.	NEC	Minor	F	P	N/A
Electrical	Disconnect	Both	A suitable disconnect is provided for heat pump at exterior unit.	NEC	Major	F	P	N/A
Electrical	Fuse Size	Both	The fuse/breaker size is appropriate for the maximum circuit ampacity.	NEC	Critical	F	P	N/A
Electrical	Grounding	Both	The indoor unit, the outdoor unit, and the electrical panel connections are properly grounded per the NEC.	NEC	Major	F	P	N/A
Electrical	Wiring	Both	Wiring connections at the panels and heat pump units conform to the NEC.	NEC	Major	F	P	N/A
Electrical	Wiring	Both	The wiring conductor size is adequate for the equipment.	NEC	Critical	F	P	N/A
Electrical	Wiring	Both	The electrical conductor type is suitable for the installation.	NEC	Major	F	P	N/A
Electrical	Wiring	Both	All electrical raceways installed have correct fittings, are suitable for the location, and are properly supported.	NEC	Minor	F	P	N/A
Equipment	Access	Both	Service access and sufficient clearance from walls, overhangs, doors, windows, and other protrusions has been provided around the interior and exterior units, per code and manufacturer instructions. Air flow is unobstructed.	IMC 306	Minor	F	P	N/A
Equipment	Exterior Unit	Both	Outdoor unit is installed above expected snow line.	PM page 5	Minor	F	P	N/A

Installation Category	Installation Element	System Size -Applies to Single-Family, Multifamily or Both	Installation Requirement	Code/ Program Manual (PM) Reference	Deficiency Category	Rating		
						F	P	N/A
Equipment	Exterior Unit	Both	If the unit is set under the roof line/edge, rain/snow/ice shield or drain cap is provided.	PM page 5	Minor	F	P	N/A
Equipment	Exterior Unit	Both	Unused openings in electrical equipment are closed (with protection substantially equivalent to the wall of the equipment). Refrigerant pipe penetrations of electrical compartment are properly sealed.	NEC	Major	F	P	N/A
Equipment	Interior and Exterior Unit	Both	Interior and Exterior units are level and properly supported and anchored.	PM page 5	Minor	F	P	N/A
Equipment	Filters	Both	Ducted system includes a filter system that meets manufacturer's specifications (where applicable).	PM Page 5	Incidental	F	P	N/A
Equipment	Heat	Both	Where supplemental electric-resistance heating is installed as part of the system, the supplemental heat operates correctly (only on 2nd stage or higher). When outdoor conditions are such that the heat pump capacity can meet the building heating load, controls prevent supplemental heat on any normal thermostat stage.	IECC R403.1.2; C403.2.4.11	Major	F	P	N/A
General	Equipment and Accessories	Both	All equipment and accessories are installed in a workmanlike manner.	PM page 5	Incidental	F	P	N/A
Owner Education	Documentation	Both	The owner was given a copy of the manufacturer Operation and Maintenance manual and provided with contact information for emergency service needs.	PM Page 5	Incidental	F	P	N/A
Owner Education	Operation	Both	The owner has been given training by installer, and understands basic system operation, especially heating operation; operation and adjustment of dampers (if applicable); and controls. The owner understands how to program controls and thermostats (as needed). The owner understands basic safety and maintenance.	PM Page5	Incidental	F	P	N/A
Performance Testing	Heat Pump	Both	Controls are verified to function in all basic modes of operation that can be tested under current conditions.	PM page 5	Major	F	P	N/A

Installation Category	Installation Element	System Size -Applies to Single-Family, Multifamily or Both	Installation Requirement	Code/ Program Manual (PM) Reference	Deficiency Category	Rating		
						F	P	N/A
Piping	Condensate	Both	The condensate drain is installed per the manufacturer requirements and code. Is it properly sized, pitched, and configured to permit the clearing of blockages? If a condensate pump is provided, pump operates. Discharge of condensate is to a drain or outdoors, away from crawlspaces, walkways, streets, alleys, or outdoor equipment. If damage to any building components would occur as the result of overflow or blockage, a secondary condensate drain system is installed. Does the condensate line drain water?	PM Page 5; IMC 307.2.3; IRC M-1411.3	Minor	F	P	N/A
Piping	Exterior Pipe Penetration	Both	Exterior pipe penetrations are sealed weather tight (where visible) and resistant to rodents. Provide flashing as necessary.	IRC P2606, P2607; IBC 1405.4	Minor	F	P	N/A
Piping	Insulation	Both	Pipes are insulated (no exposed copper). Insulation is installed correctly, of the correct thickness, and meets code (R-3 minimum) and manufacturer requirements.	IECC R403.4; IECC Table C403.2.10; PM Page 5	Minor	F	P	N/A
Piping	Insulation	Both	Exterior pipe insulation is covered with UV resistant cover or coating.	Required by insulation manufacturer	Incidental	F	P	N/A
Piping	Interior Pipe Penetrations	Multifamily	Pipe penetrations of rated walls and ceilings (where visible) have been fire stopped with a listed material or assembly.	IBC Chapter 7	Minor	F	P	N/A
Piping	Interior Pipe Penetrations	Multifamily	Where refrigerant piping penetrates a floor, ceiling or roof, the installation conforms to one of the exceptions in the mechanical code.	IMC 1107.2	Minor	F	P	N/A
Piping	Joining	Both	The use of a refrigerant leak detector shows that field- installed fitting(s) are not leaking.	PM Page 5	Major	F	P	N/A
Piping	Sizing	Both	The refrigerant pipe sizing, height change, and line length meets manufacturer requirements.	PM Page 5	Major	F	P	N/A

Installation Category	Installation Element	System Size -Applies to Single-Family, Multifamily or Both	Installation Requirement	Code/ Program Manual (PM) Reference	Deficiency Category	Rating		
						F	P	N/A
Piping	Supports	Both	Pipe supports and support spacing, where visible, conform to the code and manufacturer instructions; piping and piping supports appear to be securely installed.	IMC 305	Minor	F	P	N/A
System Documentation	Confirmation of Startup Report	Both	The system was pressure tested with nitrogen and evacuated to 250 microns (or manufacturer's required evacuation limit).	PM Page 5, IMC 1108, Manufacturer's Instructions	Major	F	P	N/A
System Documentation	Equipment	Both	The model number matches the application and is listed on the NEEP Cold Climate ASHP Specification Listing (NYSERDA Approved Application).	PM Page 4	Critical	F	P	N/A
System Documentation	Labeling	Both	Proper labeling is present in electrical panels and disconnects in accordance with the NEC.	NEC	Incidental	F	P	N/A
System Documentation	Property	Both	The property is a full-time occupied, residential property served by a CEF or SBC utility payment.	PM Page 4	Critical	F	P	N/A
System Documentation	Warranty	Both	Warranty provided meets the System Warranty section of the Air Source Heat Pump Program Manual (PM).	PM Page 5	Minor	F	P	N/A

Air-Source Heat Pump Commissioning Checklist

Project Application No.:	
Site Owner Name:	
Manufacturer:	Model #:

Installer to Complete. Check Done or N/A Column. Fill in Blanks. Installer to Sign.

Done	N/A	Item Description
		Heat Pump Units
		Outdoor unit height above grade (inches) to avoid snow line: ______________________________.
		Outdoor unit is under roof drip line and is protected by ice/snow shield.
		Outdoor unit was measured to be level and is fastened to structure or mechanical pad.
		Outdoor unit has unobstructed airflow as required by manufacturer.
		Indoor unit has clearance for service and operation as required by manufacturer.
		Indoor unit is properly located, properly fastened to structure, and is level.
		Condensate line is supported every 4 feet, is pitched to outlet, and drains water.
		Line Set
		Diameter of line set __________________
		Minimum line set length per manufacturer ______________ Maximum Length ______________
		Maximum line set length permitted by manufacturer for factory charge _____________________
		Maximum line set vertical difference per manufacturer ___________________
		Installed line set length __________________ Installed vertical difference __________________
		Line set length exceeds manufacturer's requirements for factory charge
		Refrigerant added: Pounds _________________ Ounces __________________
		Line set purged with N_2; Pressure tested with N_2; Evacuated to 250 $_{\mu m}$ or per manufacturer.
		N_2 test pressure (PSIG) __________________ Test duration (minutes) __________________
		Vacuum Level ($_{\mu m}$) __________________ Vacuum duration (minutes) __________________
		Brazing joint(s) was required. N_2 purge used during brazing operations.
		Flare connection tightened per mfg.'s recommended torque. Torque setting _______________
		Line sets and units were sensed with refrigerant detector and no leaks were found.
		Insulation completely covers line sets. Insulation UV protection provided exterior of building.
		Floor/Wall/Ceiling pipe penetrations are sealed.

Air-Source Heat Pump Commissioning Checklist (continued)

Done	N/A	Item Description
		Operation/Controls
		Unit(s) were operated in heating and cooling modes to verify proper operation.
		Continuous fan function disabled.
		Ducted Units
		Design airflow ________________ Design discharge static pressure ______________
		Measured airflow ________________ Measured static pressure ________________
		Ducts were sized to ACCA Manual D or equivalent.
		Ducts are sealed, and no leaks are evident.
		Any ducts outside condition space are insulated to Code.
		Information to Site Owner
		I have provided an Owner's Manual for the Heat Pump to the Site Owner.
		I showed the Site Owner how to control the Heat Pump including turning on and off, adjust the temperature, and switch between heating and cooling, I explained preventive maintenance requirements including how to clean and/or change the filter. I showed the Site Owner what alarms look like when the heat pump is not functioning properly.
		I provided the Warranty to the Site Owner. The Site Owner understands who to contact for service.

Installer Signature:	**Date:**
Installer Name:	

Appendix B. Heat Pump System Design Details for each Site

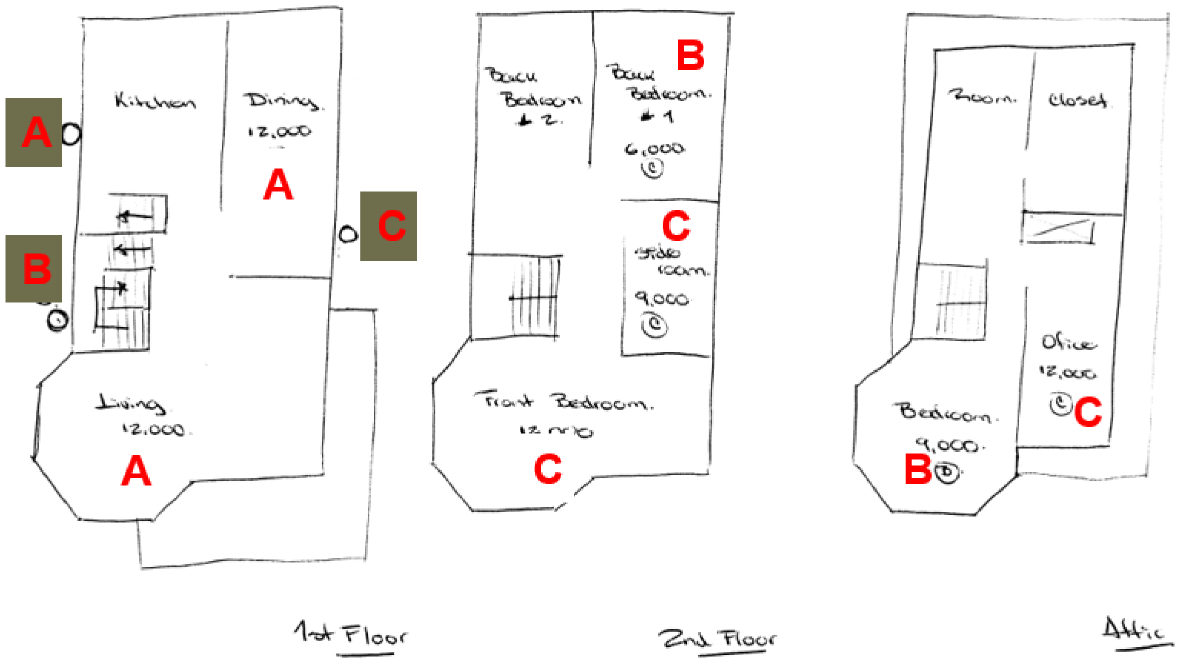
This appendix provides a more detailed description of the heat pumps installed at each site.

Appendix B – Site Design Details

S1

		RHVAC sizing calcs		Outdoor unit (Operational Performance)			Indoor units		
Floor	Room	Cooling	Heating	Model	Cooling	Heating	Model	Cooling	Heating
1st floor (garden level)	Living Room			not installed; hydronic system remains					
	kitchen								
	Total	16,123	14,199						
2nd floor (parlor level)	Living Room			AOU24RLXFZH			ASU12RLF1	12,000	13,500
	Kitchen/Dining						ASU12RLF1	12,000	13,500
	Total	15,957	20,738		22,000	25,000	**Indoor total**	24,000	27,000
3rd floor	Office			AOU36RLXFZH			ASU7RLF	7,000	8,100
	Hallway						ASU9RLF	9,000	10,200
	Front Bedroom						AUU12RLF	12,000	13,500
	Rear Bedroom						ASU9RLF	9,000	10,200
	Total	18,908	22,260		35,200	36,400	**Indoor total**	37,000	42,000
Total flr 2&3	Btu	34,865	42,998		57,200	61,400		61,000	69,000
	Ton	2.9	3.6		4.8	5.1		5.1	5.8

		Outdoor unit			Indoor units		
Floor	Room	Model	Cooling	Heating	Model	Cooling	Heating
1st	Living Room	MXZ-3C24NAHZ	**22,000**	**25,000**	MSZ-FH12NA	12,000	13,600
	Dining Bedroom				MSZ-FH09NA	12,000	13,600
	Total				**Indoor unit total**	**24,000**	**27,200**
Attic	Front Room	MXZ-3C24NAHZ	**22,000**	**25,000**	MSZ-FH12NA	12,000	13,600
2nd	Back Bedroom				MSZ-FH06NA	6,000	8,700
	Total				**Indoor unit total**	**18,000**	**22,300**
2nd	Front Bedroom	MXZ-3C30NAHZ	**28,400**	**28,600**	MSZ-FH12NA	9,000	10,900
Attic	Office				MSZ-FH12NA	12,000	13,600
2nd	Side Bedroom				MSZ-FH09NA	9,000	10,900
	Total				**Indoor unit total**	**30,000**	**35,400**
		Total Cap Outdoor	**72,400**	**78,600**			
		RHVAC load calc	**82,230**	**99,462**			

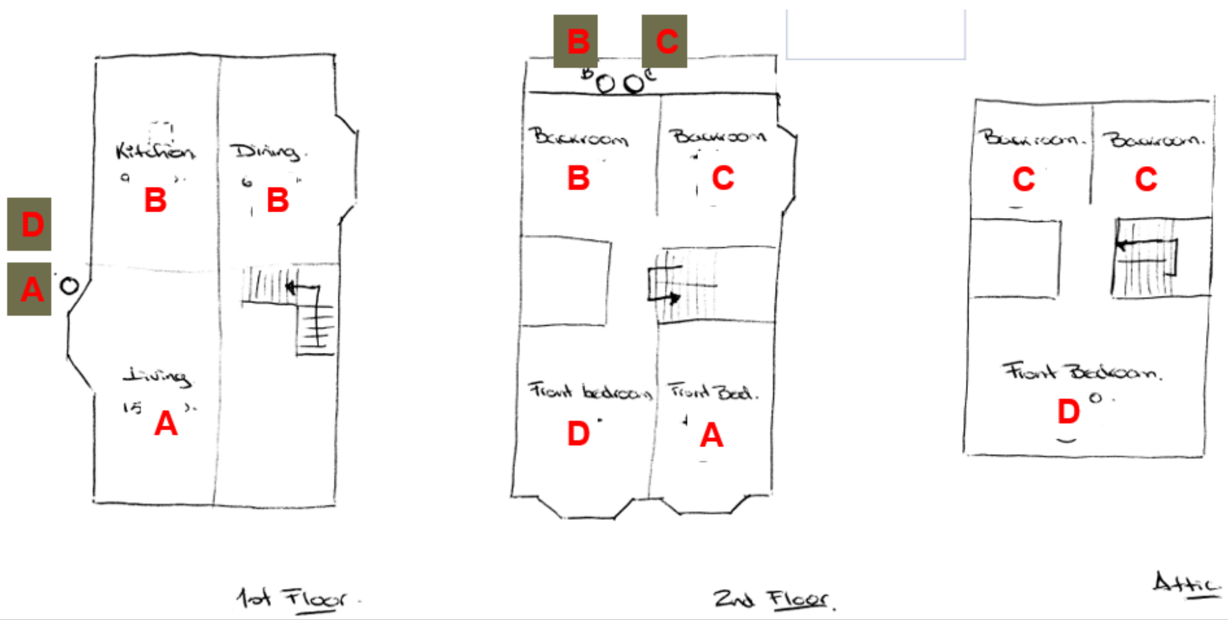


A
B
C
Kitchen
Dining.
12,000
A
Living
12,000.
A
Back Bedroom # 2.
Back Bedroom. # 1
6,000
B
C
9,000
Front Bedroom.
C
Room.
Closet.
Office
12,000
C
Bedroom.
9,000.
B
1st Floor
2nd Floor
Attic

Appendix B

		Outdoor unit			Indoor units		
Floor	**Room**	**Model**	**Cooling**	**Heating**	**Model**	**Cooling**	**Heating**
1st	Living Room	MXZ-3C24NAHZ2			MSZ-FH15NA	15,000	18,000
2nd	Front Bedroom 1				MSZ-FH06NA	6,000	8,700
	Total	**A**	**22,000**	**25,000**	**Indoor unit total**	**21,000**	**26,700**
1st	Dining Room	MXZ-3C24NAHZ2			MSZ-FH06NA	6,000	8,700
	Kitchen				SLZ-KA09NAR1.TH	9,000	10,900
2nd	Back Bedroom 2	**B**			MSZ-FH06NA	6,000	8,700
	Total		**22,000**	**25,000**	**Indoor unit total**	**21,000**	**28,300**
2nd	Back Bedroom 1	MXZ-3C24NAHZ2			MSZ-FH06NA	6,000	8,700
Attic	Back Bedroom-1				MSZ-FH06NA	6,000	8,700
	Back Bedroom 2	**C**			MSZ-FH06NA	6,000	8,700
	Total		**22,000**	**25,000**	**Indoor unit total**	**18,000**	**26,100**
Attic	Front Room	MXZ-3C24NAHZ2			MSZ-FH09NA	9,000	10,900
2nd	Front Bedroom 2				MSZ-FH06NA	6,000	8,700
	Total	**D**	**22000**	**25000**	**Indoor unit total**	**15,000**	**19,600**

Total capacity		Calculated loads	
Cooling	Heating	Cooling	Heating
88,000	100,000	67,176	80,226

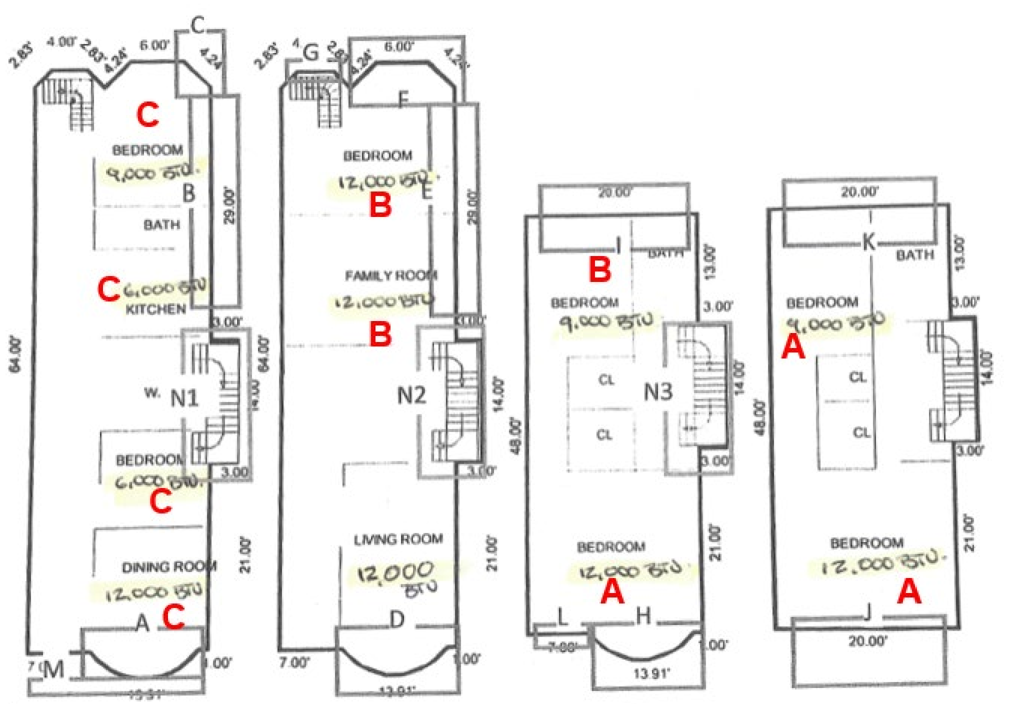


Appendix B

S10

		Equipment Selection					
		Outdoor unit			Indoor units		
Floor	Room	Model	Cooling	Heating	Model	Cooling	Heating
1st floor	Living Room (C1)	MXZ-4C36NAHZ C			MSZ-FH12NA	12,000	10,900
	Bedroom (C2)				MSZ-FH06NA	6,000	8,700
	Kitchen (C3)				MSZ-FH06NA	6,000	8,700
	Back Bedroom (C4)				MSZ-FH09NA	9,000	10,900
	Total		**36,000**	**45,000**	**total**	**33,000**	**39,200**
2nd floor	Dining/Kitchen (B1)	MXZ-3C30NAHZ B			MSZ-FH15NA	15,000	12,900
	Back Bedroom (B2)				MSZ-FH12NA	9,000	7,900
3rd Floor	Bedroom (B3)				MSZ-FH09NA	9,000	7,900
	Total		**28,400**	**28,600**	**total**	**33,000**	**28,700**
3rd Floor	Front Bedoom (A1)	MXZ-3C30NAHZ A			MSZ-FH12NA	12,000	13,600
4th floor	Front Bedroom (A2)				MSZ-FH12NA	12,000	13,600
	Bedroom (A3)				MSZ-FH09NA	9,000	10,900
	Total		**28,400**	**28,600**	**total**	**33,000**	**38,100**
House Total	BTUH		92,800	102,200		99,000	106,000
	Tons		7.7	8.5		8.3	8.8

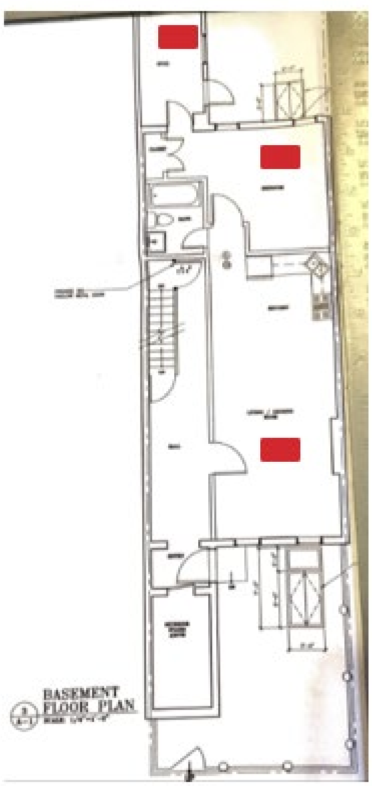
Loads	
93,273	110,633

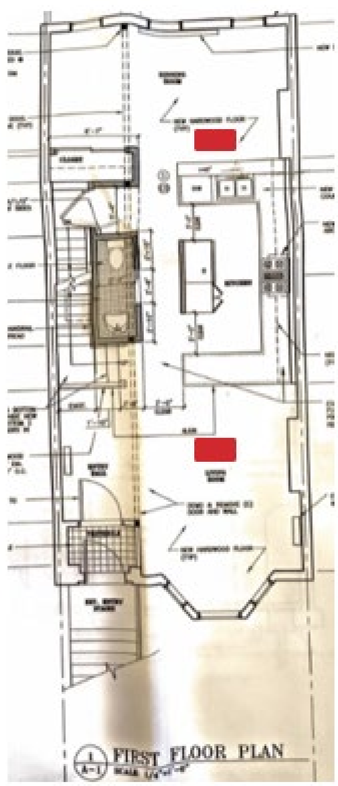


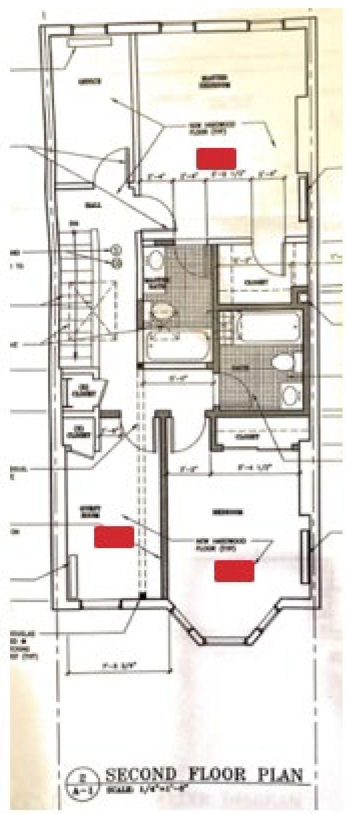
Appendix B

S12

		Outdoor unit			Indoor units		
Floor	***Room***	***Model***	***Cooling***	***Heating***	***Model***	***Cooling***	***Heating***
Ground floor	Living Room	MXZ-3C24NAHZ2			MSZ-FH12NA	12,000	13,600
	Main Bedroom				MSZ-FH06NA	6,000	8,700
	Baby Bedroom				MSZ-FH06NA	6,000	8,700
	total		22,000	25,000	**Indoor unit total**	**24,000**	**31,000**
2nd	Kitchen-Dining	MXZ-3C24NAHZ2			MSZ-FH15NA	15,000	18,000
3rd	Front Room 2				MSZ-FH09NA	9,000	10,900
			22,000	**25,000**	**Indoor unit total**	**24,000**	**28,900**
3rd	Front Room 1	MXZ-3C24NAHZ2			MSZ-FH06NA	6,000	8,700
	Office				MSZ-FH06NA	6,000	8,700
	Back Room+Bathroom				MSZ-FH12NA	12,000	13,600
	total		**22,000**	**25,000**	**Indoor unit total**	**24,000**	**31,000**







S14

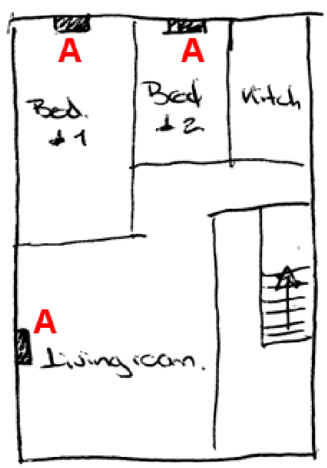
		Outdoor unit			Indoor units		
Floor	Room	Model	Cooling	Heating	Model	Cooling	Heating
1st	Living Room	MXZ-3C24NAHZ2			MSZ-FH15NA	15,000	18,000
2nd	Front Bedroom				MSZ-FH06NA	6,000	8,700
	Total		**22,000**	**25,000**	**Indoor unit total**	**21,000**	**26,700**
1st	Dining/Kitchen	MXZ-3C24NAHZ2			MSZ-FH15NA	15,000	18,000
2nd	Back Bedroom 1				MSZ-FH06NA	6,000	8,700
	Total		**22,000**	**25,000**	**Indoor unit total**	**21,000**	**26,700**
2nd	Back Bedroom 2				MSZ-FH06NA	6,000	8,700
Attic	Front Room	MXZ-3C24NAHZ2			MSZ-FH06NA	6,000	8,700
	Back Room				MSZ-FH06NA	6,000	8,700
	Total		**22,000**	**25,000**	**Indoor unit total**	**18,000**	**26,100**
Total			**66,000**	**75,000**			

S18

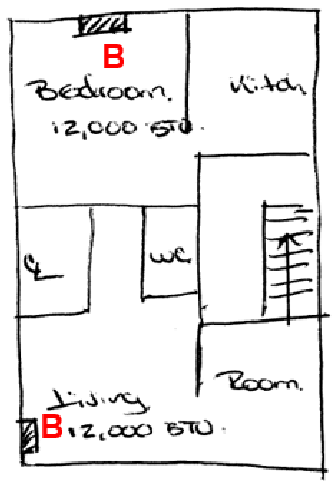
Condenser	Condenser Model #	Condenser Location	Evaporator	Evaporator Model #	Evaporator type	Evaporator location	Btu
A	2MXL18QMVJU	Rear yard	A1	FTXS09LVJU	Wall	Garden fron	9,000
			A2	FTXS09LVJU	Wall	Garden rear	9,000
B	3MXL24RMJU	Rear yard	B1	FFQ09Q2VJU	Cassette	Parlor front	9,000
			B2	FFQ09Q2VJU	Cassette	Parlor rear	9,000
			B3	CTXS07LVJU	Wall	Cellar	7,000
C	2MXL18QMVJU	Roof	C1	FFQ09Q2VJU	Cassette	3rd rear	9,000
			C2	FFQ09Q2VJU	Cassette	4th bath	9,000
D	3MXL24RMJU	Roof	D1	FFQ09Q2VJU	Cassette	3rd front	9,000
			D2	FFQ09Q2VJU	Cassette	3rd den	9,000
			D3	FFQ09Q2VJU	Cassette	4th master	9,000
						Total Btu	79,000

S19

		RHVAC sizing calcs		Outdoor unit			Indoor units		
Floor	**Room**	**Cooling**	**Heating**	**Model**	**Cooling**	**Heating**	**Model**	**Cooling**	**Heating**
1st	Living Room			MXZ-3C24NAHZ			MSZ-FH06NA	6,000	8,700
	Back bedroom 1						MSZ-FH06NA	6,000	8,700
	Back bedroom 2						MSZ-FH06NA	6,000	8,700
	Total	15,367	23,415		22,000	25,000	indoor unit total	18,000	26,100
2nd	Front Bedrooms			MXZ-3C30NAHZ			MSZ-FH12NA	12,000	13,600
	Back Bedroom						MSZ-FH12NA	12,000	13,600
	Total	22,307	30,197		28,400	28,600	indoor unit total	24,000	27,200
Total	Btu	37,674	53,612		50,400	53,600		42,000	53,300
	Tons	3.1	4.5		4.2	4.5		3.5	4.4



1st Floor

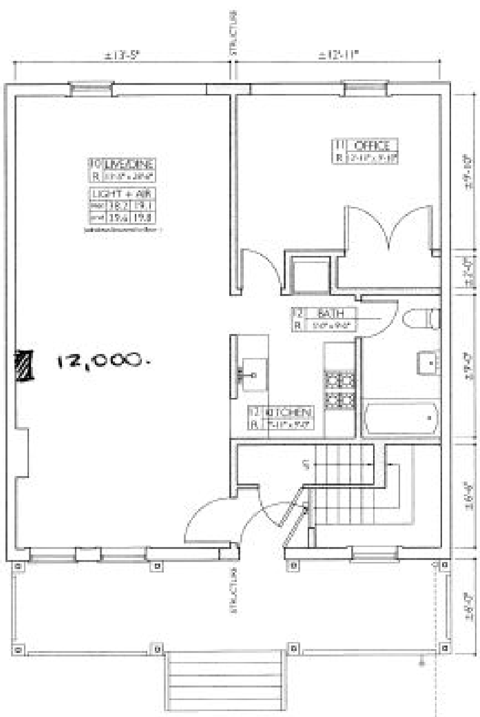


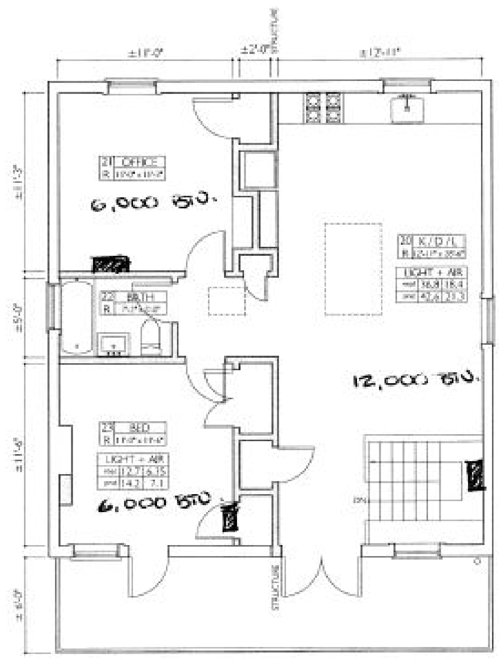
2nd Floor

Appendix B

S21

			RHVAC sizing calcs		Outdoor unit			Indoor units		
Floor	**Room**	**BTU/unit**	**Cooling**	**Heating**	**Model**	**Cooling**	**Heating**	**Model**	**Cooling**	**Heating**
1st	Living Room	12,000			MUFZ-KJ15NAHZ			MSZ-FH15NA	15,000	20,000
	Total	12,000	13,751	16,899		15,000	20,000	Indoor Total	15,000	20,000
2nd	Living Room	12,000			MXZ-3C24NAHZ			MSZ-FH06NA	6,000	8,700
	Front Bedroom	6,000						MSZ-FH09NA	9,000	10,900
	Back Bedroom	6,000						MSZ-FH12NA	12,000	13,600
	Total	**24,000**	**23,121**	**26,196**		**22,000**	**25,000**	**Indoor Total**	**27,000**	**33,200**
Total	Btu	36,000	36,872	43,095		37,000	45,000		42,000	53,200
	Ton	3.0	3.1	3.6		3.1	3.8		3.5	4.4





Appendix B

S23

				Equipment Selection					
		Manual J sizing		Outdoor unit			Indoor units		
Floor	Room	Cooling	Heating	Model	Cooling	Heating	Model	Cooling	Heating
Basement	Basement						ASU15RLF1	14,000	16,300
	Total	6,908	32,897						
1st floor	Living Room			AOU36RLXFZ1H			ASU7RLF1	7,000	8,100
	Kitchen						ASU7RLF1	7,000	8,100
	Total	12,237	11,381		35,200	36,400	Indoor total	28,000	32,500
2nd floor	Master Bedroom						ASU7RLF1	7,000	8,100
	Bedroom 1						ASU7RLF1	7,000	8,100
	Bedroom 2						ASU7RLF1	7,000	8,100
	Total	7,329	6,260	AOU36RLXFZ1H					
Attic	Bedroom 3						ASU7RLF1	7,000	8,100
	Total	3,248	3,873		35,200	36,400	Indoor total	28,000	32,400
House Total	BTUH	29,722	54,411		70,400	72,800		56,000	64,900
	Tons	2.5	4.5		5.9	6.1		4.7	5.4

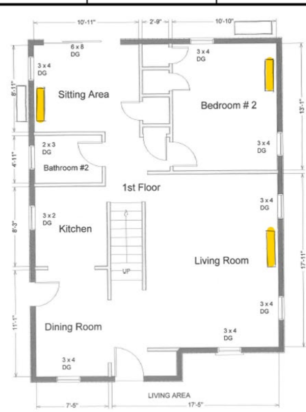
Appendix B

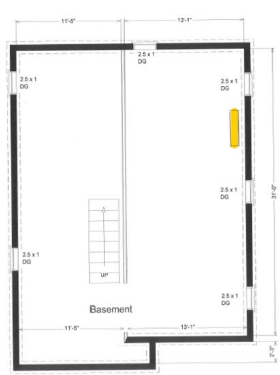
S25

		Manual J Sizing		Outdoor unit			Indoor units		
Floor	Room	Cooling	Heating	Model	Cooling	Heating	Model	Cooling	Heating
Front Condenser (A)	A1. Basement	1,122	3,146	AOU36RLXFZH	35,200	39,341	ASU9RLP1	9,000	10,200
	A2. 2nd Fl master (W facing)	3,493	4,022				ASU9RLP1	9,000	10,200
	A3. 2nd Fl office (NE facing)	1,300	2,477				ASU7RLP1	7,000	8,100
	A4. 3rd Fl bedroom (E facing)	1,566	1,217				ASU9RLP1	9,000	10,200
	Total	7,481	10,862				Indoor unit total	34,000	38,700
Back Condenser (B)	B1 Kitchen	3,102	6,444	AOU36RLXFZH	35,200	39,341	ASU9RLP1	9,000	10,200
	B2 Living room	3,906	9,039				ASU9RLP1	9,000	10,200
	B3 2nf Fl Rec room (SE Facing)	2,391	3,789				ASU7RLP1	7,000	8,100
	B4 3rd bedroom (W facing)	1,978	1,585				ASU9RLP1	9,000	10,200
	Total	11,377	20,857				Indoor unit total	34,000	38,700
		18,858	31,719		70,400	78,682	Indoor unit total	68,000	77,400

S31

		Manual J		Outdoor unit			Indoor unit		
		Cooling Load	Heating Load	Model #	cooling	heating	Model #	cooling	heating
Basement	Basement	867	7,966	AOU36RLXFZ1H			ASU9RLF1	9,000	10,200
1st Floor	Sitting Area	4,893	6,979				ASU7RLF1	7,000	8,100
	Bedroom #2	2,743	3,030				ASU7RLF1	7,000	8,100
	Living Room	6,377	8,377				ASU12RLF1	12,000	13,500
					35,200	39,341	Total	35,000	39,900
2nd Floor	Bedroom #1	2,568	4,531	AOU24RLXFZH			ASU7RLF1	7,000	8,100
	Master Bedroom	4,056	6,678				ASU7RLF1	7,000	8,100
	Home Office	2,211	3,836				ASU7RLF1	7,000	8,100
					22,000	26,000	Total	21,000	24,300
Total	Btu/h	23,715	41,397		57,200	65,341		56,000	64,200
	Ton	2.0	3.4		4.8	5.4		4.7	5.4

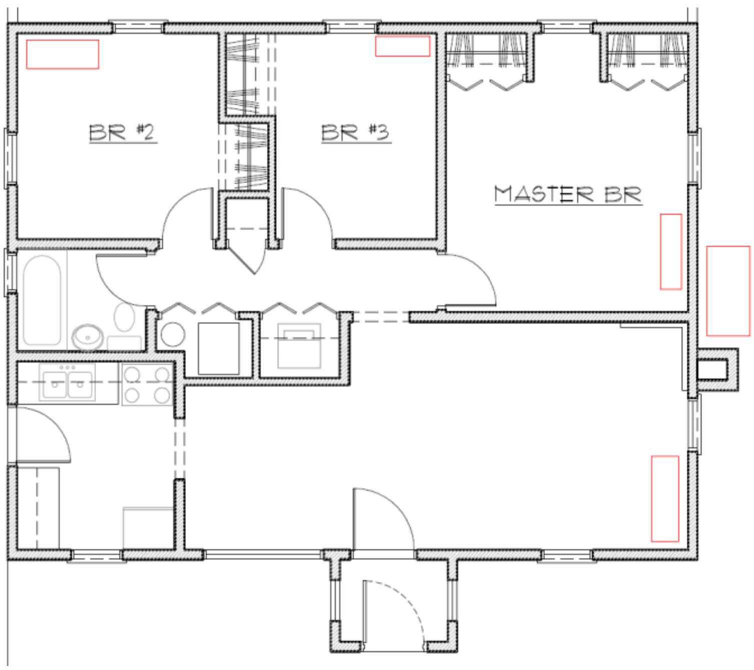




Appendix B

S32

	Manual J		Outdoor unit			Indoor unit		
	Cooling Load	Heating Load	Model #	cooling	heating	Model #	cooling	heating
Living Room	10,227	10,757				ASU12RLP1	12,000	13,500
Master Bedroom	2,693	3,699	AOU36RLXFZH			ASU7RLP1	7,000	8,100
Bedroom 3	1,589	2,066				ASU7RLP1	7,000	8,100
Bedroom 2	2,025	3,488		35,200	39,341	ASU7RLP1	7,000	8,100
Btu/h	16,533	20,009		35,200	39,341		33,000	37,800
Ton	1.38	1.67		2.93	3.28		2.75	3.15



S35

		Manual J		Outdoor unit			Indoor unit		
		Cooling Load	Heating Load	Model #	cooling	heating	Model #	cooling	heating
Basement	Basement	2,141	12,155				ASUA12TLVA1	12,000	13,500
1st Floor	Sun Room + Kitchen	4,053	7,797				ASUA7TLVA1	7,500	9,500
	\								
	Living Room	4,627	12,971				ASUA12TLVA1	12,000	13,500
				AOU48RLAVM			Total	31,500	36,500
2nd Floor	Bedroom #2	1,839	4,241				ASUA4TLVA1	4,000	4,400
	Master Bedroom	1,810	4,370				ASUA4TLVA1	4,000	4,400
	Bedroom#3	1,514	3,718				ASUA4TLVA1	4,000	4,400
					48,000	54,000	Total	12,000	13,200
Total	Btu/h	15,984	45,252		48,000	54,000		43,500	49,700
	Ton	1.3	3.8		4.0	4.5		3.6	4.1

Appendix B

S39

		Manual J		Outdoor unit			Indoor unit		
		Cooling Load	Heating Load	Model #	cooling	heating	Model #	cooling	heating
1st Floor	Entire floor	6,223	19,649	AOU36RLXFZ1H			ASU18RLF	18,000	21,600
							Room Total	18,000	21,600
2nd Floor	Bedroom #1	622	1,844				ASU7RLF1	7,000	8,100
	Master Bedroom	2,971	8,630				ASU7RLF1	7,000	8,100
	Bedroom #2	622	1,844				ASU7RLF1	7,000	8,100
					35,200	39,341	Room Total	21,000	24,300
Total	Btu/h	10,438	31,967		35,200	39,341		39,000	45,900
	Ton	0.9	2.7		2.9	3.3		3.3	3.8

S40

		Manual J		Outdoor unit			Indoor unit		
		Cooling Load	Heating Load	Model #	cooling	heating	Model #	cooling	heating
1st Floor	Living room / Kitchen	7,743	15,929	AOU24RLXFZH			ASU12RLF1	12,000	16,000
	Bedroom 2	1,056	1,373				ASU7RLF1	7,000	8,100
	Master Bedroom	3,159	6,392				ASU7RLF1	7,000	8,100
					22,000	26,000	Total	26,000	32,200
Total	Btu/h	11,958	23,694		22,000	26,000		26,000	32,200
	Ton	1.0	2.0		1.8	2.2		2.2	2.7

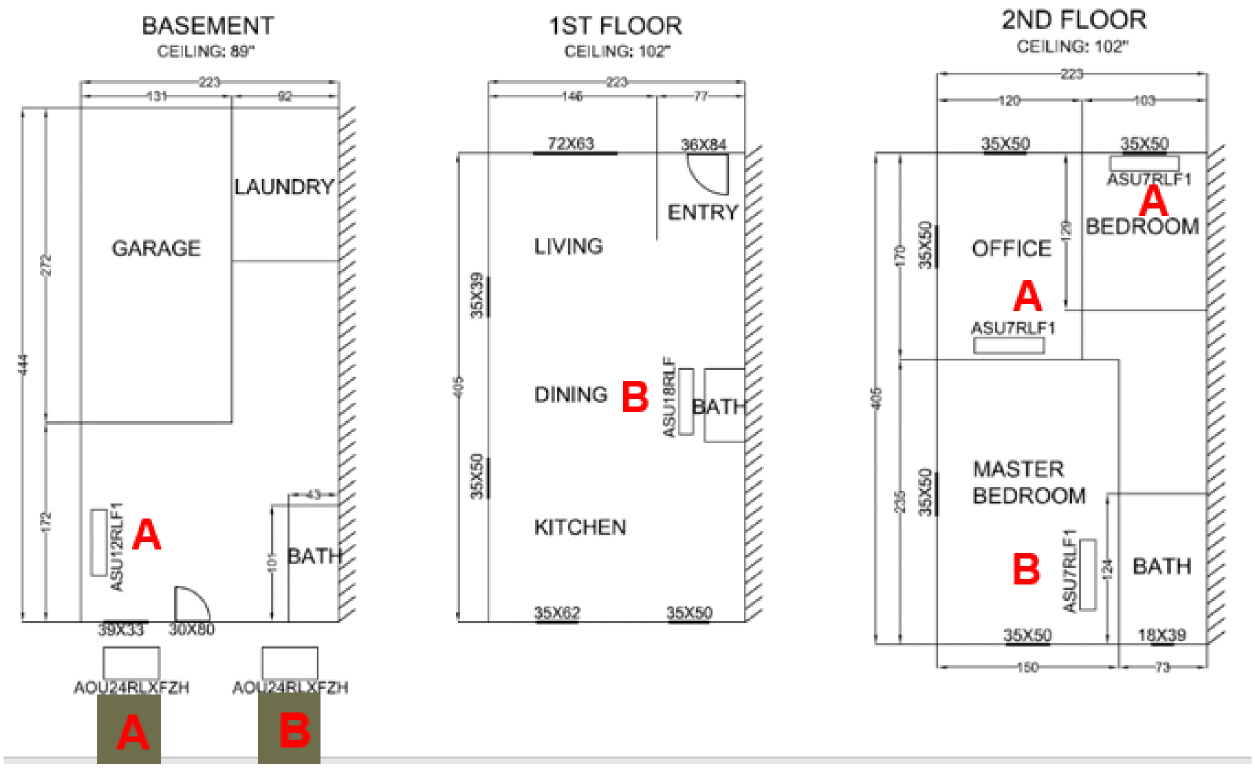
S41

Ducted system using one outdoor condenser.

Model	AccuComfort Platinum 18
Capacity	36,800

S44

		Design						Manual J Loads	
Floor	**Room**	**Indoor Model**	**Cooling**	**Heating**	**Outdoor Model**	**Cooling**	**Heating**	**Cooling**	**Heating**
Basement	Basement front	ASU12RLP1	12,000	13,500	**AOU24RLXFZH, connected to a 12k unit in basement and two 7k units on the 2nd floor**				
	Total		**12,000**	**13,500**				**6,460**	**12,026**
1st floor	Living room	ASU18RLP1	18,000	20,000					
	Total		**18,000**	**20,000**		**22000**	**26000**	**10,463**	**10,084**
2nd floor	Office	ASU7RLP1	7,000	8,100	**AOU24RLXFZH, connected to a 18k unit on the 1st floor and a 7k unit on the 2nd floor**				
	Bedroom	ASU7RLP1	7,000	8,100					
	Master Bedroom	ASU7RLP1	7,000	8,100					
	Total		**21,000**	**24,300**		**22,000**	**26,000**	**11,798**	**15,816**
Total	btuh		**51,000**	**57,800**		**44,000**	**52,000**	**28,721**	**37,926**
	ton		**4.3**	**4.8**		**3.7**	**4.3**	**2.4**	**3.2**



Appendix B

S45

		Pre-installed Design					
Floor	**Room**	**Indoor Model**	**Cooling**	**Heating**	**Outdoor Model**	**Cooling**	**Heating**
Basement	Basement front	ASU12RLP1	12,000	13,500	AOU12RLS3H	**12000**	**13500**
	Basement back	ASU9RLP1	9,000	10,200	AOU18RLXFZH		
	Total		**21,000**	**23,700**			
1st floor	Living room	ASU9RLP1	9,000	10,200		**18000**	**23500**
	Dining/kitchen	ASU9RLP1	9,000	10,200	AOU24RLXFZH		
	1st floor MBR	ASU7RLP1	7,000	8,100			
	1st floor small room	ASU7RLP1	7,000	8,100			
	Total		**32,000**	**36,600**		**22000**	**26000**
2nd floor	Apt 1 BR1	ASU7RLP1	7,000	8,100	AOU24RLXFZH		
	Apt 1 BR2	ASU7RLP1	7,000	8,100			
	Apt 1 kitchen/dining	ASU9RLP1	9,000	10,200			
	Total		**23,000**	**26,400**		**22000**	**26,000**
2nd floor	Apt 2 kitchen/dining	ASU9RLP1	9,000	10,200	AOU24RLXFZH		
	Apt 2 BR1	ASU7RLP1	7,000	8,100			
	Apt 2 BR2	ASU7RLP1	7,000	8,100			
	Total		**23,000**	**26,400**		**22000**	**26000**
Total	btuh		**99,000**	**113,100**		**96,000**	**115,000**
	ton		**8.3**	**9.4**		**8.0**	**9.6**

S46

		Pre-installed Design					
Floor	**Room**	**Indoor Model**	**Cooling**	**Heating**	**Outdoor Model**	**Cooling**	**Heating**
Basement	Bedroom	MSZ-FH06NA	5,300	6,000	MXZ-8C48NA		
	Wall-in Closet	MSZ-FH06NA	5,300	6,000			
	Living Room	MSZ-FH12NA	10,700	12,000			
	Total	floor indoor unit total	21,300	24,000			
1st flr	Kitchen	MSZ-FH15NA	13,300	15,000			
	Living Room	MSZ-FH15NA	13,300	15,000			
	Total	floor indoor unit total	26,600	30,000		48,000	54,000
2nd flr	Guest Room+Office	MSZ-FH12NA	12,000	15,000	MXZ-4C36NAHZ		
	Guest Room	MSZ-FH12NA	12,000	15,000			
	Master Bedroom	MSZ-FH12NA	12,000	15,000			
	Total	floor indoor unit total	36,000	45,000		36,000	42,000
Total	Btuh		83,900	99,000		84,000	96,000
	Ton		7.0	8.3		7.0	8.0

Appendix C. Performance Validation Plan and Survey Instrument

This appendix provides the performance validation plan developed at project onset as well as the survey instrument.

Performance Validation Plan

for

The Levy Partnership:

Replacing Fossil Fuel Heat with Mini-Split Heat Pumps in Urban Housing Stock

under

NYSERDA PON 3127
Emerging Technologies Demonstration Projects – Residential HVAC

May 8, 2017

Submitted to:

New York State Energy Research and Development Authority
17 Columbia Circle
Albany, NY 12203-6399

Submitted by:

CDH Energy Corp.
2695 Bingley Road
Cazenovia, NY 13035
315-655-1063

Validation Project Participants

NYSERDA Staff

518-862-1090

*Bill Mitchell		bill.mitchell@nyserda.ny.gov
*Scott Smith	x3344	scott.smith@nyserda.ny.gov
*Donovan Gordon		donovan.gordon@nyserda.ny.gov
*Chris Corocan		chris.corcoran@nyserda.ny.gov
*Kerry Hogan		kerry.hogan@nyserda.ny.gov

Technical Consultant

CDH Energy Corp.
2695 Bingley Road, Cazenovia, NY 13035
315-655-1063

*Hugh I. Henderson, Jr. P.E., General Manager	x13	hugh.henderson@cdhenergy.com
Carina Paton, Project Engineer	x26	carina.paton@cdhenergy.com
Nicholas Genzel, Project Engineer	x16	nicholas.genzel@cdhenergy.com

Applicant Team

The Levy Partnership, Inc.
1776 Broadway, Suite 2205, New York, NY 10019

*Jordan Dentz, Vice President	jdentz@levypartnership.com

Air-Source Heat Pump (ASHP) Advisory Group

Dave Lis		djlis@neep.org
Jonathon Comstock		jpc8@cornell.edu
Laura Tajima		ltajima@cityhall.nyc.gov
Richard Faesy	802-482-5001	rfaesy@energyfuturesgroup.com
Russ Hearton		rhearton@getzerodraft.com
Rick Nortz	607-733-1058	rnortz@hvac.mea.com
Paul Romano		romanop@coned.com

Persons marked with an * above are also members of the ASHP Advisory Group.

Contents

Introduction

Background

The Levy Partnership has been awarded a project under NYSERDA PON 3127 (Residential HVAC) to install 20 mini-spilt, air-source heat humps in residential buildings in New York City. NYSERDA's Residential HVAC initiative seeks to accelerate the market uptake of commercially available, but underused building technologies and strategies in the residential sector. This initiative aims to demonstrate technologies that offer measurable energy savings and greenhouse gas (GHG) reductions. It seeks to address barriers to wider commercialization in the residential market via a series of multi-site demonstration projects in existing homes and residential buildings.

One emerging technology for northern climates is ductless, mini-split heat pumps. Mini-splits consist of an outdoor compressor/condenser unit combined with an indoor air-handler unit. Often, one outdoor unit can serve multiple indoor air-handling units. These ductless systems are often well suited as a retrofit technology for homes that do not have existing ductwork. Recent advancements in this heat pump technology means that it is now practical for heating in colder climates such as the metro NY area.

The Levy Partnership (TLP) claims that the New York City region is an ideal location to begin promoting mini-split heat pumps as an alternative to legacy fossil fuel heating systems. The city has many multi-family homes built with brick and wood frame construction that do not accommodate traditional ducted heating and cooling systems. Over 86% of households in New York City use boilers for space heating (oil or gas), and about 86% use window air conditioner units or have no cooling. The potential market for this new technology is sizable: there are 1.2 million 1- to 4-family homes in the New York portion of the NYC metro area alone.

Approach

The Levy Partnership (TLP) team plans to demonstrate the application of highly-efficient mini-split heat pump technology as a replacement for old-inefficient heating and cooling systems. These systems will be installed in 20 one- to four-family homes. Most of these will be urban row houses, or "brownstones," and some may be detached homes. Alongside the heat pump installation, TLP will implement home performance energy efficiency measures, such as air sealing, additional insulation, and attic ventilation. They may also add a fresh air ventilation systems if required.

Alongside the demonstration projects, TLP will also conduct dissemination and promotional activities for mini-split heat pumps, including open houses and social media events, which it will conduct in collaboration with neighborhood organizations and community leaders.

Performance Validation Approach

Overview

The Levy Partnership (TLP) team will identify 20 homes in Brooklyn and Queens where they will install high performance air source heat pumps (ASHPs). Each building is expected to have 1 to 4 apartments. The buildings will be owner-occupied with rental units. The existing heating system in each building is expected to use either fuel oil or natural gas in one or more steam or hot water boilers that serve the apartments. The boilers may also provide DHW for the building, especially for fuel oil applications. Buildings with natural gas may have a separate, stand-alone water heater.

Along with the heat pump installation, the building envelope will be upgraded and improved. The heat pumps will be sized to meet the new thermal loads. It is expected that each apartment will have its own heat pump system, most likely with multiple ductless indoor, wall-mounted heads. The heat pump units will be either Mitsubishi, Fujitsu, or others. The heat pumps will generally be sized to be able to serve the peak heating load in the building. However, the original boiler system will remain in place for at least 12 months, and will be available to run in conjunction with the heat pumps as a backup system.

Pilot Design

The overall goal of this performance validation effort is to gather the necessary field data from this sample of pilot sites to address market barriers and other concerns of various stakeholders:

- Consumers/homeowners want confidence and confirmation that their expected benefits will be achieved, namely reduced fuel bills and net energy cost savings while maintaining adequate comfort.
- Consumers want confidence that air-source heat pump (ASHP) systems can perform as needed on the coldest days.
- Consumers/homeowners want to know that the installation process will be minimally invasive (in comparison to a boiler replacement).
- Policy makers similarly want to confirm that expected energy impacts and GHG reductions are realized.
- Installers want assurance that software tools and calculation procedures to size equipment and predict energy savings are reliable and accurate.
- Installers and policy makers want to understand what issues motivate consumers/homeowners to purchase a ASHP system, so that marketing strategies can be tuned to focus on key issues.
- Installers and the finance community want to understand the range of variation of installation costs and cost savings across a portfolio of installations, understanding the variability of cost savings at a known level of confidence.
- Utilities want to understand the impact that ASHPs will have on electric load growth, residential load shape, and peak demand.

The selection criteria for test sites included in sample for this study must be focused on the goals listed above. Further, measurements at each site must be designed to gather the required information. Each of these issues is addressed below.

Site Selection Criteria (Sample Design)

All 20 sites will be retrofits of mini-split ASHPs at one- to four-family homes in Brooklyn and Queens, New York. The installed ASHPs will be a mix of Mitsubishi, Fujitsu, and other brands. It is expected that each apartment will have its own heat pump system, most likely with multiple indoor, wall-mounted heads. The ASHP system will replace an existing boiler heating system (steam, hydronic, or forced air). In most cases, this will be a natural gas or fuel oil boiler. In some cases, water heating may also be provided by the boiler, so some accommodation will be required to provide domestic water heating (DHW) from the ASHP loop and/or another source if the boiler is removed.

Many of the homes will have building envelope upgrades implemented as part of the ASHP system installation. The upgrades will be in keeping with the EPA Home Performance with Energy Star (HPwES) performance requirements. The heat pump will be sized to meet the new loads.

Homeowners will voluntarily choose to participate in this study and ultimately make the final purchase decision for what is installed and retrofitted into their home. The TLP team will propose various options for each homeowner based on upfront estimates of cost effectiveness as well as homeowner interests and preferences. Homeowners will receive training on optimal use of the ASHP system.

For all homes in the study, CDH will work with TLP to document the key characteristics and details so that these factors can be compared to performance variations we observe in the buildings.

Data Collected at Each Site

CDH will install sensors and data loggers to collect measured performance data at each site. Pre-retrofit utility bills and customer survey results will round out the data collection at each site. The collected data will answer the following questions:

- What are the heating and cooling energy and cost savings achieved with the retrofit? What portion of the savings can be attributed to the ASHP system and to the building envelope improvements?
- How does the ASHP system impact the electric load shape or demand profile for the home that is imposed on the electric utility? What are the peak demands during key seasons?
- How are comfort conditions (measured and perceived) impacted by the ASHP retrofit?

Data Collection Details

CDH will verify the performance of the ASHPs using installed sensors and data loggers to measure post-retrofit energy use and comfort conditions. Pre-retrofit energy use will be quantified with monthly utility bills or fuel delivery logs from before the ASHP installation. A survey will be administered to assess the comfort conditions and occupant satisfaction both before and after the retrofit.

ASHP Monitoring at Each Site (Post-Retrofit)

CDH will measure the power use of all the heat pumps in all 20 buildings to quantify electric energy use. We expect most heat pump breakers to be located in the basement, allowing for simplified monitoring. We will also measure the status of the boiler components in order to determine boiler runtime. We will use the runtime with the expected or measured firing rate to infer fuel use.[1] Data will be logged at 15-minute intervals. Battery-powered data loggers will also be installed to measure temperature (and in some cases humidity) in various spaces in the home. The monitoring equipment to be installed at each site is listed in Table 1. At the end of the monitoring period, we will return to the site to retrieve the data loggers and monitoring sensors.

Table 1. Measured Data Points at Each Site (average across 20 sites)

Measured Quantity	Equipment
Heat pump electricity use	2 x Wattnode P3, 4 x CTs 1 x Onset UX90-001M pulse data logger
Boiler runtime and inferred fuel use	Status CTs (on boiler control wiring) 1 x Onset UX90-001M pulse/status data logger
Space temperature and supply air temperatures (4 locations)	4 x Onset UX100 temperature loggers

Optional Detailed Monitoring

If questions arise during the post-retrofit period, detailed monitoring may be installed on one or two heat pumps. Detailed monitoring can be used to determine:

- Seasonal Heating COPs and cooling EERs
- Heating and Cooling Capacity (output) and efficiency at peak conditions for heating and cooling
- Coincident peak demands for both summer and winter
- Space heating and cooling loads (seasonally and as a function of outdoor temperature) for the post-retrofit building

Pre-Retrofit Utility Bills/Fuel Logs

Because detailed pre-retrofit performance data will not be available, the energy use and space heating and cooling loads will be primarily determined by evaluating monthly fuel oil delivery logs and/or gas and electric utility bills. TLP will provide CDH with at least 12 months of logs and bills (with exact delivery dates or meter read dates) to quantify pre-retrofit performance. CDH will correlate this data with outdoor temperature data from the

[1] We can compare measured runtime to fuel use within billing periods in the post-retrofit period to estimate the average firing rate.

nearest airport weather station for each monthly period (from Weather Underground at www.wunderground.com). CDH will use the linear trend of heating energy use with temperature to discern the portion of the bill attributable to space heating. The same process will be repeated for electric utility bill data to discern the space cooling energy use trend with ambient temperature.

At a limited number of sites[2]—where high quality utility bill data are not available—data loggers may be installed on the boilers to verify pre-retrofit use. This would be especially appropriate in buildings where utility bills or fuel delivery logs are not complete or are questionable. Space temperature loggers may also be installed at that time to gather pre-retrofit temperatures. In the case that supplemental electric space heaters are used, extra "plug loggers" may be installed on electric space heaters (to measure long term kWhs) prior to the retrofit. It may also be useful to install loggers earlier in cases where the building envelope retrofit is implemented several weeks or months before the heat pumps are installed.

We may also ask homeowners to continue providing fuel logs and utility bills into the post-retrofit period to corroborate readings determined with the data loggers and other meters.

Site Characteristics Data Collection

In addition to the measured data, TLP will provide general information on the ASHP installation and other details about the existing facility at each site (Table 2).

Table 2. Site and System Characteristics

Parameter	Description
City or town	
Building Size	Gross sq. ft.
Number of families/apartments in building	
Application	Residential New, Residential Retrofit, Non-Residential
Heat pump model and size	
List and number of outdoor units, connected indoor units, and zones at Site	
DHW Arrangement	Number of water heaters, connected to space heating boiler or stand-alone, fuel type (if separate)
Description of any envelope improvements	
Description of any distribution system improvements	Ductwork or distribution modifications

[2] The budget includes pre-monitoring at four (4) sites.

Parameter	Description
Existing heating system	Boilers, supplemental heat: number, model, type, size, fuel source
Existing cooling system	Model, type, number, size
Boiler-ASHP control method	Are boilers used as backup? Control settings for combined operation?
Other Considerations	Supplemental heater use, etc.

Customer Feedback Survey

In addition to the measurements described above, CDH will administer web-based surveys to homeowners and some non-owner occupants. The goal of the surveys is to solicit feedback from customers to assess their perceptions and satisfaction of the ASHP system. In many cases, we will ask for their perceptions of metrics that we will also directly measure.

Two surveys will be administered to building owners and occupants of each of the 20 townhomes who participate in the ASHP upgrade under this program. The first will be around the time of the ASHP retrofit, and the second will be after 9 to 12 months of operation. Table 3 lists the research questions that the web survey intends to address and the specific subtopics through which responses will be elicited. Draft survey questions are given in Appendix A.

CDH Energy will prepare and administer the survey with the assistance of TLP and/or NYSERDA. CDH will design the survey using the online service SurveyMonkey. Prior to CDH sending the survey to the customers, NYSERDA and/or TLP will send customers an email informing them that they will be receiving a survey, CDH will work with NYSERDA and/or TLP to draft the email text. NYSERDA and/or TLP will provide CDH with the customer email address, and CDH will send the survey to the customer via the SurveyMonkey system. We expect all survey recipients to complete the survey.

After each round of surveys, we expect to follow up by phone with at least half of the customers with a series of follow-on questions based on the responses provided in the web-based survey.

Table 3. Research Questions to be Addressed via Web Survey

Research Question	Topic(s)	Subtopic(s)
What motivated the customer to install an ASHP system?	Motivations	Why customer decided to purchase and install the system
How does customer satisfaction change between the original system and the new system?	Overall rating	Satisfaction with original heating and cooling systems Satisfaction with new ASHP system

Research Question	**Topic(s)**	**Subtopic(s)**
How does customer perception of comfort levels change from before to after the ASHP and building envelope retrofit?	Comfort levels (temperature levels and distribution)	Perceived ability to reach and maintain desired temperature throughout home during winter and summer prior to retrofit Expected temperature during winter and summer after retrofit (asked at time of retrofit) Perceived temperature during winter and summer after retrofit
How do customers perceive energy costs, maintenance, and performance of the new system compared to the original system?	Perception and expectation of systems	<u>At time of retrofit:</u> Perceived energy costs of original heating and cooling systems Expected change in energy costs during winter and summer Perceived maintenance costs of original heating and cooling systems Expected maintenance costs for new ASHP system Expected performance of new ASHP system compared to original heating and cooling systems <u>After retrofit:</u> Perceived energy costs of new ASHP system Perceived energy costs compared to expectations Perceived maintenance costs of new ASHP system Perceived performance of new ASHP system compared to original heating and cooling systems
Do the customers experience any unexpected benefits or problems, and if so, what are they?	Unexpected effects	Unexpected benefits Unexpected problems
Do the customers experience any unexpected benefits or problems, with the envelope retrofit?	Envelope Retrofits	Did the customer notice any comfort impacts or changes related to the building envelope retrofit Any aesthetic issues or changes
Have there been any other changes throughout the study period that may impact results?	Occupancy or Control Changes	Track these issues pre and post as well as across the post period: Changes in household occupancy Use of thermostat setback/setup Other control changes
How do customers perceive the level of effort required to retrofit the system?	Level of customer effort	Level of effort required to install an ASHP system compared to a boiler replacement Level of effort versus achieved benefits

Survey data will be presented in aggregate or in subsets. Individual surveys will not be published without the express permission of the homeowner. The survey results will be summarized in a Survey Findings document, which will appear as an Appendix in the Validation Report. The survey results will be combined with the site characteristics and the measured data for an integrated analysis. The analysis will compare expectations and perceived changes to actual changes for each point where possible.

Data Analysis

Pre-Retrofit Data Analysis

CDH will correlate the pre-retrofit utility bill or fuel log data with outdoor temperature data from the nearest airport weather station for each monthly billing period. We will use the exact dates of the billing period to find the average temperature corresponding to that period as well. CDH will use the linear trend of energy use with temperature to discern the portion of the bill attributable to space heating and space cooling. The result is expected to be similar to the data shown in Figure 1 for a multi-family building. In this example from a real site, the average rate of fuel use for each billing period (in therms per day) is well-correlated to the average temperature in the period.

Gas use reaches a minimum value in the summer, which corresponds to gas use for domestic water heating (DHW).

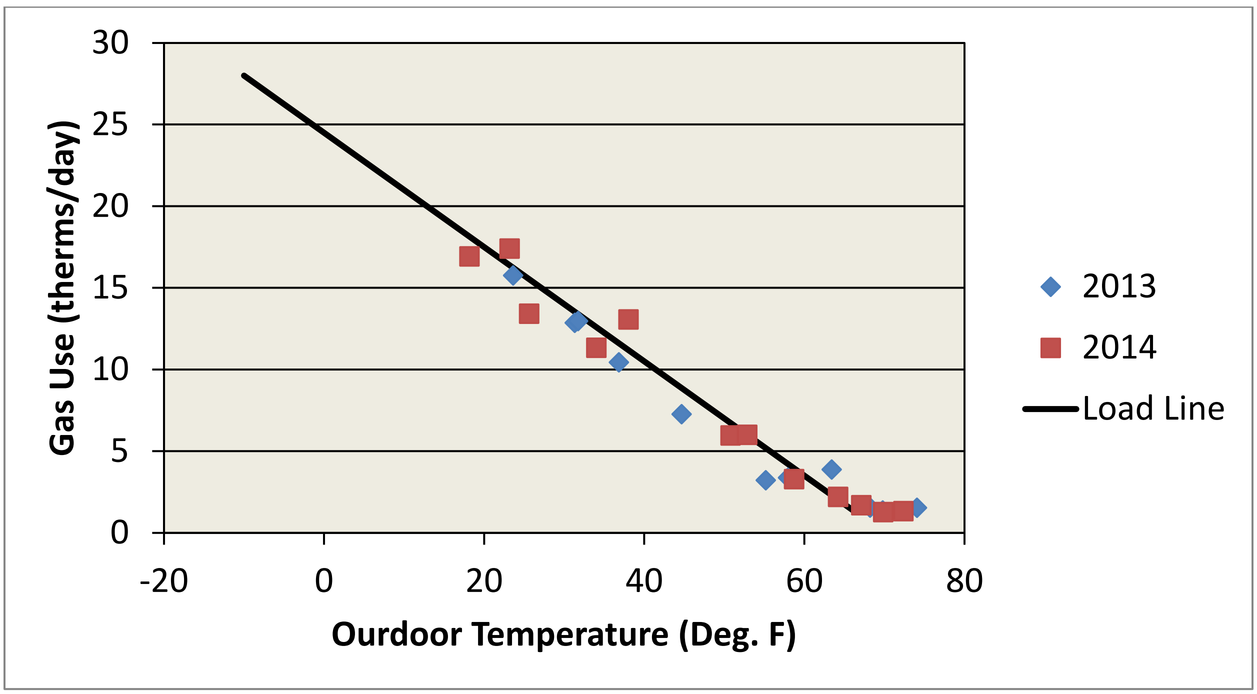


Figure 1. Example of Building Gas Use Correlated to Average Ambient Temperature in Monthly Billing Periods

The pre-retrofit space heating and cooling loads will be determined by the energy and fuel use trends using appropriate heating efficiencies and air conditioner performance curves (extracted from mainstream simulation models such as EnergyPlus). From this analysis, we will be able to measure or infer:

- Heating and cooling energy use trends with outdoor temperature (measured)
- DHW fuel or energy use
- Space heating and cooling loads with outdoor temperature (inferred)

Post-Retrofit Data Analysis

Boiler Runtime and Energy Use

Status measurements using current switches on the boilers will be used to ascertain boiler run time. Total run time will be correlated with fuel bills to estimate the average firing rate (fuel use per hour) over the billing period.

Separating Heat Pump and Envelope Improvements

At most sites, it is likely that some envelope improvements will be included with the ASHP installation as part of each retrofit. In these cases, it would be desirable to separate the energy impacts of the ASHP and envelope measures. In some cases, we will measure pre-retrofit boiler runtime before the heat pumps are installed (as described above) and develop a separate correlation with outdoor temperature; however, this approach might not be possible at all sites.

Flip-flop testing may be implemented at some of the sites. In this case the heat pumps will be disabled for a few 1- to 2-week periods throughout the winter and the original boiler system will be used to meet the new heating loads in the post-retrofit period.

Determining Energy Impacts and Cost Savings

The energy savings from the ASHP and envelope improvements combined will be determined by directly comparing pre-retrofit energy use and post-retrofit energy use. Both electricity and fuel use will be determined. The pre-and post-retrofit data can also be correlated to outdoor temperature and combined with hourly typical year weather data (or bin data) to determine normalized energy use impacts for a normal or typical year.

To determine the impact of the ASHP alone (i.e., separate from envelope improvements), we will use the predicted energy use for the original system meeting the post-retrofit heating and cooling loads (described above) compared to the measured post-retrofit energy use data.

Determining Energy Cost Savings

Utility costs for each home (or average costs for a sample of homes) will be used to determine energy costs and savings. The energy impacts described above will be used to determine energy costs in pre- and post-retrofit conditions. Electric tariff details (classification changes, kWh blocks, demand charges, etc.) will be applied as appropriate in the pre- and post-retrofit periods.

Validation Results and Reporting

Cross Site Analysis and Comparisons

Based on the analysis at each site, we can compare high level performance metrics at the sites, factoring in the different characteristics and customer perceptions for each site. The goal is to look for performance trends in the 20-site sample that can be correlated to or explained by the characteristics of the site that are listed in Table 2. We will also compare customer perceptions of cost savings and comfort with actual measured results. We will use regression analysis or statistical methods to assess trends and understand the uncertainty associated with them. Some of the performance metrics we plan to compile for each site are listed in Table 4.

Table 4. High-Level Performance Metrics (Values) for Each Site

Total kWh (or kWh per sq ft) for heating season, post-retrofit
Total kWh (or kWh per sq ft) for cooling season, post-retrofit
Total boiler runtime and fuel use, pre-retrofit
Total boiler runtime and fuel use, post-retrofit (if any)
Average on-peak demand in each season (noon to 9 pm)
Heating Costs Savings (using local fuel and electric costs)
Average supply air temperature in Heating (avg or load-weighted)
Average supply air temperature in Cooling (avg or load-weighted)
Max and Min supply air temperature

The data will be collected from all the sites as well as the high-level metrics (annual energy use and cost savings, etc.) will be summarized and compared. The metrics will be normalized to a typical meteorological year for prediction and comparison purposes.

It is likely that the 20 sites will provide a statistically representative sample of homes that provide a P90 prediction for the performance metrics of interest. It is likely that predictive trends will emerge as well. For instance:

- Annual cost savings are proportional to house size
- Annual cost savings depend on base case fuel type
- Annual cost savings are proportional to the fraction of the boiler load that is displaced.

CDH will prepare a Validation Report summarizing our analysis from these 20 sites for the NYSERDA Residential HVAC program. The report will summarize the results and findings, and it will document the analysis procedures and per site characteristics and results. Survey results will also be summarized in the report, and detailed results from the web and phone surveys will be included in an appendix of the main report.

We will also combine the data from this 20-site study in Brooklyn and Queens with the results from the separate evaluation of 20 ASHP sites in the Hudson Valley. This combined analysis of the two 20-site studies will be included as a separate section of the final report. The combined sample of 40 sites may be able to provide meaningful predictions of performance metrics and savings at the P95 level.

Validation Project Schedule

Project activities by CDH (green) and TLP (blue) are indicated in the two tables below.

Table 5. Validation Project Schedule - Individual Site

Task \ Month[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Site Identification														
Web and Phone Survey 1														
ASHP Installation and Envelope Retrofit														
Data Acquisition														
Validation Site Visit														
Site Report														
Web and Phone Survey 2														
Monitoring Data Analysis														

[1] Month from identification of site by TLP

Table 6. Validation Project Schedule - After All Data Collection Complete

Task \ Month[1]	1	2	3
Final Survey Collected			
Monitoring Data Analysis			
Survey Analysis			
Survey Results Report			
Validation Report			

[1] Month from date CDH collects final survey

Appendix A. Draft Surveys

Pre-Retrofit Customer Survey

All questions are required to be answered unless specified otherwise. The survey is to be completed by homeowners and some non-owner occupants. CDH will elicit elaboration on answers during phone interviews.

Welcome to the Pre-Retrofit Customer Survey

This survey is being collected by CDH Energy on behalf of NYSERDA for their Emerging Technology and Accelerated Commercialization (ETAC) program to understand customer satisfaction with air-source heat pumps.

You are being asked to complete this survey because an air-source heat pump was installed at your home through The Levy Partnership under NYSERDA PON 3127, Emerging Technologies Demonstration Projects – Residential HVAC.

You will receive two surveys: this one, around the time of installation, and one 9 to 12 months after the air-source heat pump system is installed. Please answer both surveys as accurately as possible.

We will not release individual answers publicly. Rather, we will publish answers and analysis as an aggregate for all surveys collected together.

Note: we are collecting your address in this survey to use to correlate survey results with measured heat pump performance data, as well as ensure that we have survey results for each home. We will not release your address publicly, unless you give us explicit permission to do so.

General

Q1. What is the street address of the building or unit that the heat pump system is being/has been installed in? (e.g. 121 Genesee St Apt 1)

(text box)

Q2. Do you own this building/unit?

(yes/no)

Q3. Do you reside in this building/unit?

(yes/no)

Q4. (owners only) How important were the following in your decision to install an air-source heat pump system?

(Not at All Important, Somewhat Important, Very Important)

a. Lower operating costs (save on energy bills)
b. Ability to both heat and cool
c. Quieter than existing heating/cooling system(s)
d. Reduced greenhouse gas emissions
e. Reduced peak load and need for more electric generating plants

f. Reduce or remove chance of carbon monoxide poisoning
g. Lower maintenance costs
h. Lower life cycle cost due to longer equipment lifetime
i. Dehumidification during summer
j. Consistent room temperature
k. Reduced installation costs compared to alternate HVAC system
l. Ability to control temperature separately in each room
m. Modern, trendy technology
n. Recommended by someone I trust
o. Financial incentives (e.g. rebate)

Heating

Q5. (owners & occupants) Overall, how satisfied or dissatisfied are/were you with your heating system prior to the heat pump upgrade?

a. Very satisfied
b. Somewhat satisfied
c. Neither satisfied nor dissatisfied
d. Somewhat dissatisfied
e. Very dissatisfied

Q6. (occupants only) How did your home heating system perform over the most recent winter, prior to the heat pump upgrade?

a. My desired temperature was maintained in all rooms of my home.
b. My desired temperature was maintained in some rooms, but not in others (e.g. it was warm enough in some rooms but too cold in others)
c. It was not able to reach my desired temperature in any area of my home (e.g. it was too cold in every room).

Q7. (occupants only) Overall, how well do you expect your heat pump will maintain desired temperatures throughout your home in the winter compared to before the heat pump upgrade?

a. Much better
b. Slightly better
c. About the same
d. Slightly worse
e. Much worse

Q8. (owners & occupants) How do/did you feel about the cost of energy from your heating system prior to the heat pump upgrade?

a. Very high
b. Slightly too high
c. About right
d. Slightly too low
e. Too low
f. I don't pay the heating energy bill.

Q9. (skip if answer f above) How do you expect your winter energy bills to change overall after the heat pump upgrade?

a. Increase
b. Little to no change

c. Decrease

Q10. (owners only) How do/did you feel about the level of effort needed to maintain your existing heating system prior to the heat pump upgrade?

(multiple choice, pick one; homeowners only)

a. Very easy
b. Moderately easy
c. Neither easy nor difficult
d. Moderately difficult
e. Very difficult

Cooling

Q11-Q16: Questions will be the same as for heating, but with the word "cooling" replacing "heating", "cool" replacing "heat", and "summer" replacing "winter."

Other

Q17. (owners only) How do you expect the level of effort required to maintain your heat pump system will compare to your old heating and cooling equipment?

a. Much easier
b. Slightly easier
c. About the same
d. Slightly more difficult
e. Much more difficult

Q18. (owners only) How satisfied or dissatisfied are you with the work carried out by the contractor?

a. Very satisfied
b. Somewhat satisfied
c. Neither satisfied nor dissatisfied
d. Somewhat dissatisfied
e. Very dissatisfied

Q19. (owners only) How likely is it that you would recommend the contractor to a friend or colleague? (Net Promoter Score)

0-10 scale, 0 is not at all likely, 10 is extremely likely

Q20. (owners & occupants) Did you receive written instructions on how to operate the heat pump?

(yes/no)

Q21. (owners & occupants) Were you trained on how to use your new system?

(yes/no)

Q22. (owners & occupants) Was the information provided to you sufficient for you to operate your heat pump?

(yes/no, please explain why not)

Q23. (owners only) Have you considered installing solar PV at your home?

a. Yes, I have installed (or have decided to install) solar PV

b. Yes, I am currently considering it
c. Yes, but I decided not to go ahead at this point
d. No, I have not considered solar PV

Q24. (owners & occupants) If you have any further comments about the survey and/or your heating and cooling systems, please enter them here.

(text box, optional)

Post-Retrofit Customer Survey

(9-12 months after retrofit)

All questions are required to be answered unless specified otherwise.

Q1. What is the street address of the building or unit that the heat pump system was installed in? (e.g. 121 Genesee St Apt 1)

(text box)

Q2. Do you own this building/unit?

(yes/no)

Q3. Do you live in this building/unit?

(yes/no)

Q4. (owners & occupants) Overall, how satisfied or dissatisfied are you with your air-source heat pump system?

(same options as corresponding question from Survey 1)

Q5. (occupants only) How easy is it to operate your air-source heat pump?

a. Extremely easy
b. Very easy
c. Somewhat easy
d. Not so easy
e. Not at all easy

Q6. (occupants only) How did your air-source heat pump perform during the first winter after the heat pump upgrade?

(same options as corresponding question from Survey 1)

Q7. (occupants only) How do you feel your new air-source heat pump system maintained temperatures throughout your home during winter compared to your old heating system?

(same options as corresponding question from Survey 1)

Q8. (owners & occupants) How did your heating energy bills over the first winter after the heat pump upgrade compare to what you expected prior to the heat pump upgrade?

a. Much higher than expected
b. Higher than expected
c. As expected
d. Lower than expected
e. Much lower than expected
f. I don’t pay the heating energy bill.

Q9. (occupants only) How did your air-source heat pump perform during the first summer after the heat pump upgrade?

(same options as corresponding question from Survey 1)

Q10. (occupants only) How do you feel your new air-source heat pump system maintained desired temperatures throughout your home during summer compared to your old cooling system?

(same options as corresponding question from Survey 1)

Q11. (owners & occupants) How did your cooling energy bills over the first summer after the heat pump upgrade compare to what you expected prior to the heat pump upgrade?

a. Much higher than expected
b. Higher than expected
c. As expected
d. Lower than expected
e. Much lower than expected

Q12. (owners only) How do you feel about the level of effort required to maintain your air-source heat pump system compared to your old heating and cooling equipment?

(same options as corresponding question from Survey 1)

Q13. (owners & occupants) Briefly describe any unexpected benefits that you have gained from the air-source heat pump system, if any.

(text box, optional)

Q14. (owners & occupants) Describe any unexpected problems that you have experienced with the air-source heat pump system, if any.

(text box, optional)

Q15. (owners & occupants) Briefly describe any unexpected benefits that you have gained from the building envelope retrofit, if any (e.g., impacts or changes in comfort, aesthetic (visual) changes).

(text box, optional)

Q16. (owners & occupants) Briefly describe any unexpected problems that you have experienced with the building envelope retrofit, if any (e.g., impacts or changes in comfort, aesthetic (visual) changes).

(text box, optional)

Q17. (occupants) Have you noticed any change in the temperature of your basement since your air-source heat pump was installed?

a. No
b. Yes (describe)

Q18. (owners & occupants) Have there been any changes in the number of people residing in the building in the past two years? If yes, please give any details of any changes (number of occupants increased/decreased and approximate date).

a. No
b. Yes (give details)

Q19. (owners & occupants) Have there been any changes to heating or cooling controls or settings (e.g. desired temperature set on thermostat) since installation? If yes, please briefly describe.

a. No
b. Yes (describe)

Q20. (owners & occupants) How did you feel about the installation process compared to an equipment replacement (e.g. replacing your old boiler with a new boiler)?

a. It was less invasive
b. There was little to no difference
c. It was more invasive

Q21. (owners & occupants) Was the level of effort you put into this project worth the achieved benefits of your air-source heat pump system?

a. No
b. Yes

Q22. (owners & occupants) Would you switch back to your old heating and cooling systems? If yes, please explain why.

c. No
d. Yes (please explain why)

Q23. If you have any other comments about the survey and/or about your air-source heat pump system, please enter them here.

(text box, optional)

Appendix D. Analysis of Measured Data for Each Site

The following pages in this appendix provide a detailed savings analysis of the energy use and savings at each site.

Site 1 Savings Analysis

This 1,600 sq ft multi-family brownstone home originally used a gas boiler with conventional baseboard radiation. Two electric heat pumps with a total capacity of 5 tons were added to two of the three floors in this the home in 2019 as part of a remodeling project[1]. The gas boiler remained in place to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on August 15, 2019 to collect data at 15-minute intervals. In spite of the extensive renovation, the house only had air sealing completed according to the design report (with savings of 85 therms).

Table 1. Summary List of Proposed and Final Envelope Savings

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage of heated area from 8,885 to 7,500 cfm50 SAVINGS: 85 therms	same

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

[1] 1600 sq ft is 2 of 3 floors in the entire 2400 sq ft building.

Table 2. Summary of Monthly Heat Pump Energy Use

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)
Aug-19	53%	158.8	85.9	72.9
Sep-19	100%	138.9	81.7	57.2
Oct-19	100%	20.5	11.5	9.0
Nov-19	100%	257.2	124.3	132.9
Dec-19	100%	416.7	238.8	177.9
Jan-20	100%	539.8	294.7	245.1
Feb-20	104%	404.9	176.2	228.7
Mar-20	100%	220.5	111.0	109.6
Apr-20	100%	195.6	106.8	88.8
May-20	100%	52.5	22.8	29.7
Jun-20	100%	204.5	71.4	133.1
Jul-20	100%	503.9	238.6	265.3
Aug-20	79%	258.5	79.3	179.2
Annual	99%	3,213.5	1,557.1	1,656.5
Summer (Jun-Sep)		1,105.8	471.0	634.8
Winter (Oct-May)		2,107.7	1,086.1	1,021.7

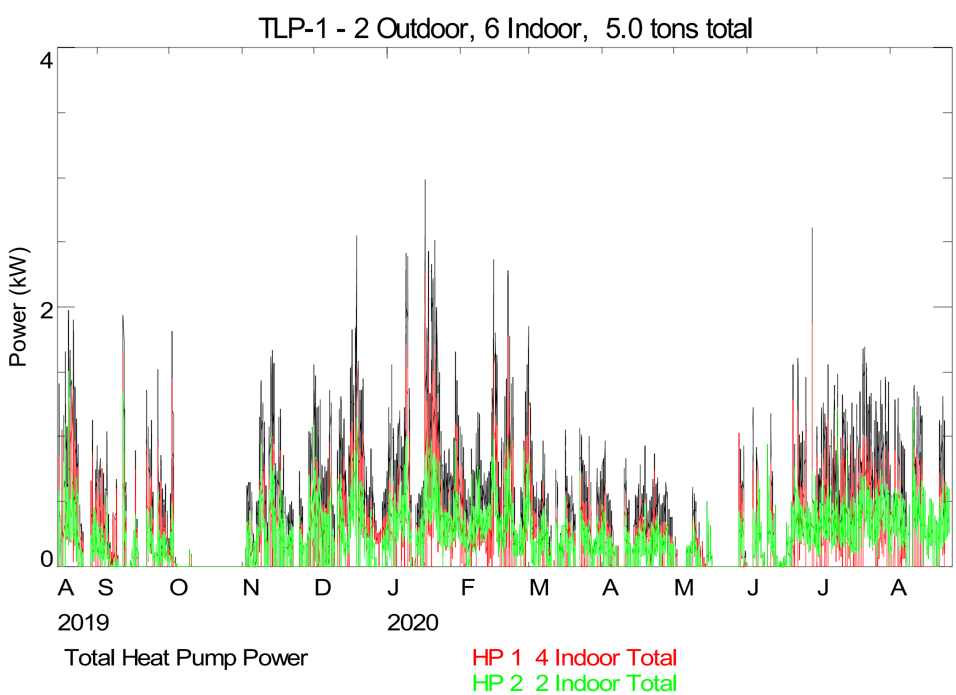


Figure 1. Plot of Power Use for All Heat Pumps at Site

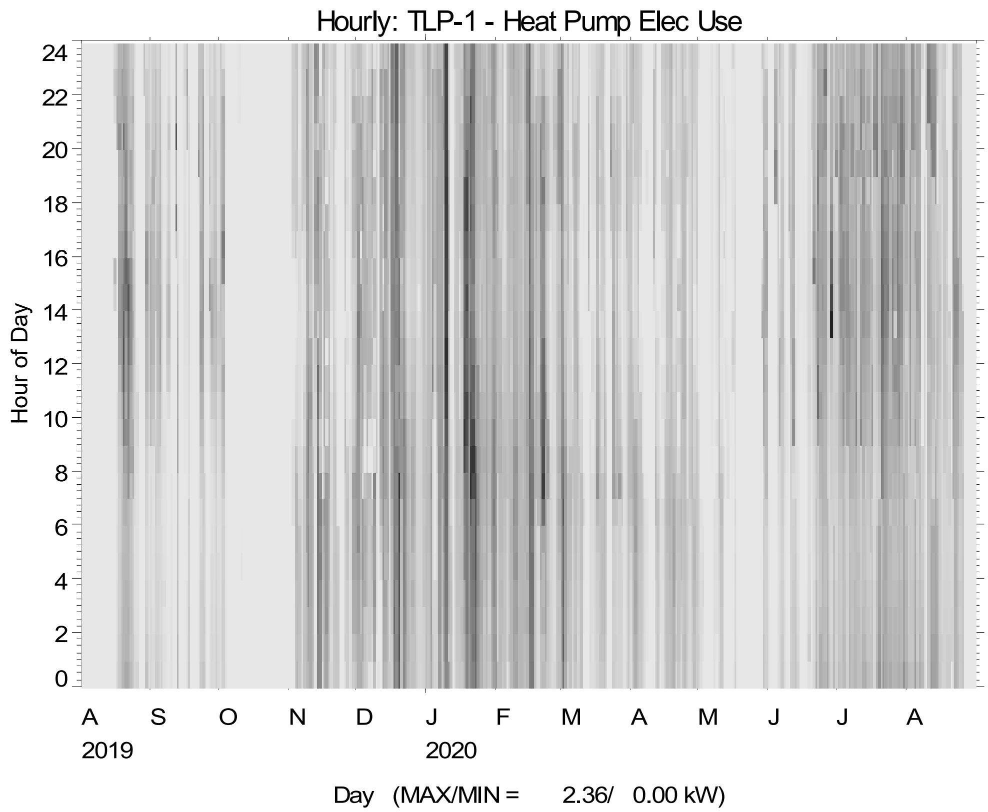


Figure 2. Shade Plot of Total Heat Pump Power

Figure 3 shows the daily energy use of the all the heat pumps.

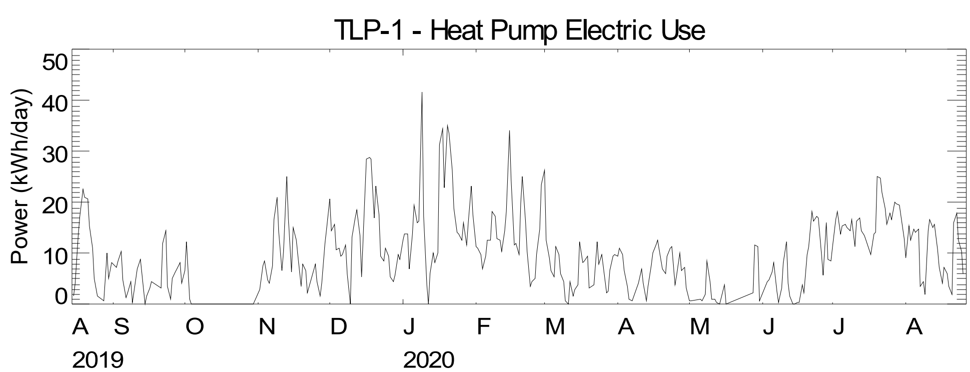


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.

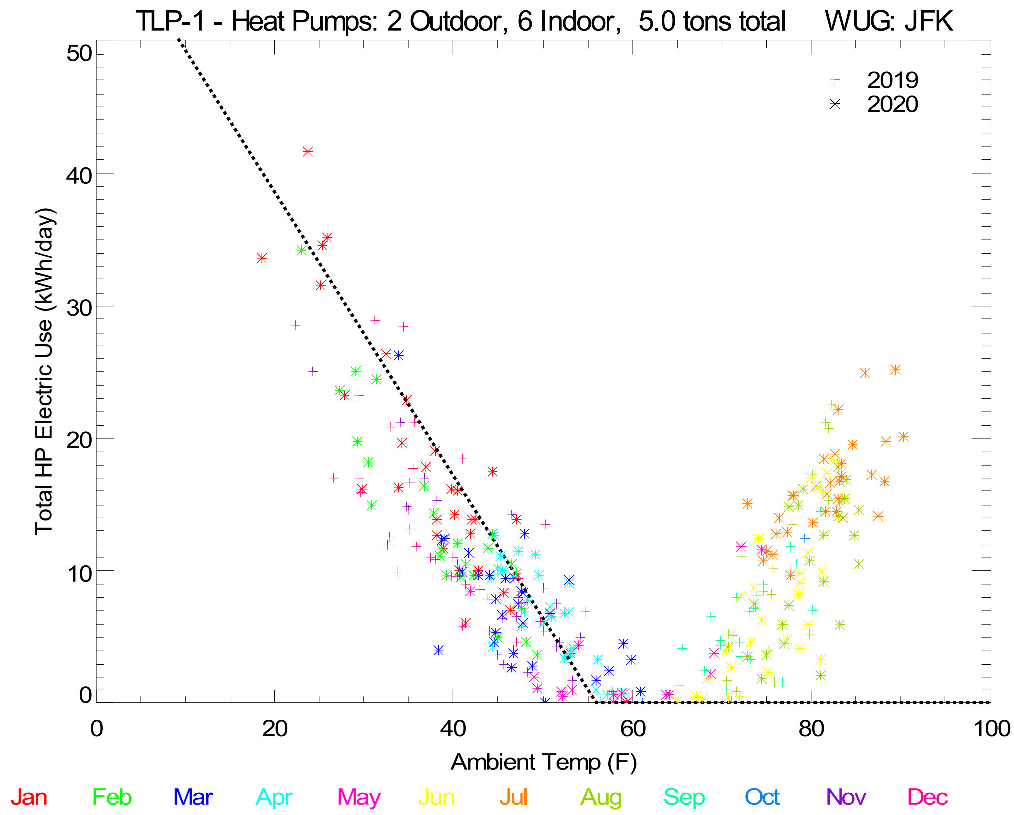


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature (from JFK)

Figure 5 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. Readings from the pre-retrofit period are shown as diamonds while post-retrofit readings have month number next to each point. The solid black line shows the linear best fit line to the pre-retrofit data (note that two readings in 2016 implied a prolonged vacation). The dotted line is the best fit to the post retrofit data.

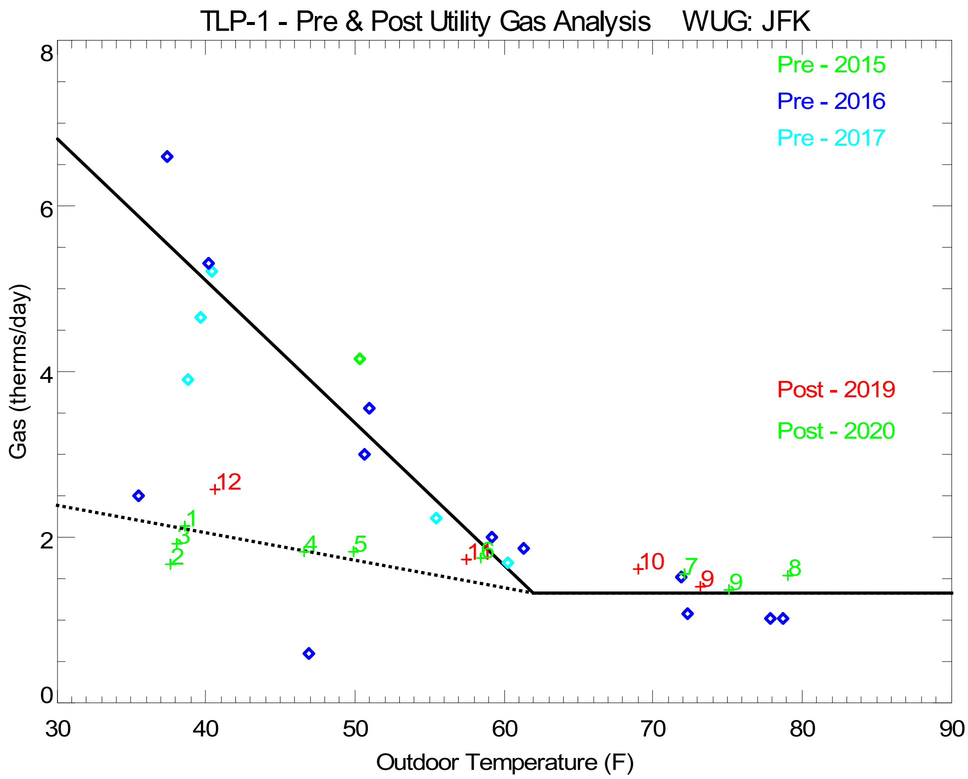


Figure 5. Trend of Gas Use With Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-1** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Gas** $ 1.403 per therm

Floor Area **1600**

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	16.7	4.3	89.5	4.3	3.1	23.4	23.9	
-22.5	0	15.8	4.1	84.1	4.1	3.1	22.2	22.6	
-17.5	0	15.0	4.0	78.8	4.0	3.1	21.0	21.3	
-12.5	0	14.1	3.8	73.4	3.8	3.2	19.8	20.0	
-7.5	0	13.2	3.6	68.0	3.6	3.2	18.6	18.7	
-2.5	0	12.4	3.5	62.7	3.5	3.2	17.4	17.4	
2.5	0	11.5	3.3	57.3	3.3	3.2	16.2	16.1	
7.5	11	10.7	3.1	52.0	3.1	3.3	15.0	14.8	
12.5	22	9.8	3.0	46.6	3.0	3.3	13.8	13.5	
17.5	101	9.0	2.8	41.3	2.8	3.4	12.6	12.2	
22.5	167	8.1	2.6	35.9	2.6	3.4	11.4	10.9	
27.5	247	7.2	2.5	30.5	2.5	3.5	10.2	9.6	
32.5	475	6.4	2.3	25.2	2.3	3.7	9.0	8.3	
37.5	855	5.5	2.2	19.8	2.2	3.9	7.8	7.0	
42.5	708	4.7	2.0	14.5	2.0	4.2	6.6	5.7	
47.5	608	3.8	1.8	9.1	1.8	5.0	5.4	4.4	
52.5	880	3.0	1.7	3.8	1.7	7.9	4.2	3.1	
57.5	750	2.1	1.5	0.0	1.5	99.0	3.0	2.1	
62.5	814	1.3	1.3	0.0	1.3	0.0	1.9	1.9	
67.5	723	1.3	1.3	0.0	1.3	0.0	1.9	1.9	
72.5	751	1.3	1.3	0.0	1.3	0.0	1.9	1.9	
77.5	870	1.3	1.3	0.0	1.3	0.0	1.9	1.9	

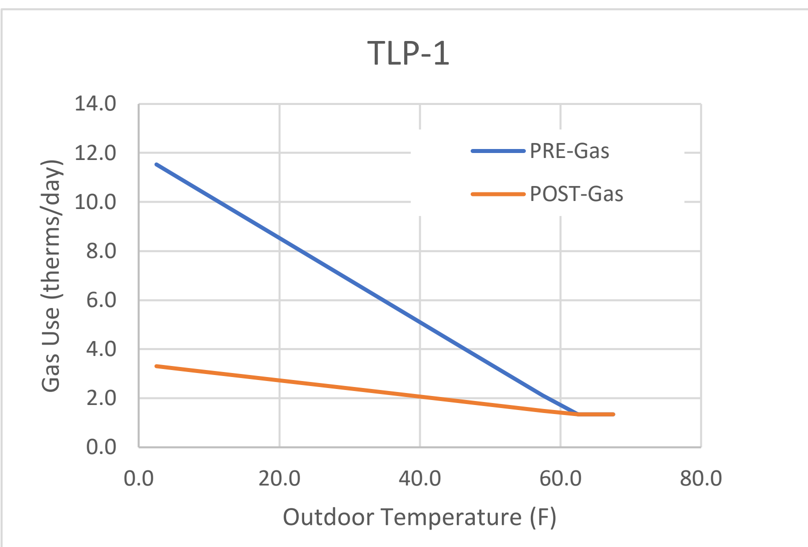


Figure 6. Trend of PRE- and POST-Retrofit Gas Use with Outdoor Temperature for Bin Analysis

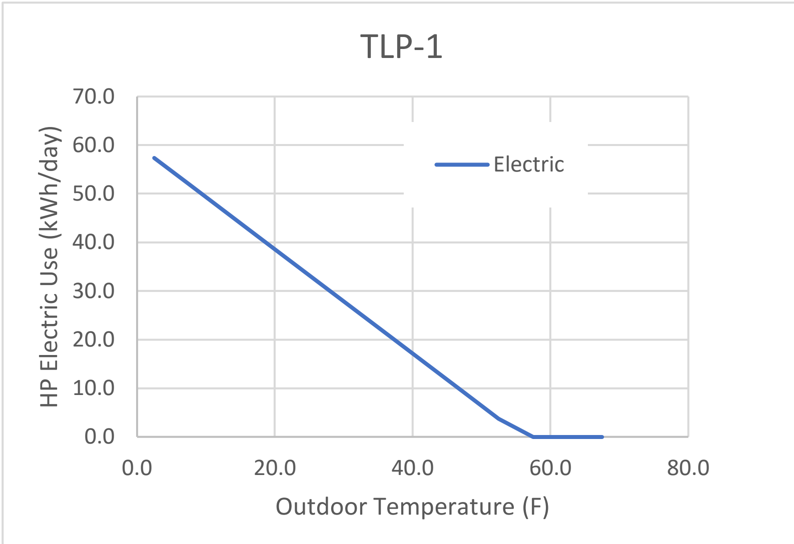


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 522 therms per year for all improvements. However, if we subtract the gas savings from the envelope improvements, the fuel savings attributable to the heat pumps is 437 therms per year. The heat pumps are estimated to use 2,804 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 3.5.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-1	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Gas (therms/yr)	647	125	85	522	437
HP Electric (kWh/yr)		2,804		(2,804)	
Total Heating Costs	$ 907	$ 736	$ 119	$ 171	$ 52
Implied Seasonal COP				4.2	3.5

Summary Statistics	
0.40	Htg therms per sq ft per year
31.9	Htg MBtu per sq ft per year
81%	Reduction in Htg Fuel Use
2,108	Measured HP Electric (kWh/yr)
75%	of typical year kWh

<u>Average Heat Pump Demand Profiles</u>

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

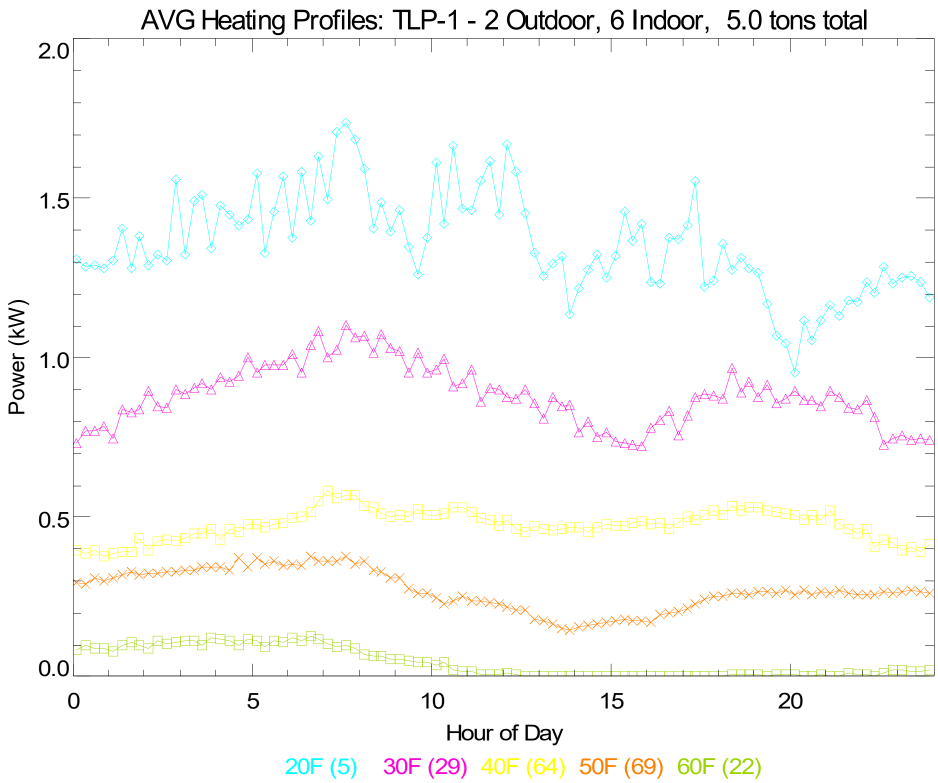


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

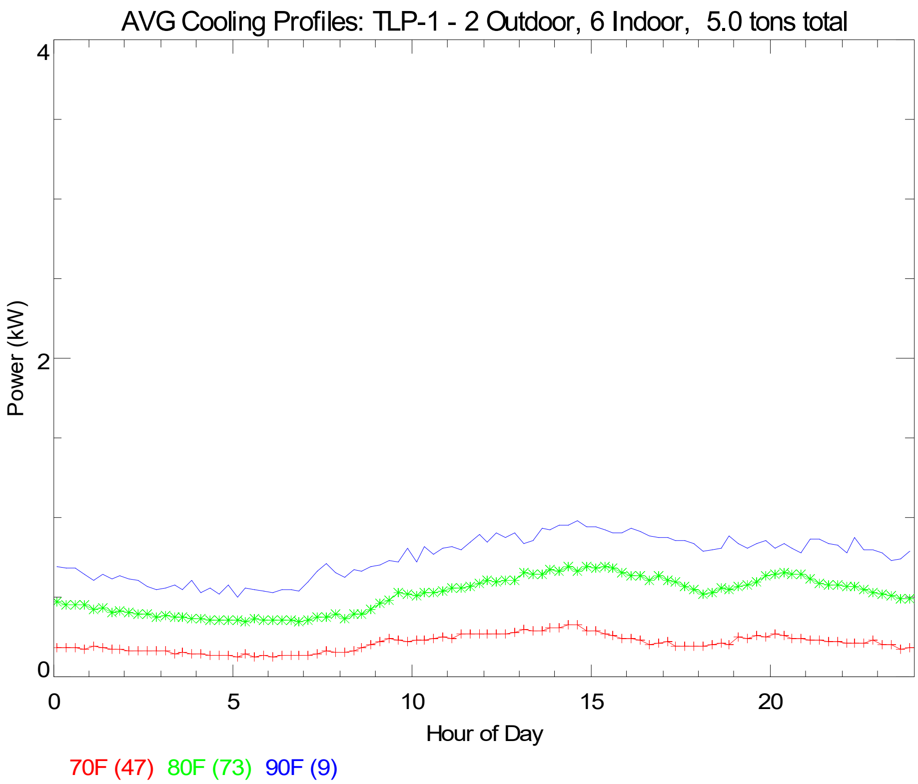


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

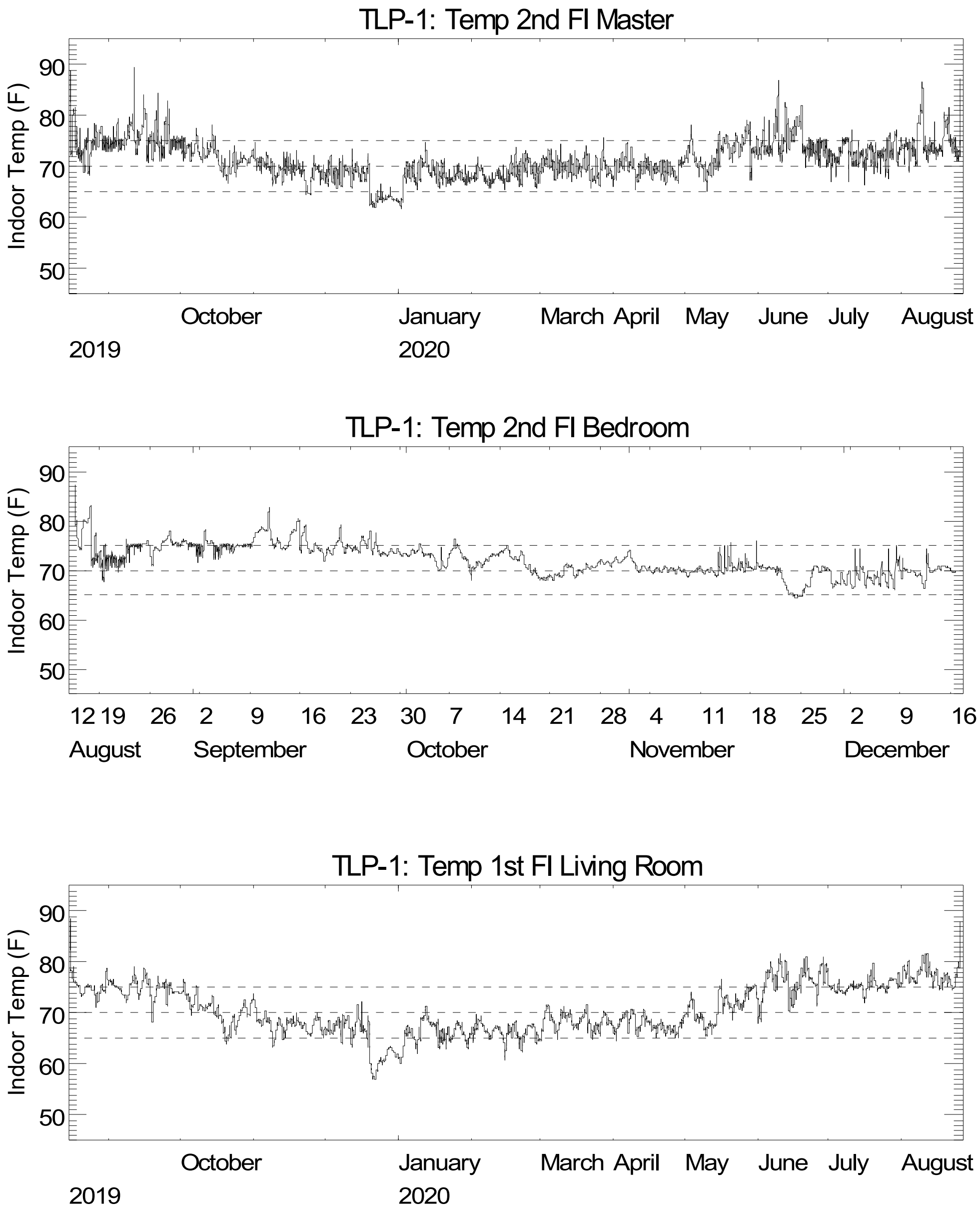


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 3 Savings Analysis

This 4,650 sq ft single-family home originally used an oil boiler with conventional baseboard radiation. Three electric heat pumps with a total capacity of 6.5 tons were added to the home on November 20, 2017. The oil boiler remained in place to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on December 18, 2017 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, insulation) proposed that were projected to save 555 gallons of oil per year. Table 1 shows that the final envelope improvements had less impact than originally expected, which total savings of 459 gallons per year.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage of heated area from 15731 CFM50 to 9000 CFM50. SAVINGS: $1,291 (466 gallons)	Reduce overall air leakage of heated area from 15731 CFM50 to **9371** CFM50. ACTUAL SAVINGS: ~440 gallons
Rim Joist	Upgrade 180 square feet of existing rim joist to 2" High Density Foam, 1.5" Wood, 0.5" Wood Siding, R-15	Completed
Attic Knee Wall	Upgrade 703 sq ft of wall to gyp board 2x4 24" OC, 1" fiberglass, 2" air, Steel R-5	Not Completed
All Insulation	SAVINGS: $247 (89 gallons)	ACTUAL SAVINGS: ~18 gallons

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	HP3 (kWh)	Boiler Runtime (hrs)
Dec-17	43%	1,705.5	446.7	351.7	907.0	33.3
Jan-18	100%	4,217.0	1,120.0	738.2	2,358.7	72.5
Feb-18	100%	2,911.8	884.1	393.8	1,633.8	30.1
Mar-18	100%	1,889.6	578.6	47.3	1,263.7	99.1
Apr-18	100%	781.1	176.8	3.5	600.8	72.4
May-18	100%	346.8	195.3	27.8	123.6	-
Jun-18	100%	310.4	252.4	45.6	12.4	-
Jul-18	100%	587.9	499.0	53.5	35.3	-
Aug-18	100%	549.7	424.9	42.2	82.5	-
Sep-18	100%	152.5	100.4	26.4	25.7	-
Oct-18	100%	524.7	184.1	169.7	170.9	26.2
Nov-18	100%	939.6	334.4	256.9	348.3	98.2
Dec-18	100%	1,982.3	670.8	362.0	949.5	66.6
Jan-19	100%	3,609.3	1,001.4	862.2	1,745.6	47.6
Feb-19	100%	1,720.7	430.9	428.6	861.2	97.7
Mar-19	43%	560.8	141.9	177.4	241.5	61.3
Annual	100%	15,193.4	5,420.8	2,166.9	7,605.2	465.1
Summer (Jun-Sep)		1,600.5	1,276.7	167.7	155.9	
Winter (Oct-May)		13,592.9	4,144.1	1,999.2	7,449.3	465.1

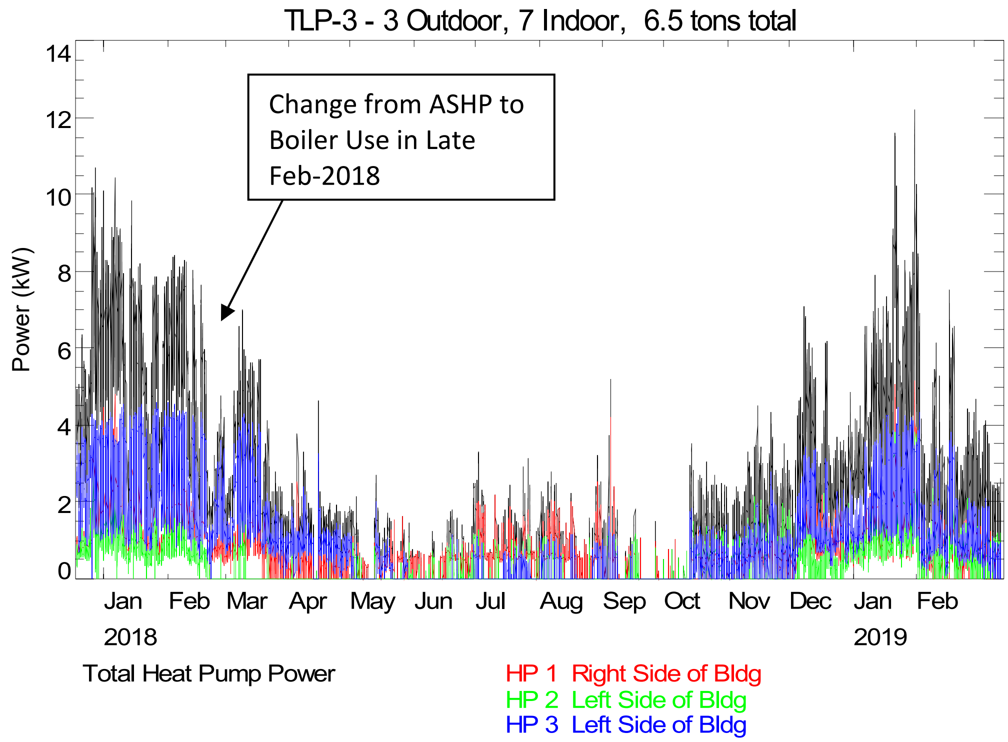


Figure 1. Plot of Power Use for All Heat Pumps at Site

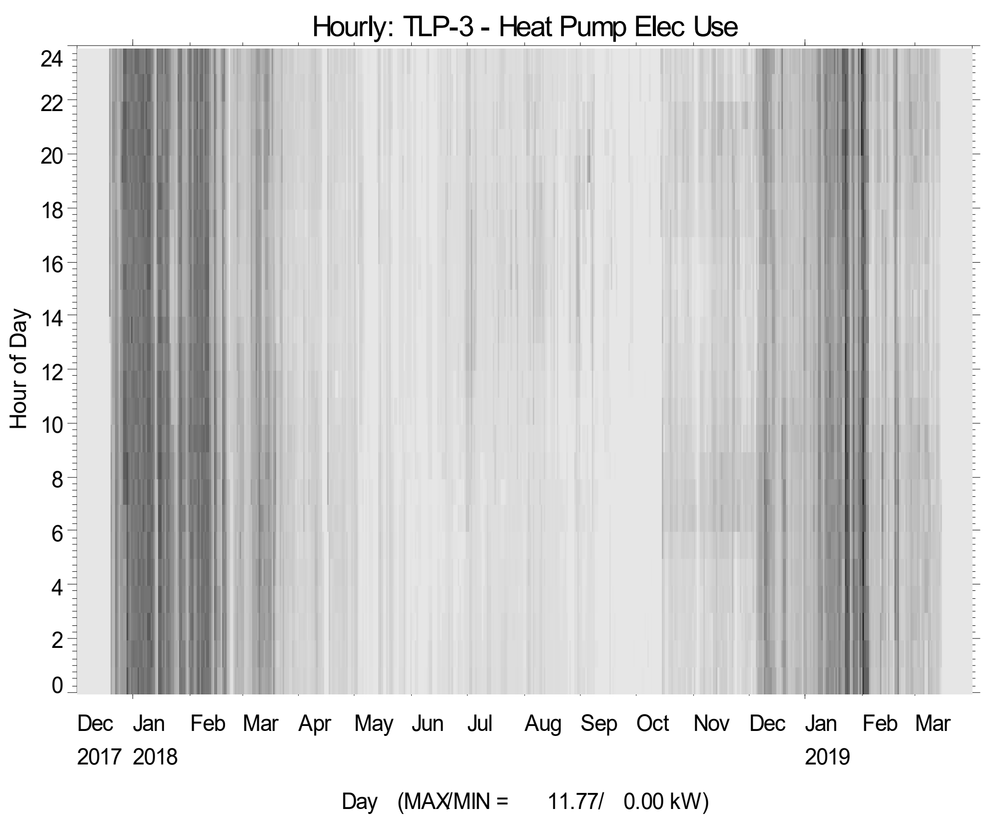


Figure 2. Shade Plot of Total Heat Pump Power

Figure 3 shows the daily energy use of the all the heat pumps. If the on-site boiler was monitored, then a plot for daily runtime is also shown.

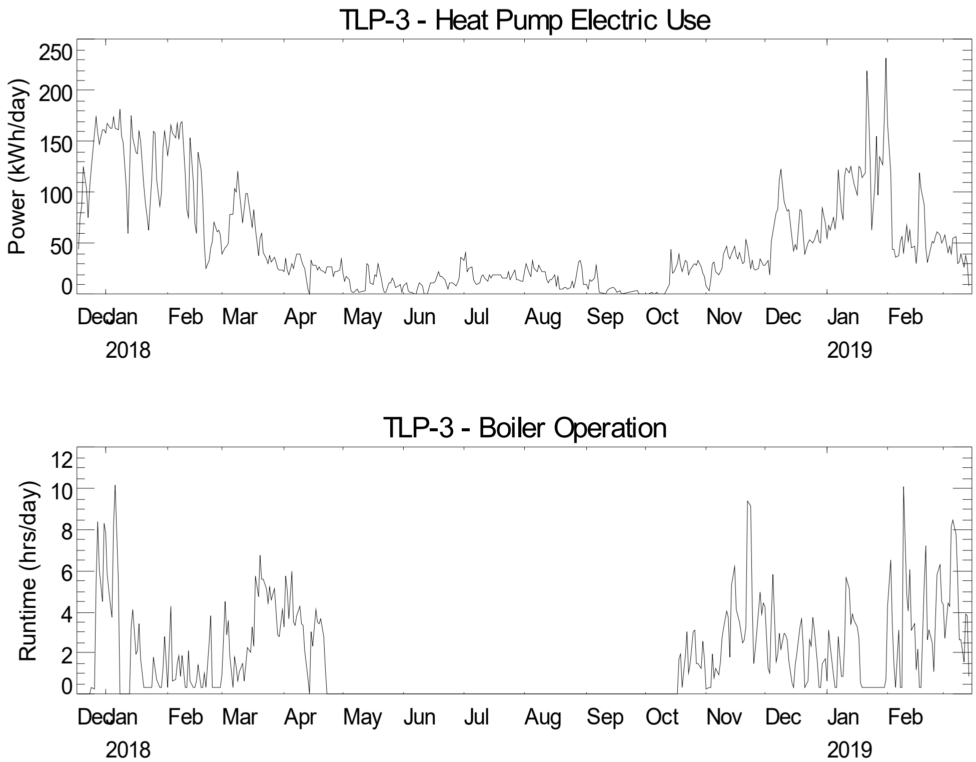


Figure 3. Plot of Daily Total HP Electric Use (and Daily Boiler Operation)

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.

Figure 5 shows the correlation between daily boiler runtime and the daily average ambient temperature from JFK. The same colors and symbols were used to represent months and years as described above for Figure 4. Again, a significant change in operation is apparent for March and April 2018, where the HPs ran less often. This change in boiler operation was also observed later in the monitoring period. The dotted line on the plot shows the linear trend using data from December 2017 through the end of February 2018 determined from boiler runtime (an oil consumption rate of 1.7 gal/h was determined by comparing boiler runtime and fuel consumption across the period corresponding to the last recorded oil delivery in October 2018). The days with more boiler runtime were driven by set point changes on the HP and boiler thermostats by the occupant.

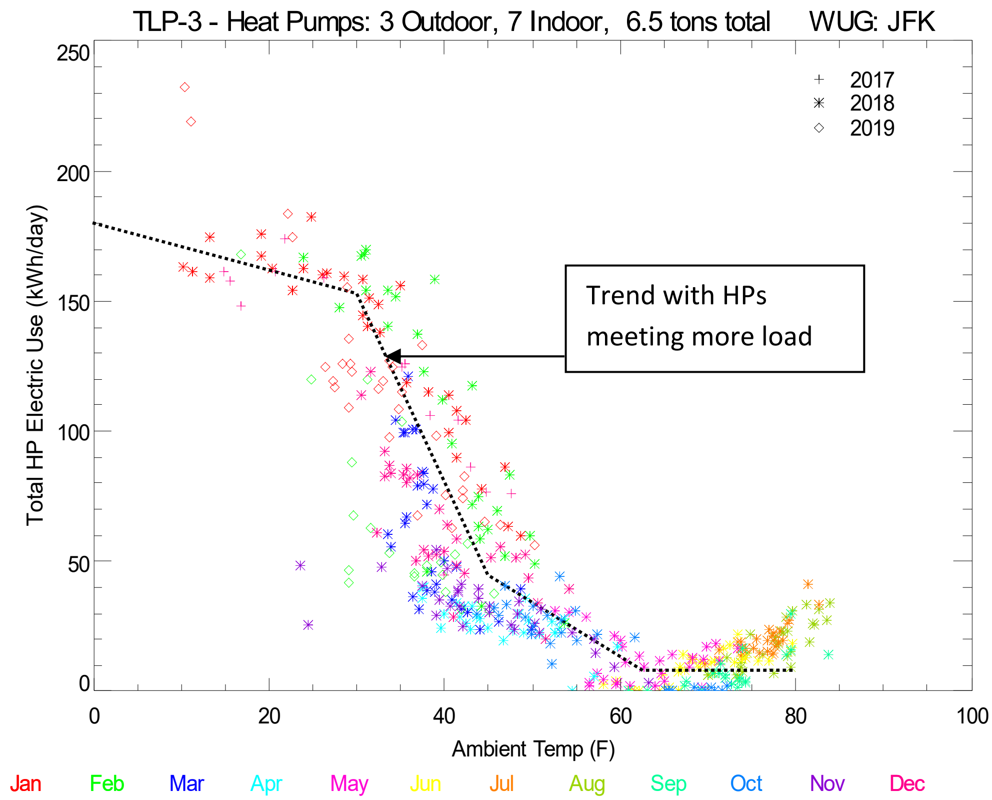


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature (from JFK)

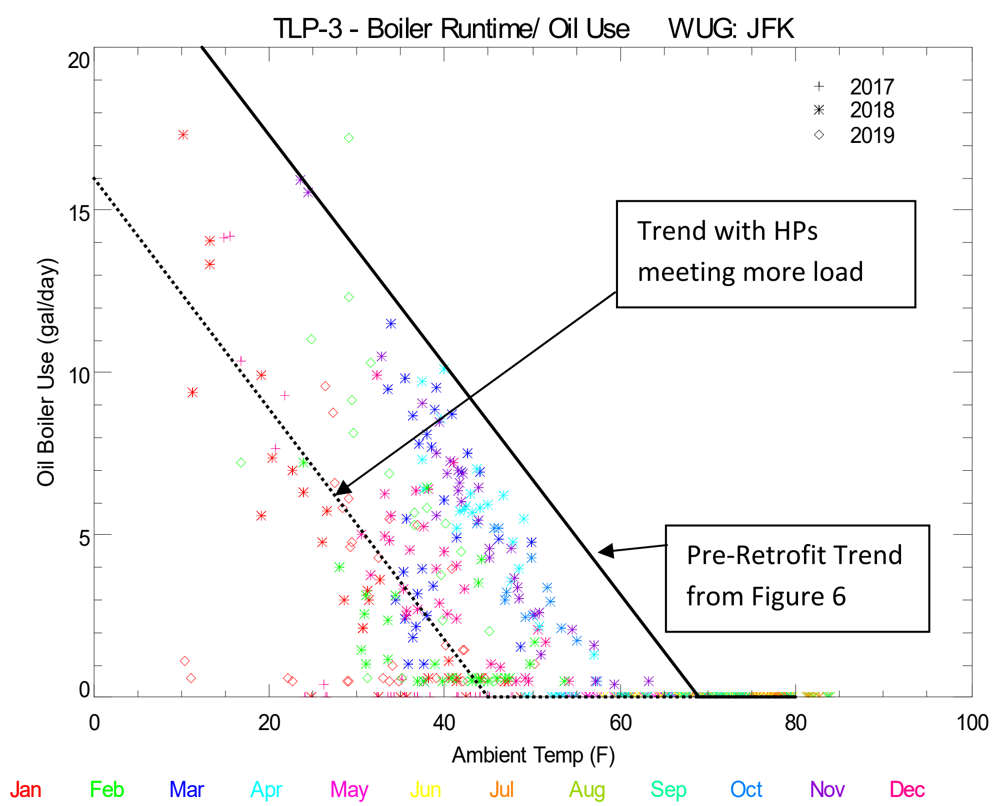


Figure 5. Daily Oil Use versus Outdoor Temperature (from JFK). Oil Use determined from Boiler Runtime.

Figure 6 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data (this line is also shown on Figure 5). There are also two post-retrofit oil readings on the plot. The dotted line is the best fit from the daily runtime data on Figure 5. The dotted line is well-aligned with the post-retrofit fuel reading from October 2018 on the plot – confirming the validity of the approach.

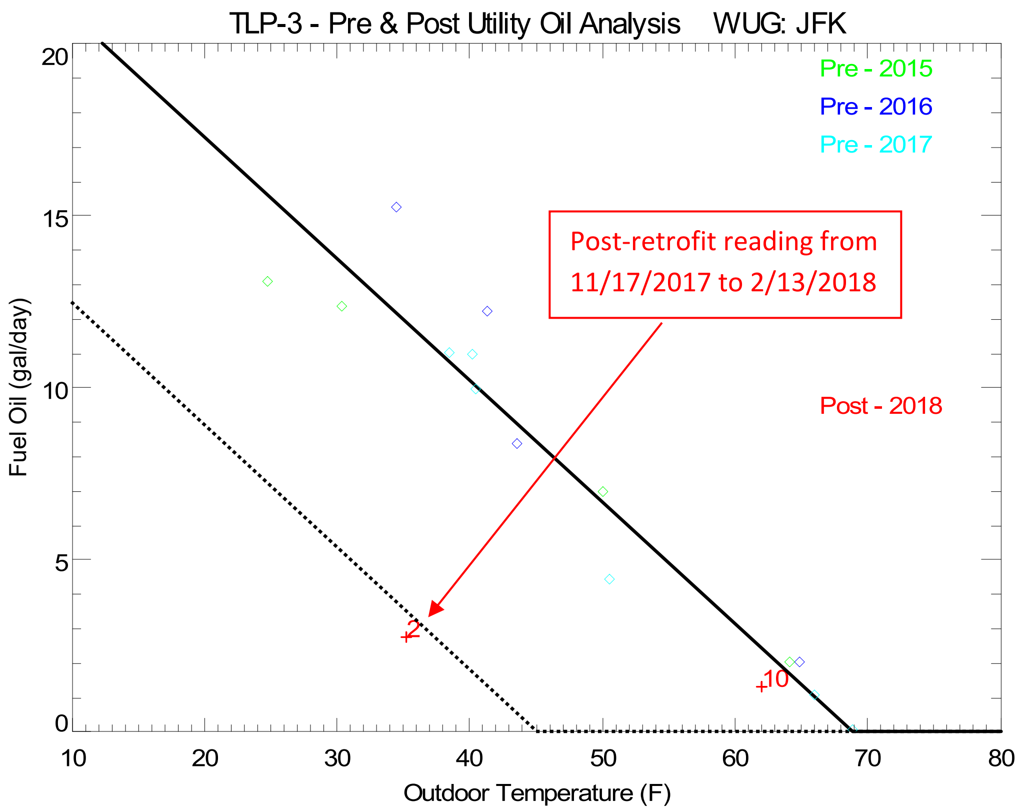


Figure 6. Trend of Oil Use With Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

Annual Savings Analysis

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 7 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 8 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE:	TLP-3	WEATHER:	New_York	$ 0.20 per kWh
FUEL:	Oil			$ 2.447 per gal

Floor Area 4650

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	34.1	25.8	204.8	25.8	1.1	83.4	104.0	
-22.5	0	32.3	24.0	200.3	24.0	1.1	79.0	98.8	
-17.5	0	30.5	22.2	195.8	22.2	1.2	74.7	93.5	
-12.5	0	28.8	20.4	191.3	20.4	1.2	70.4	88.3	
-7.5	0	27.0	18.7	186.8	18.7	1.2	66.1	83.0	
-2.5	0	25.2	16.9	182.3	16.9	1.2	61.7	77.8	
2.5	0	23.5	15.1	177.8	15.1	1.3	57.4	72.5	
7.5	11	21.7	13.3	173.3	13.3	1.3	53.1	67.3	
12.5	22	19.9	11.6	168.8	11.6	1.4	48.8	62.0	
17.5	101	18.2	9.8	164.3	9.8	1.4	44.4	56.8	
22.5	167	16.4	8.0	159.8	8.0	1.4	40.1	51.5	
27.5	247	14.6	6.2	155.3	6.2	1.5	35.8	46.3	
32.5	475	12.9	4.4	135.0	4.4	1.7	31.5	37.9	
37.5	855	11.1	2.7	99.0	2.7	2.3	27.1	26.3	
42.5	708	9.3	0.9	63.0	0.9	3.7	22.8	14.8	
47.5	608	7.6	0.0	39.7	0.0	5.2	18.5	7.9	
52.5	880	5.8	0.0	29.1	0.0	5.4	14.2	5.8	
57.5	750	4.0	0.0	18.6	0.0	5.9	9.8	3.7	
62.5	814	2.3	0.0	8.0	0.0	7.7	5.5	1.6	
67.5	723	0.5	0.0	8.0	0.0	1.7	1.2	1.6	
72.5	751	0.0	0.0	8.0	0.0	0.0	0.0	1.6	

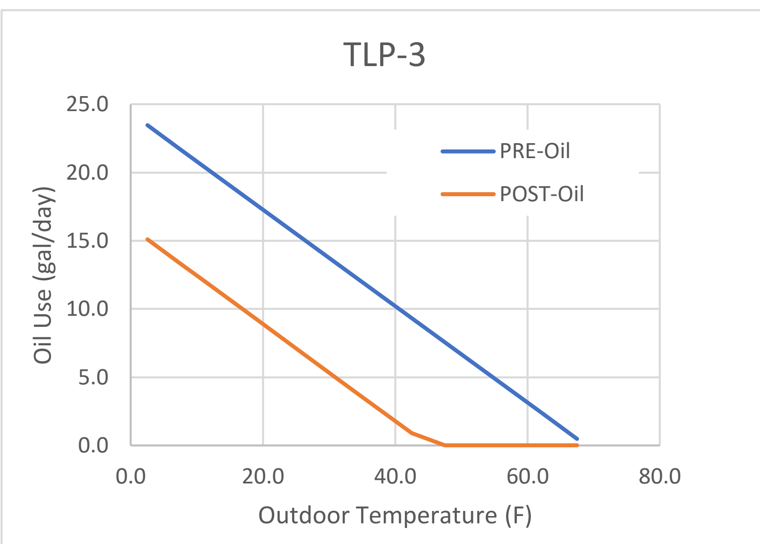


Figure 7. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

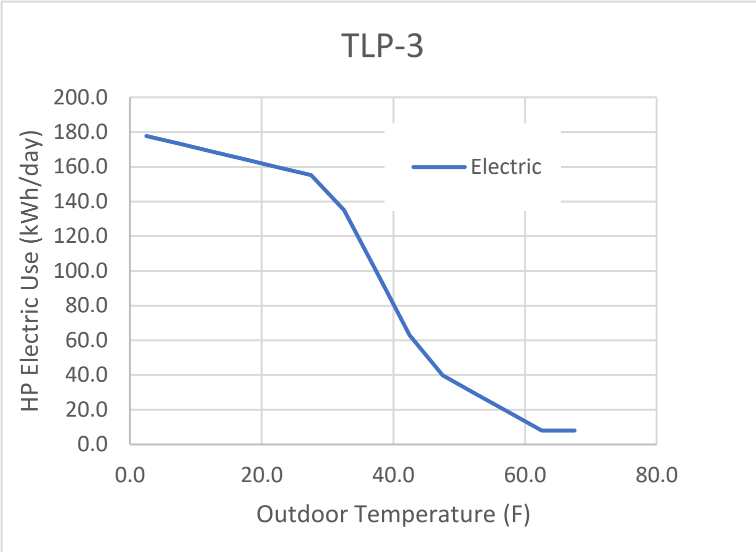


Figure 8. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 1,528 gallons per year for all improvements. However, if we subtract the oil savings from the envelope improvements, the fuel savings attributable to the heat pumps is 1,069 gallons per year. The heat pumps are estimated to use 14,859 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.0.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-3	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	1,915	387	459	1,528	1,069
HP Electric (kWh/yr)		14,859		(14,859)	
Total Heating Costs	$ 4,685	$ 3,918	$ 1,122	$ 767	$ (355)
Implied Seasonal COP				2.8	2.0

Summary Statistics	
0.41	Htg gal per sq ft per year
48.1	Htg MBtu per sq ft per year
80%	Reduction in Htg Fuel Use
13,593	Measured HP Electric (kWh/yr)
91%	of typical year kWh

<u>Average Heat Pump Demand Profiles</u>

Figure 9 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 10 shows the same calculation process associated with cooling operation.

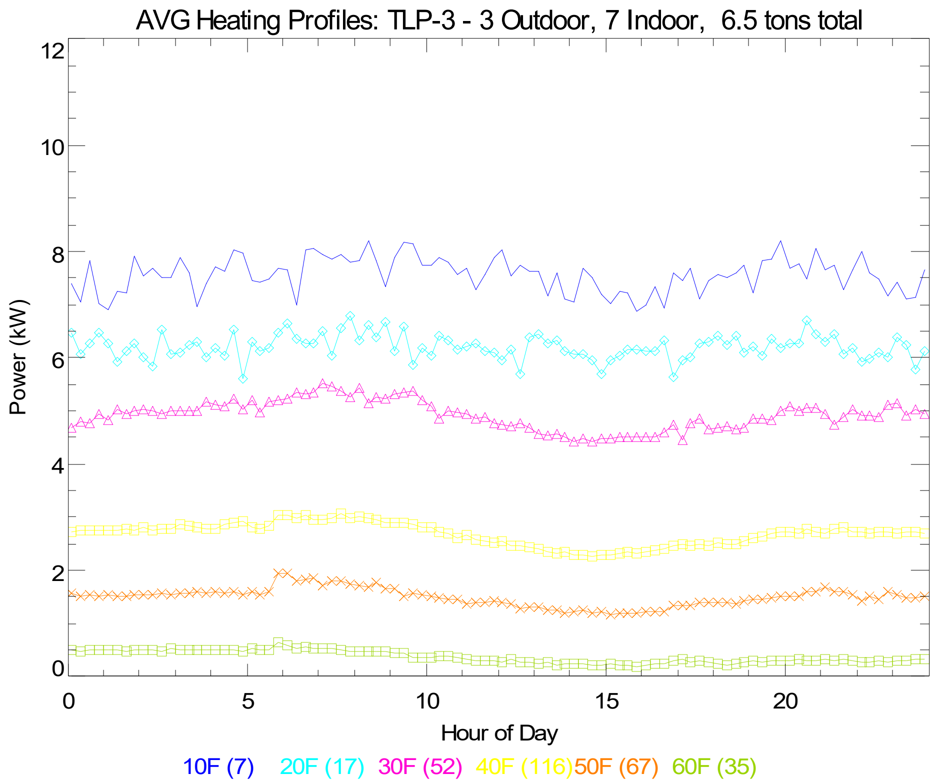


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

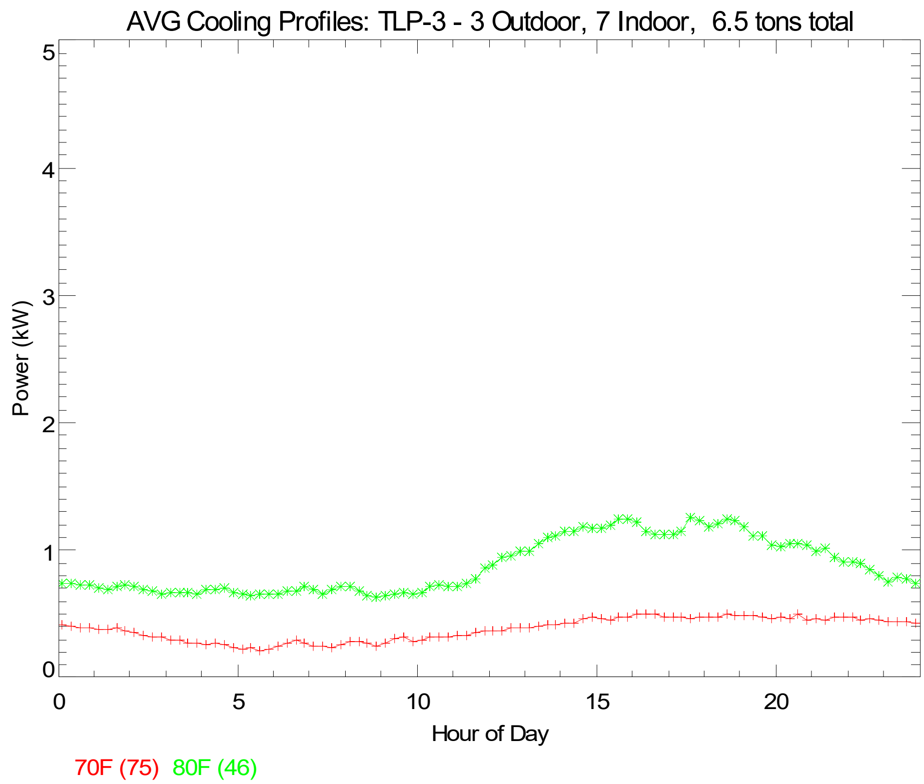


Figure 10. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 11.

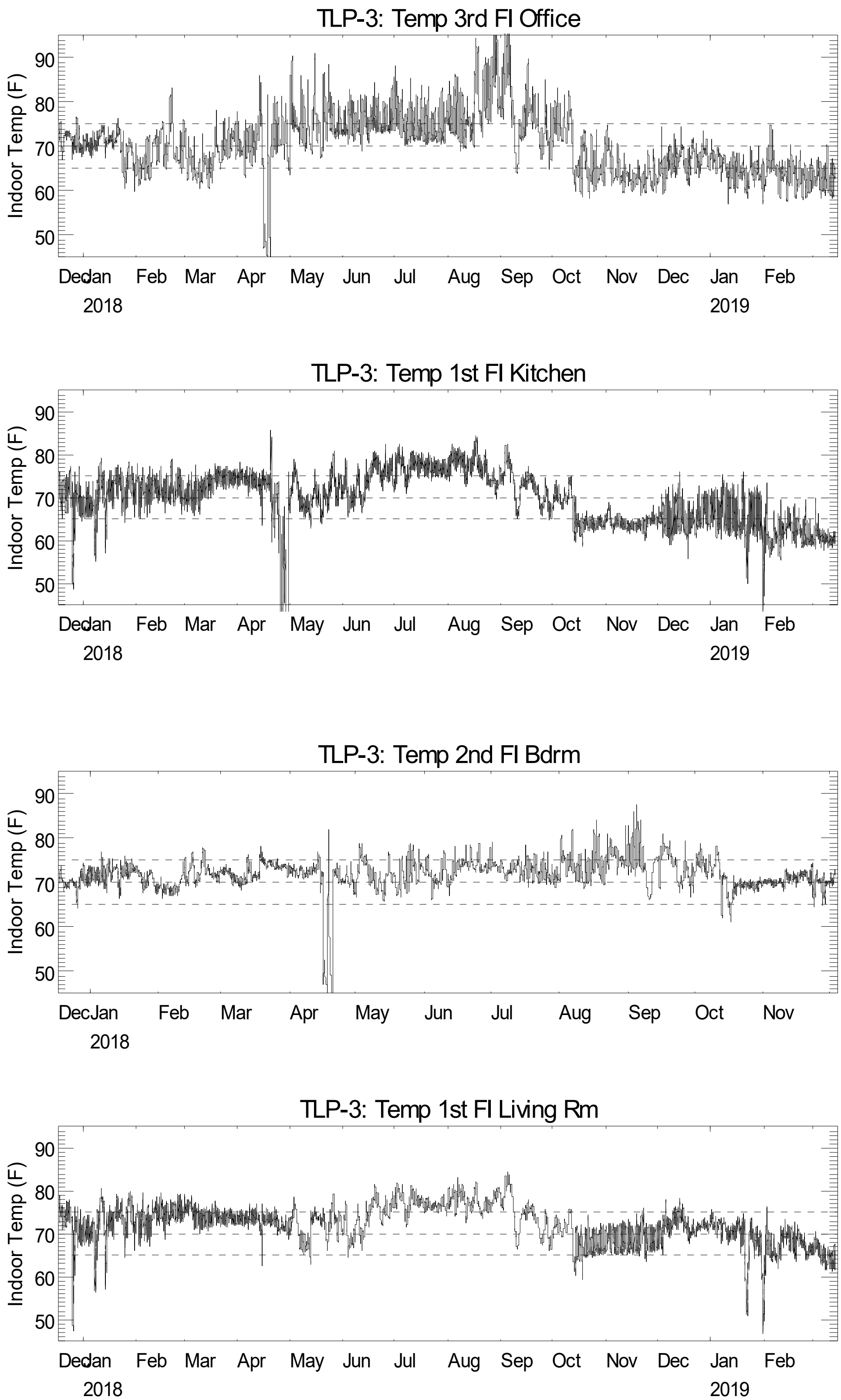


Figure 11. Plot of Space Temperatures at Various Indoor Locations

Site 5 Savings Analysis

This 3,370 sq ft single-family home originally used a gas boiler with conventional baseboard radiation. Four electric heat pumps with a total capacity of 8.5 tons were added to the home in early 2018 as part of a remodeling project. The gas boiler remained in place to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on April 12, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, rim joist, ceiling) implemented that were projected to save 776 therms per year. The final project savings were 697 therms per year. Table 1 compares the proposed and final envelope measures.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage of heated area from 2 ACH to 0.75 ACH SAVINGS: $990 (688 therms)	Completed
Rim Joist	Upgrade 136 sq ft to R15	Completed
Ceiling Insulation	Upgrade 1075 sq ft to R29	Not Completed
All Insulation	SAVINGS: $128 (89 therms)	ADJUSTED SAVINGS: ~10 therms

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	HP3 (kWh)	HP4 (kWh)
Apr-18	62%	901.5	373.8	170.6	198.3	158.9
May-18	100%	253.0	111.8	23.6	61.5	56.1
Jun-18	100%	274.0	106.7	85.7	6.4	75.1
Jul-18	100%	492.1	140.0	127.3	38.9	185.9
Aug-18	100%	675.0	152.5	52.1	187.1	283.3
Sep-18	100%	377.2	143.6	60.5	55.9	117.2
Oct-18	100%	649.8	305.4	16.4	168.3	159.6
Nov-18	100%	1,531.3	626.0	123.1	342.3	439.9
Dec-18	100%	2,028.6	708.6	224.8	442.6	652.5
Jan-19	100%	2,635.1	953.7	141.2	636.9	903.3
Feb-19	69%	1,679.3	666.0	83.8	414.8	514.7
Mar-19	78%	1,115.7	588.3	-	170.7	356.8
Apr-19	100%	729.7	468.1	14.2	124.8	122.6
May-19	100%	326.0	194.8	33.5	61.7	36.0
Jun-19	100%	282.8	49.8	85.9	42.4	104.6
Jul-19	100%	1,067.3	155.5	401.4	195.1	315.3
Aug-19	100%	727.9	93.1	209.9	136.5	288.5
Sep-19	100%	323.7	28.1	137.9	60.5	97.2
Oct-19	100%	323.9	28.7	104.4	13.5	177.3
Nov-19	100%	1,722.4	622.2	104.9	367.0	628.2
Dec-19	54%	1,487.6	591.9	178.3	277.8	439.7
Annual	96%	12,440.8	4,970.7	952.7	2,650.2	3,867.0
Summer (Jun-Sep)		1,818.3	542.8	325.6	288.3	661.5
Winter (Oct-May)		10,622.5	4,427.9	627.1	2,361.9	3,205.5

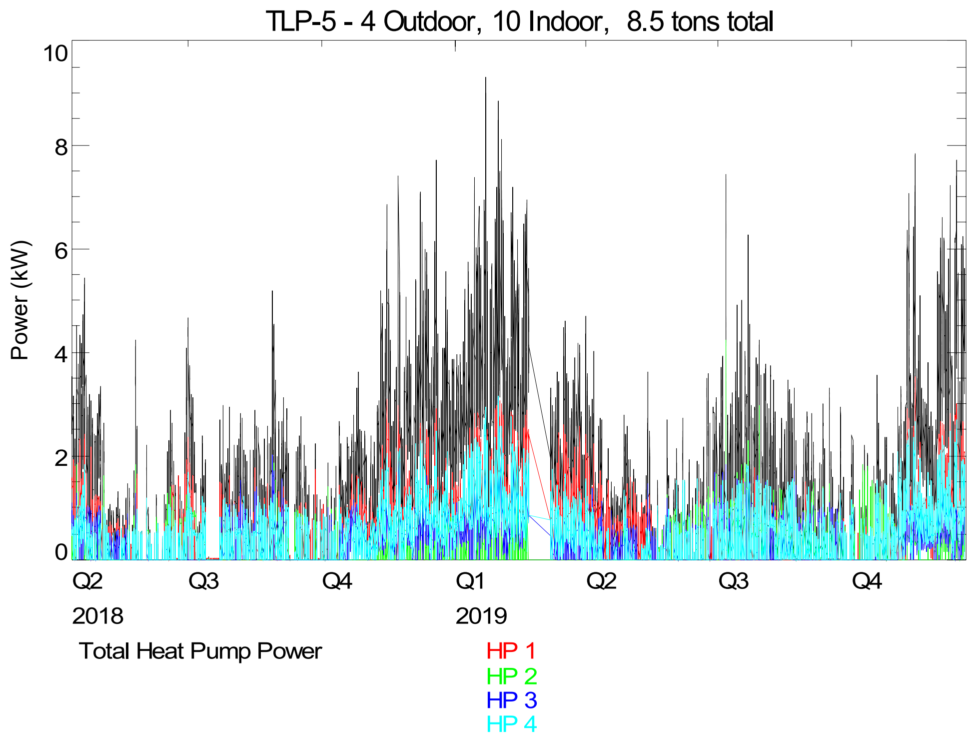


Figure 1. Plot of Power Use for All Heat Pumps at Site

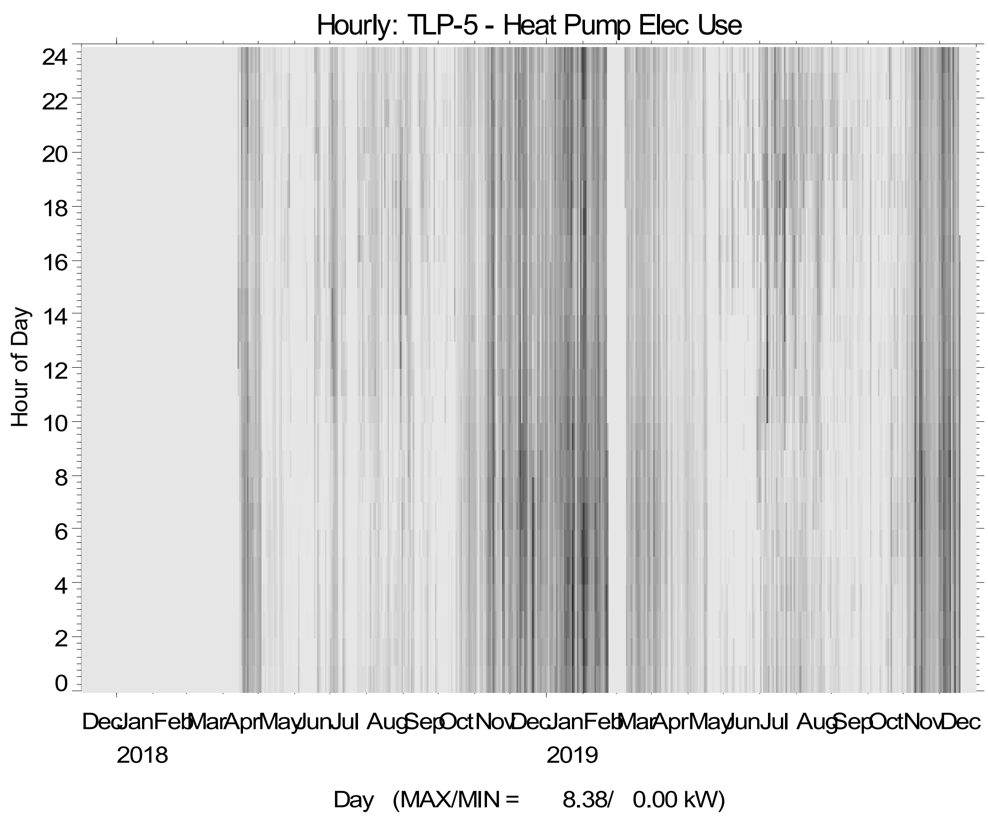


Figure 2. Shade Plot of Total Heat Pump Power

Figure 3 shows the daily energy use of the all the heat pumps.

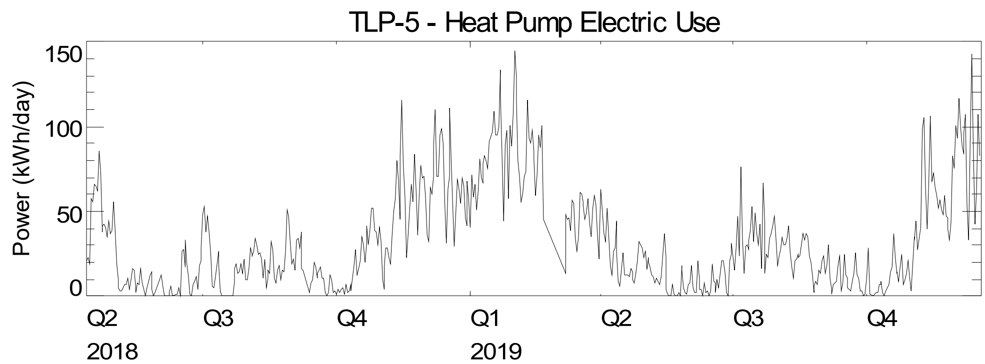


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.

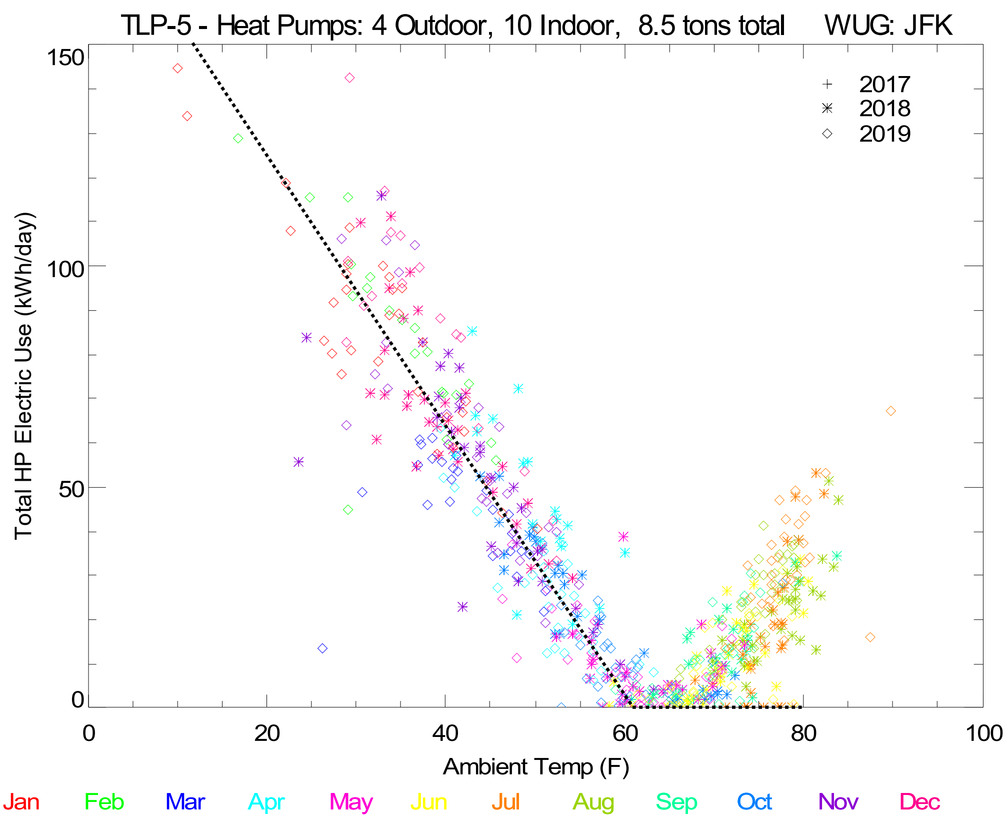


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature (from JFK)

Figure 5 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. The dotted line is the best fit to the post retrofit data, determined by ignoring the two circled points from February and March 2019. These two readings were ignored because the ASHPs were turned off for two week period (2/20/2019 to 3/7/2019) and the boiler was used to heat the house. This "flip-flop" test allowed us to estimate the energy savings associated with the envelope improvements alone. During the test the average gas consumption was 17.5 therms/day and average temperature over the 14-day period was 33.6°F. The results from the period generally show a relatively modest reduction relative to the black line – in contrast to the estimated envelope savings of 697 therms per year from the weatherization project. The flip-flop test did not corroborate the estimated weatherization savings in this case.

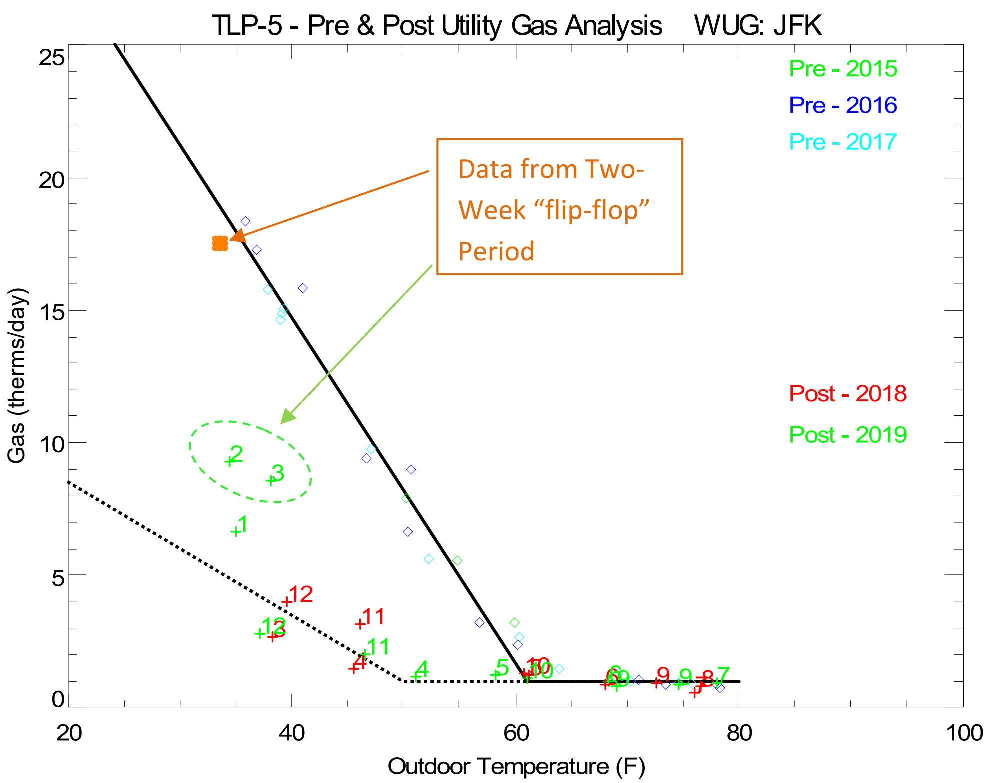


Figure 5. Trend of Gas Use With Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-5** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Gas** $ 1.403 per therm

Floor Area **3370**

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	58.8	20.4	270.4	20.4	3.3	82.6	82.7	
-22.5	0	55.6	19.1	255.1	19.1	3.4	78.0	77.8	
-17.5	0	52.3	17.9	239.7	17.9	3.4	73.4	73.0	
-12.5	0	49.0	16.6	224.4	16.6	3.4	68.8	68.2	
-7.5	0	45.8	15.4	209.1	15.4	3.4	64.2	63.4	
-2.5	0	42.5	14.1	193.8	14.1	3.4	59.6	58.6	
2.5	0	39.2	12.9	178.5	12.9	3.5	55.1	53.8	
7.5	11	36.0	11.6	163.2	11.6	3.5	50.5	48.9	
12.5	22	32.7	10.4	147.9	10.4	3.5	45.9	44.1	
17.5	101	29.4	9.1	132.5	9.1	3.6	41.3	39.3	
22.5	167	26.2	7.9	117.2	7.9	3.7	36.7	34.5	
27.5	247	22.9	6.6	101.9	6.6	3.7	32.1	29.7	
32.5	475	19.6	5.4	86.6	5.4	3.9	27.5	24.9	
37.5	855	16.4	4.1	71.3	4.1	4.0	23.0	20.0	
42.5	708	13.1	2.9	56.0	2.9	4.3	18.4	15.2	
47.5	608	9.8	1.6	40.7	1.6	4.7	13.8	10.4	
52.5	880	6.6	1.0	25.5	1.0	5.1	9.2	6.5	
57.5	750	3.3	1.0	10.5	1.0	5.1	4.6	3.5	
62.5	814	1.0	1.0	0.0	1.0	0.0	1.4	1.4	
67.5	723	1.0	1.0	0.0	1.0	0.0	1.4	1.4	
72.5	751	1.0	1.0	0.0	1.0	0.0	1.4	1.4	

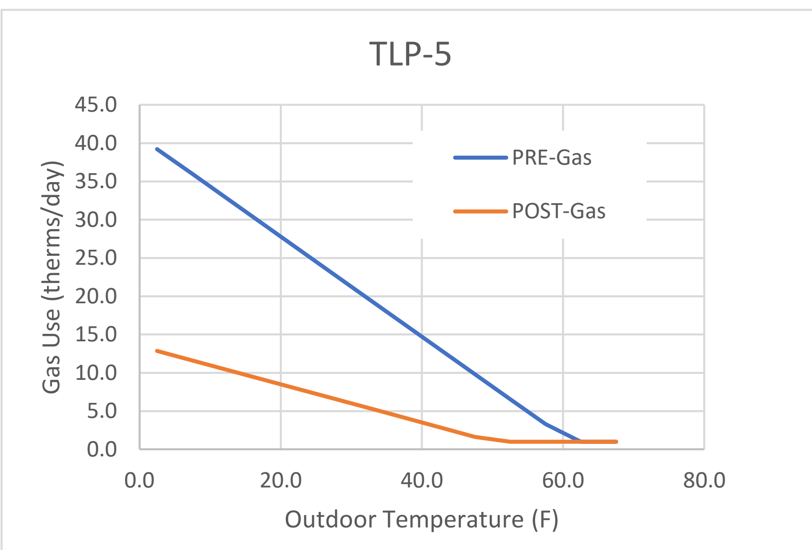


Figure 6. Trend of PRE- and POST-Retrofit Gas Use with Outdoor Temperature for Bin Analysis

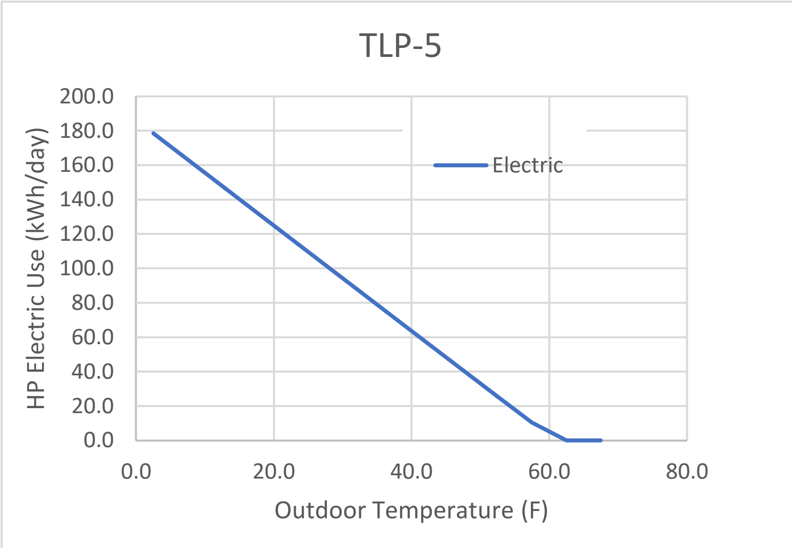


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 1,914 therms per year for all improvements. However, if we subtract the gas savings from the envelope improvements, the fuel savings attributable to the heat pumps is 1,217 therms per year. The heat pumps are estimated to use 10,830 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.6.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-5	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Gas (therms/yr)	2,337	422	697	1,914	1,217
HP Electric (kWh/yr)		10,830		(10,830)	
Total Heating Costs	$ 3,279	$ 2,759	$ 979	$ 520	$ (459)
Implied Seasonal COP				4.1	2.6

Summary Statistics	
0.69	Htg therms per sq ft per year
54.8	Htg MBtu per sq ft per year
82%	Reduction in Htg Fuel Use
10,623	Measured HP Electric (kWh/yr)
98%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

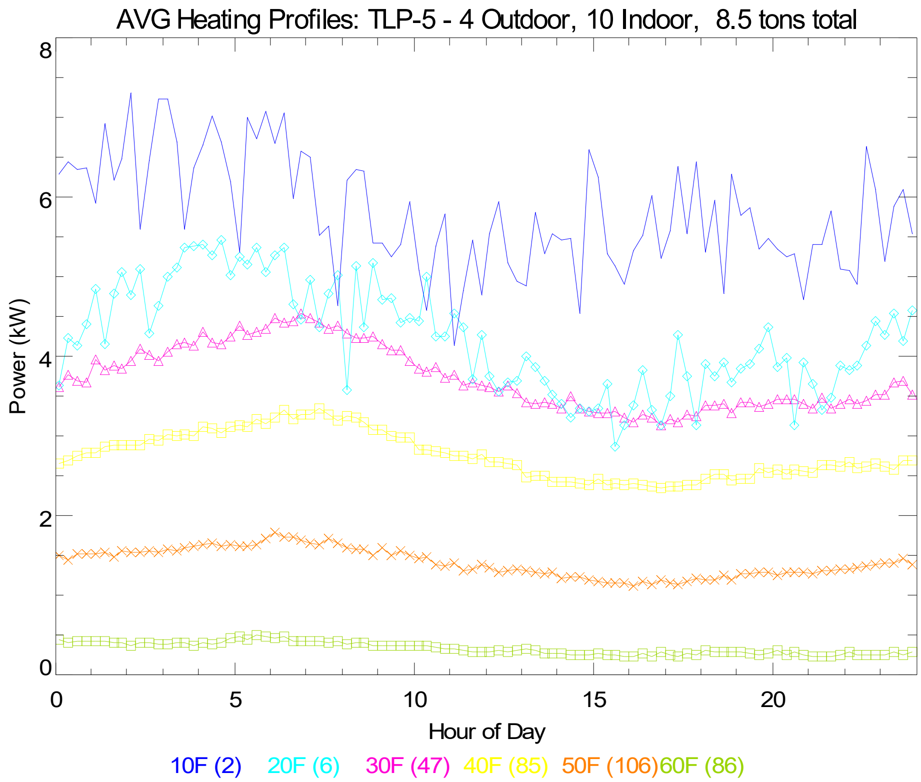


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

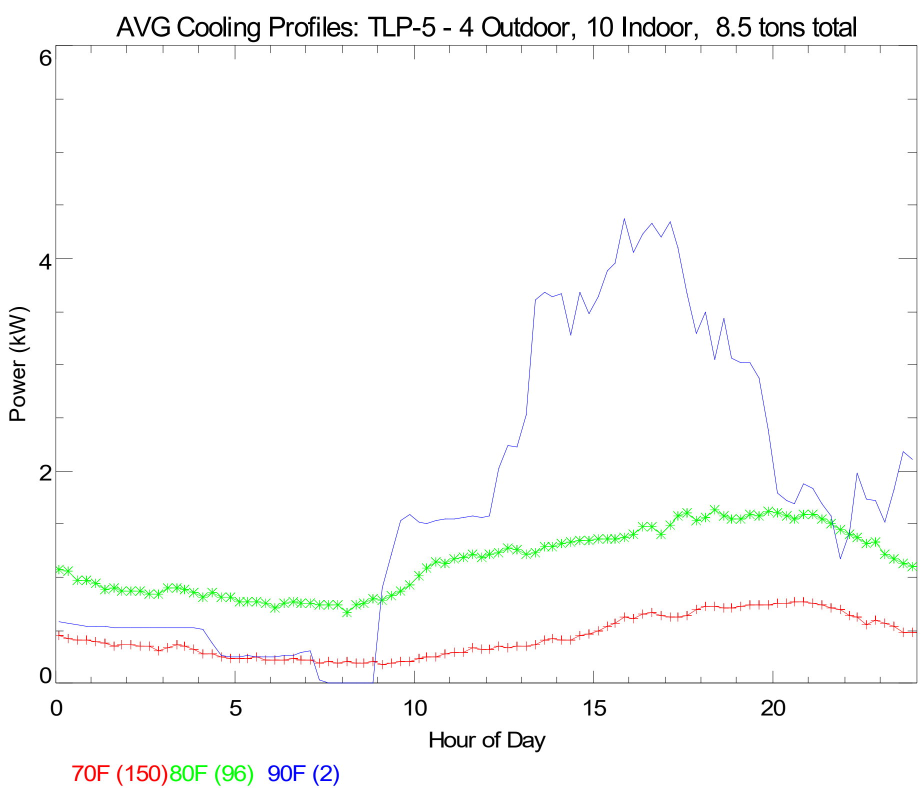


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

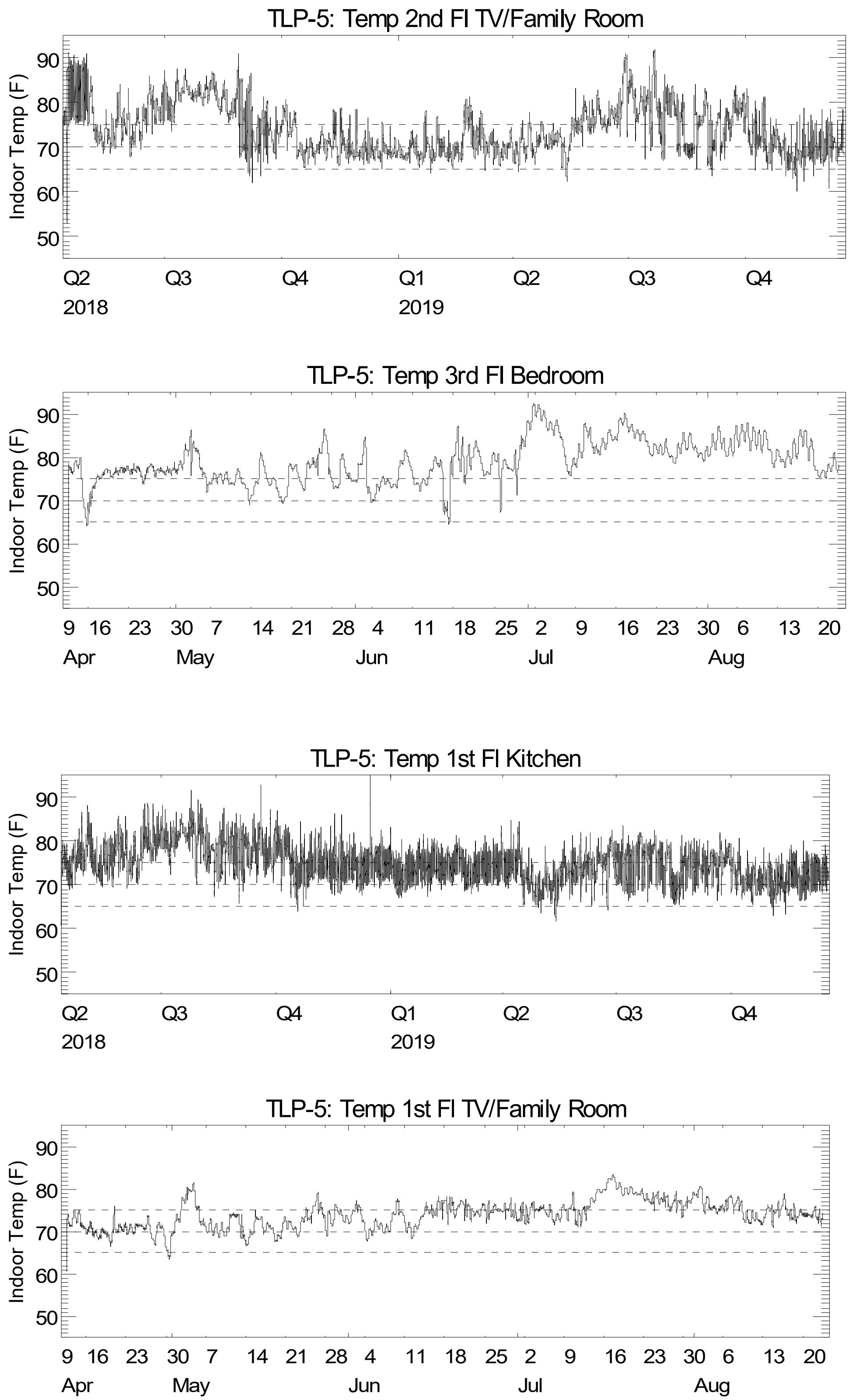


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 10 Savings Analysis

This 4,512 sq ft multifamily home originally used an oil boiler with conventional baseboard radiation. Three electric heat pumps with a total capacity of 8 tons were added to the home in March 2018. The oil boiler remained in place to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on April 11, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, insulation) proposed that were projected to save 401 gallons of oil per year. Table 1 compares the proposed and implemented envelope measures.

Table 1. Summary List of Proposed and Final Envelope Savings

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage of heated area from 1.75 ACH to 1.30 ACH. SAVINGS: $852 (308 gallons)	Reduce overall air leakage of heated area from 1.75 ACH to **1.25** ACH. ADJUSTED SAVINGS: ~342 gallons
Rim Joist	Upgrade 180 square feet of existing rim joist to 2" High Density Foam, 1.5" Wood, 0.5" Wood Siding, R-15	Completed
Second floor attic insulation	Upgrade 320 square feet of existing ceiling to Gyp Bd, 2x6 16" OC, 6" cellulose, R-19	Completed
All Insulation	SAVINGS: $163 (59 gallons)	Same

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps. If the on-site boiler was monitored, then a plot for daily runtime is also shown.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	HP3 (kWh)	Boiler (hrs)
Apr-18	65%	709.4	314.1	299.8	95.5	-
May-18	100%	362.0	108.2	141.0	112.8	-
Jun-18	100%	557.5	267.7	148.0	141.8	-
Jul-18	100%	991.3	149.8	496.1	345.4	-
Aug-18	100%	993.8	121.4	486.2	386.2	-
Sep-18	100%	602.0	153.1	212.8	236.1	-
Oct-18	100%	1,143.7	401.8	512.1	229.8	-
Nov-18	100%	2,458.6	903.4	973.3	581.9	11.4
Dec-18	100%	2,849.1	949.6	1,264.3	635.3	28.4
Jan-19	100%	3,349.1	1,377.5	1,469.8	501.8	82.4
Feb-19	71%	1,930.7	688.6	955.1	287.0	35.8
Mar-19	100%	2,797.2	906.3	1,326.2	564.7	26.5
Apr-19	100%	1,346.7	317.4	760.3	269.0	-
May-19	100%	966.1	192.8	557.0	216.4	-
Jun-19	100%	465.2	128.6	150.6	186.0	-
Jul-19	100%	1,066.1	395.6	261.0	409.5	-
Aug-19	100%	969.1	261.8	356.2	351.2	-
Sep-19	100%	543.2	160.5	164.9	217.9	-
Oct-19	100%	745.7	269.3	283.6	192.8	1.2
Nov-19	100%	2,244.4	820.7	1,011.8	411.9	27.0
Dec-19	100%	2,422.2	973.9	1,168.8	279.5	67.2
Jan-20	100%	3,111.4	1,092.8	1,371.6	647.0	56.9
Feb-20	104%	2,845.0	968.0	1,310.0	567.0	46.6
Mar-20	100%	2,385.7	659.8	1,204.4	521.4	6.5
Apr-20	100%	2,109.4	642.4	1,068.1	398.9	-
May-20	100%	1,224.6	181.3	831.7	211.7	-
Jun-20	100%	624.7	207.1	117.9	299.8	-
Jul-20	100%	903.8	342.2	104.9	456.7	-
Aug-20	80%	524.6	193.8	83.3	247.4	-
Annual	100%	19,522.3	6,487.7	8,722.0	4,312.9	225.4
Summer (Jun-Sep)		3,043.6	946.5	932.7	1,164.6	-
Winter (Oct-May)		16,478.7	5,541.2	7,789.3	3,148.3	225.4

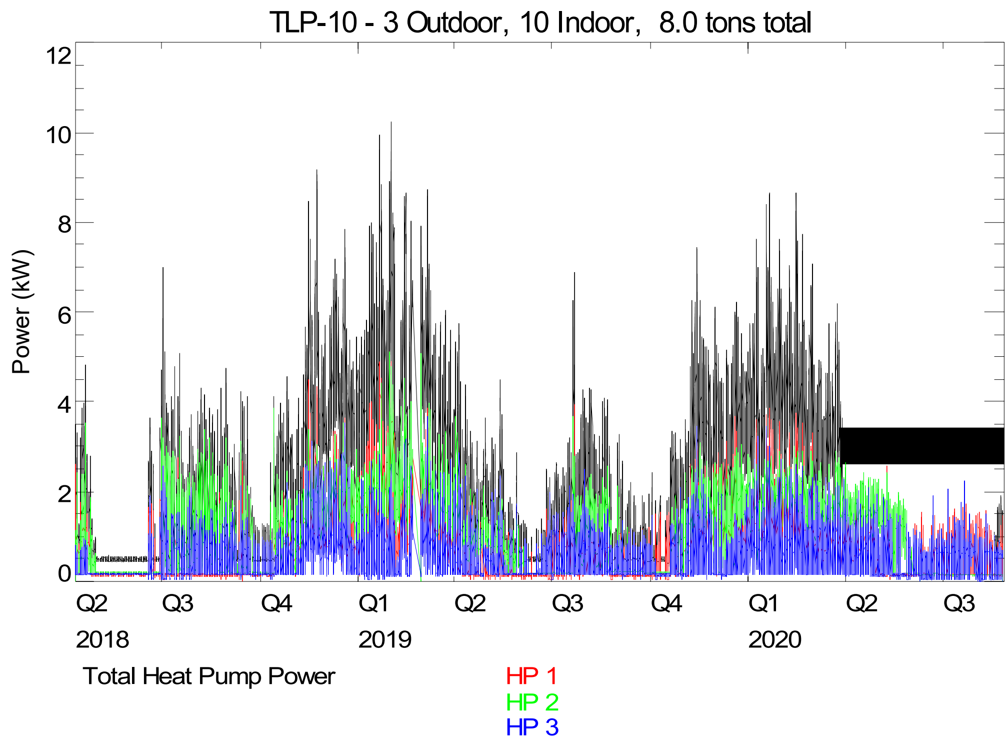


Figure 1. Plot of Power Use for All Heat Pumps at Site

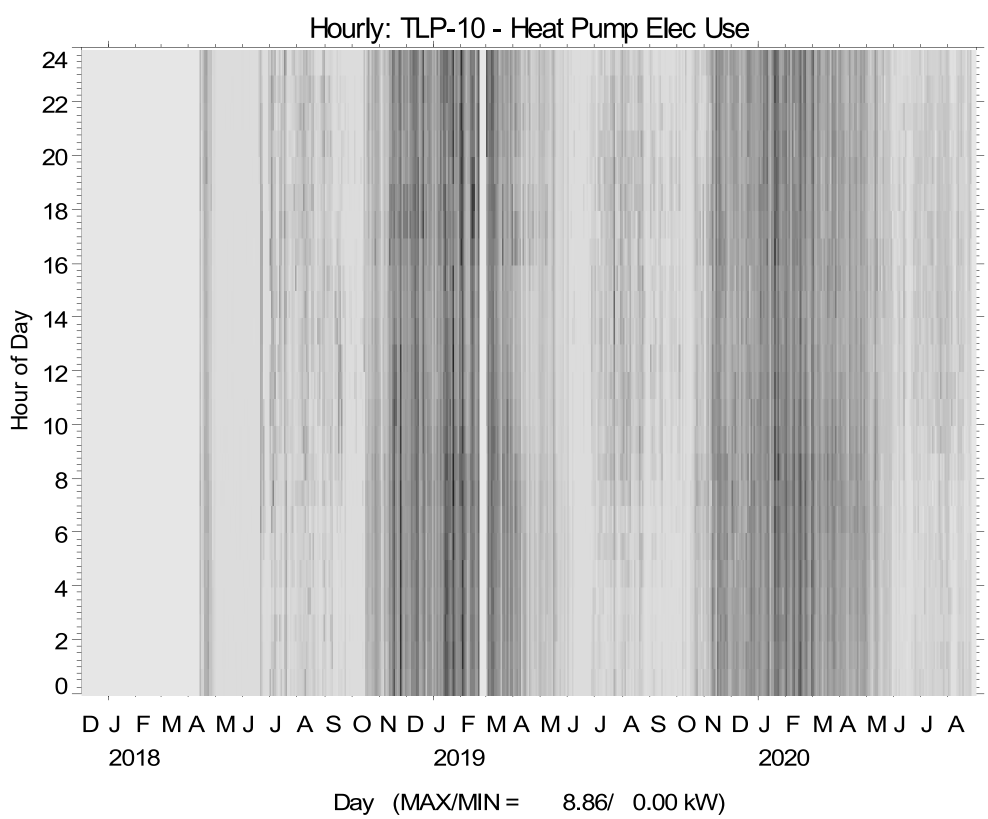


Figure 2. Shade Plot of Total Heat Pump Power

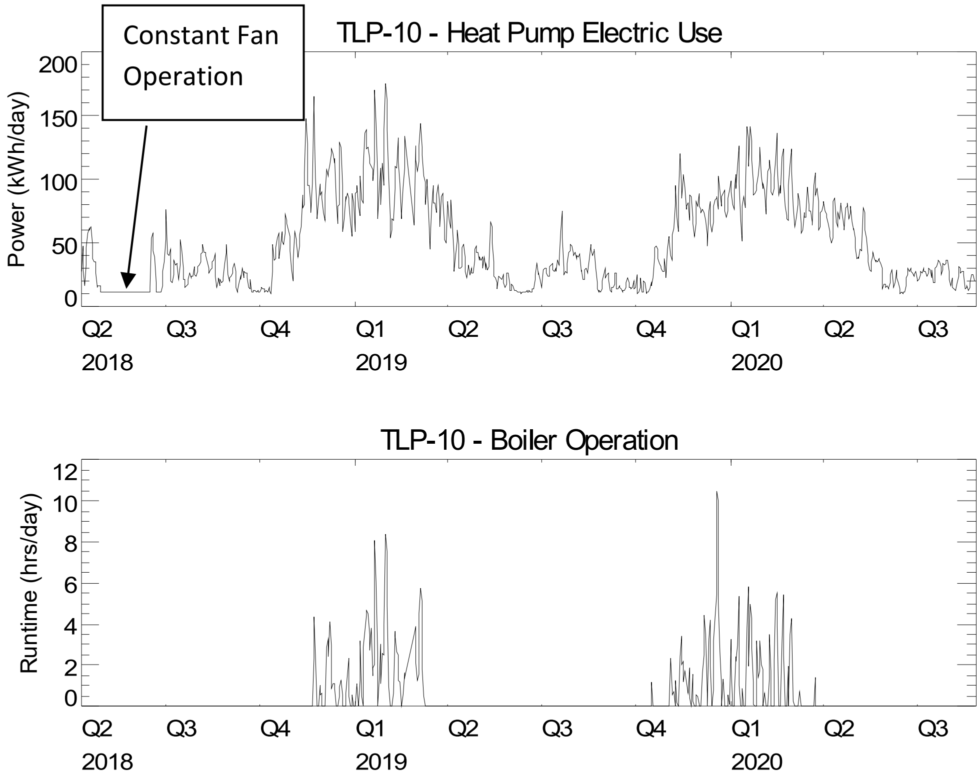


Figure 3. Plot of Daily Total HP Electric Use (and Daily Boiler Operation)

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.

Figure 5 shows the correlation between daily boiler runtime and the daily average ambient temperature from JFK. The same colors and symbols were used to represent months and years as described above.

On February 20 to 28, 2019 we conducted a “flip-flop” test where the heat pumps were turned off and the boiler picked up the house heating load. This “flip-flop” test allowed us to estimate the energy savings associated with the envelope improvements alone. The days with higher boiler runtime are shown on Figure 5.

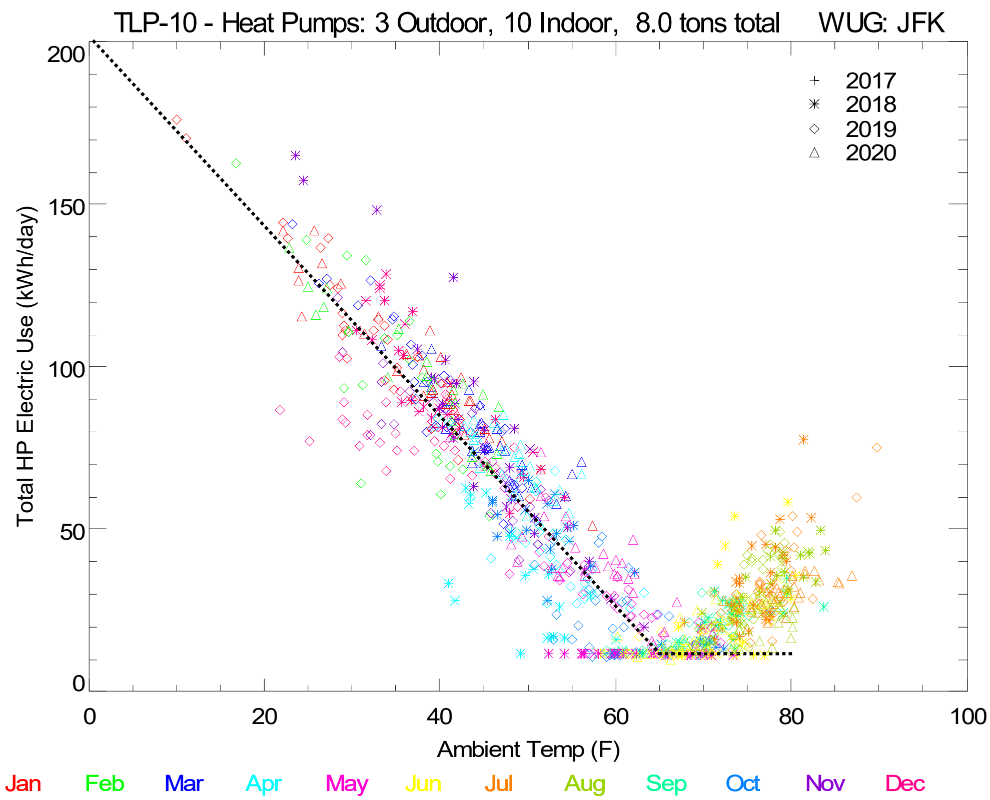


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature (from JFK)

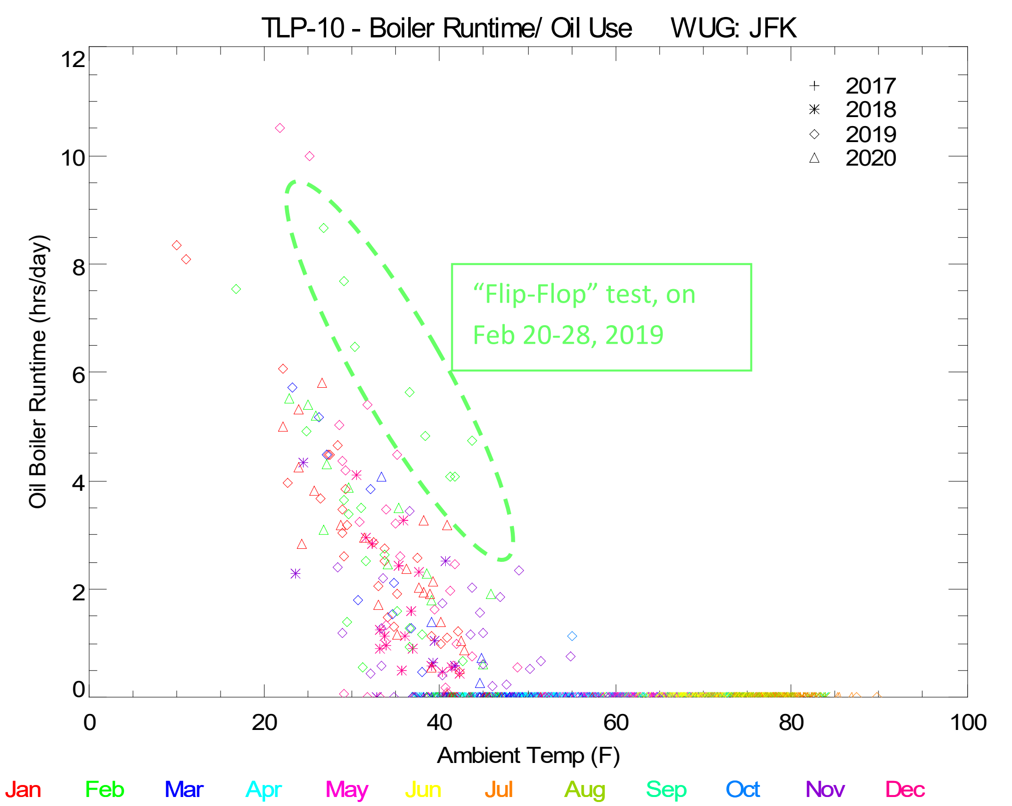


Figure 5. Daily Oil Use versus Outdoor Temperature (from JFK). Oil Use determined from Boiler Runtime.

Figure 6 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. There are only three post-retrofit oil readings on the plot. The dotted line is the approximate best fit to those values while maintaining the same baseline summer use as in the pre-retrofit period.

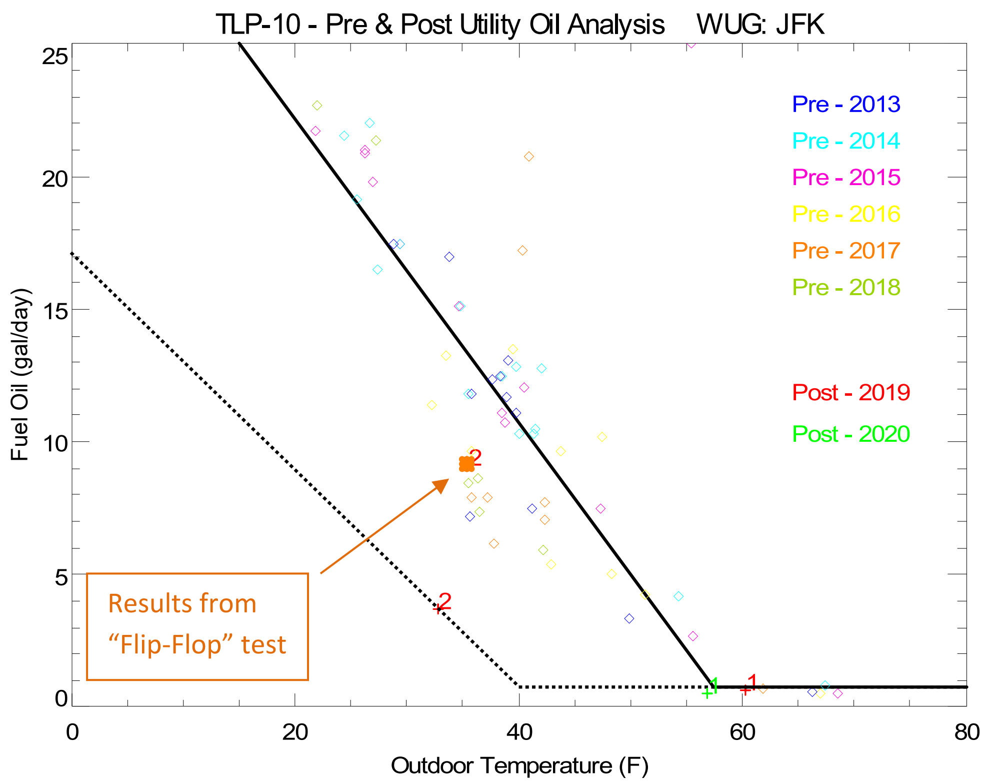


Figure 6. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

The orange symbol on Figure 6 shows the results of the "flip-flop" test. The average oil consumption during the test was 9 gallons/day and the average temperature over the 8-day period was 35.4°F. The results confirm a reduction in heating energy use relative to the black line, which would seem to be in line with the estimated envelope savings of 401 gallons per year from the weatherization proposal.

Annual Savings Analysis

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 7 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 8 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-10** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Oil** $ 2.447 per gal

Floor Area **4512**

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	49.3	28.3	282.4	28.3	2.2	120.5	125.8	
-22.5	0	46.4	26.3	267.8	26.3	2.2	113.5	117.9	
-17.5	0	43.5	24.3	253.2	24.3	2.2	106.6	110.0	
-12.5	0	40.7	22.2	238.5	22.2	2.3	99.6	102.1	
-7.5	0	37.8	20.2	223.9	20.2	2.3	92.6	94.1	
-2.5	0	35.0	18.1	209.3	18.1	2.4	85.6	86.2	
2.5	0	32.1	16.1	194.7	16.1	2.4	78.6	78.3	
7.5	20	29.3	14.0	180.1	14.0	2.5	71.6	70.4	
12.5	22	26.4	12.0	165.5	12.0	2.6	64.7	62.4	
17.5	101	23.6	9.9	150.8	9.9	2.6	57.7	54.5	
22.5	167	20.7	7.9	136.2	7.9	2.8	50.7	46.6	
27.5	247	17.9	5.9	121.6	5.9	2.9	43.7	38.7	
32.5	475	15.0	3.8	107.0	3.8	3.1	36.7	30.7	
37.5	855	12.2	1.8	92.4	1.8	3.3	29.8	22.8	
42.5	708	9.3	0.8	77.8	0.8	3.2	22.8	17.4	
47.5	608	6.5	0.8	63.2	0.8	2.6	15.8	14.5	
52.5	880	3.6	0.8	48.5	0.8	1.7	8.8	11.5	
57.5	750	0.8	0.8	33.9	0.8	0.0	1.8	8.6	
62.5	814	0.8	0.8	19.3	0.8	0.0	1.8	5.7	
67.5	723	0.8	0.8	12.0	0.8	0.0	1.8	4.2	
72.5	751	0.8	0.8	12.0	0.8	0.0	1.8	4.2	

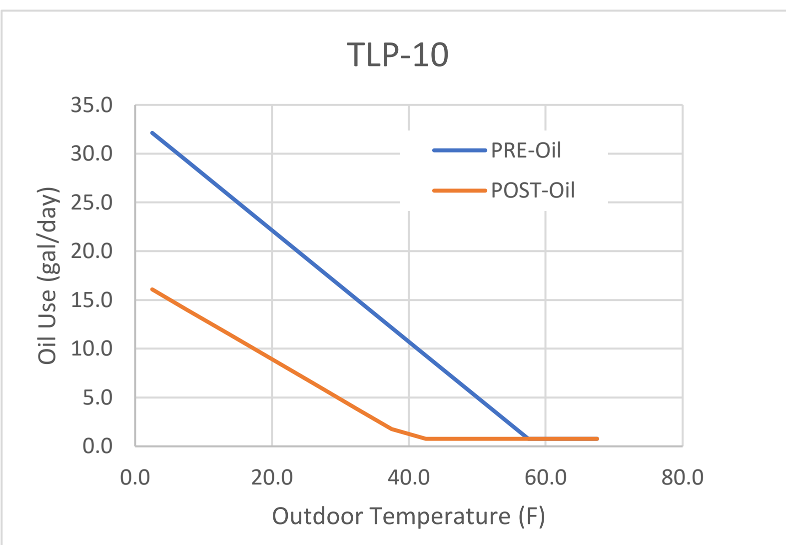


Figure 7. Trend of PRE- and POST-Retrofit Oil Use With Outdoor Temperature for Bin Analysis

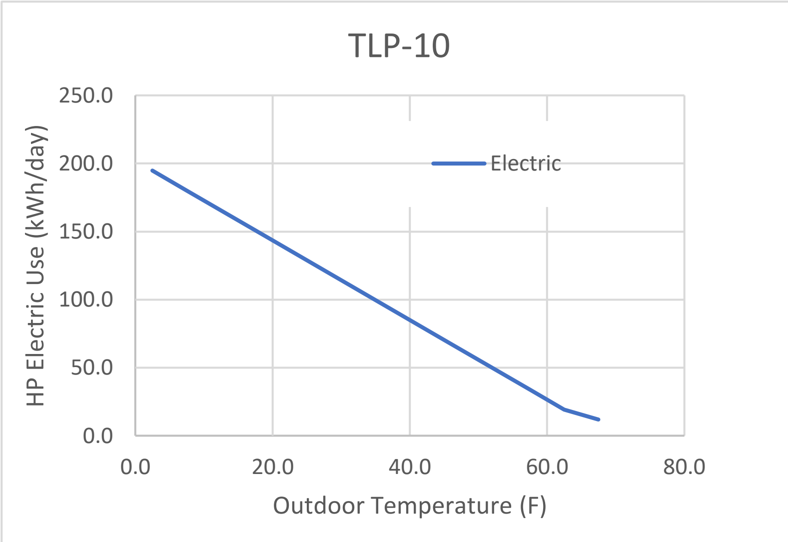


Figure 8. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 1,389 gallons per year for all improvements. However, if we subtract the oil savings from the envelope improvements, the fuel savings attributable to the heat pumps is 989 gallons per year. The heat pumps are estimated to use 13,110 kWh per year (excluding the indoor fans, which had run continuously). From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.2.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-10	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	1,649	260	401	1,389	989
HP Electric (kWh/yr)		13,110		(13,110)	
Total Heating Costs	$ 4,035	$ 3,257	$ 980	$ 778	$ (202)
Implied Seasonal COP				3.1	2.2

Summary Statistics	
0.37	Htg gal per sq ft per year
42.7	Htg MBtu per sq ft per year
84%	Reduction in Htg Fuel Use
16,479	Measured HP Electric (kWh/yr)
126%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 9 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 10 shows the same calculation process associated with cooling operation.

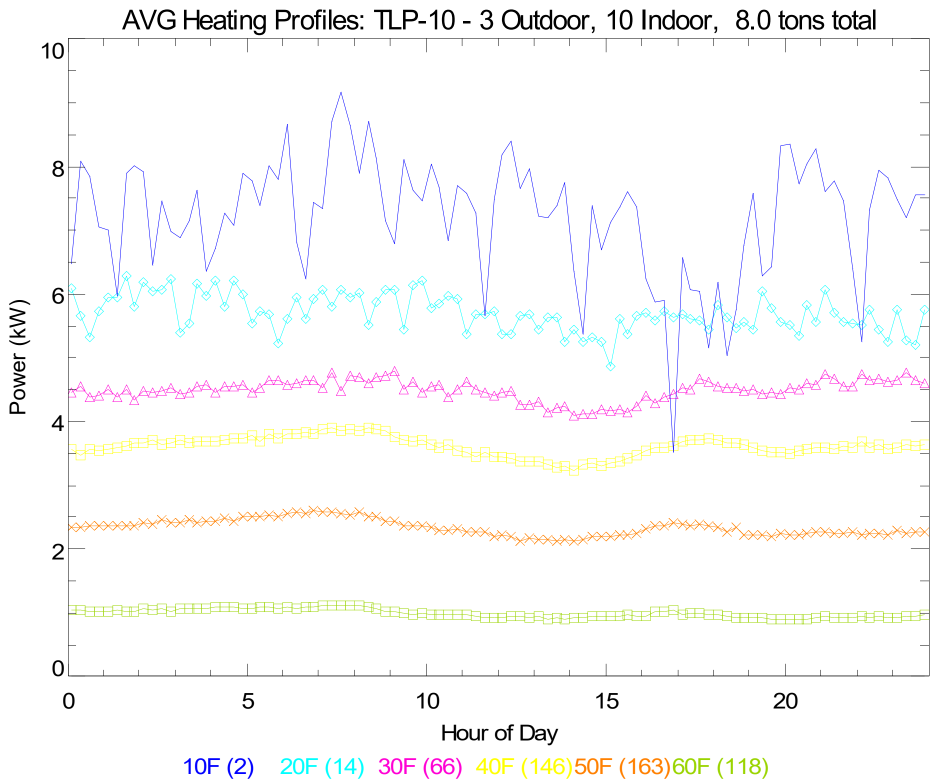


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

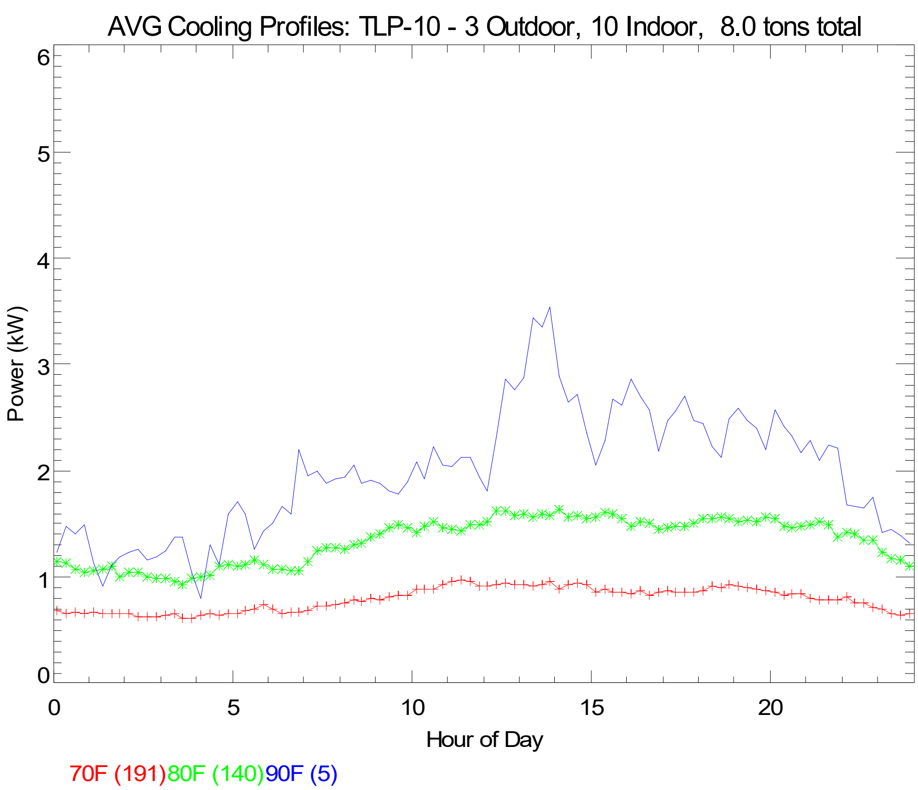
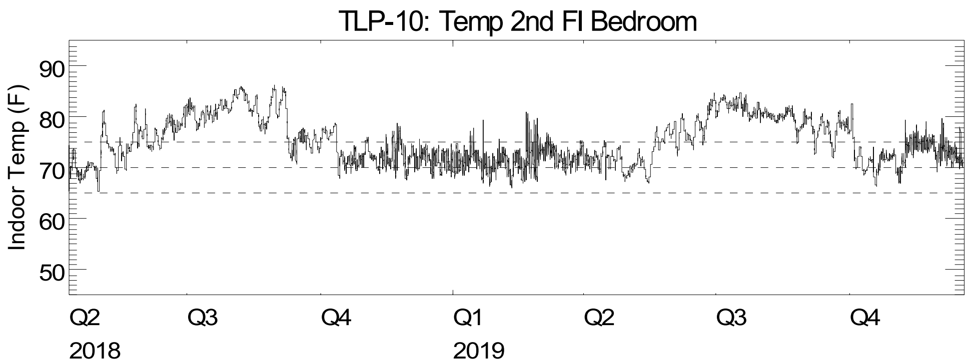
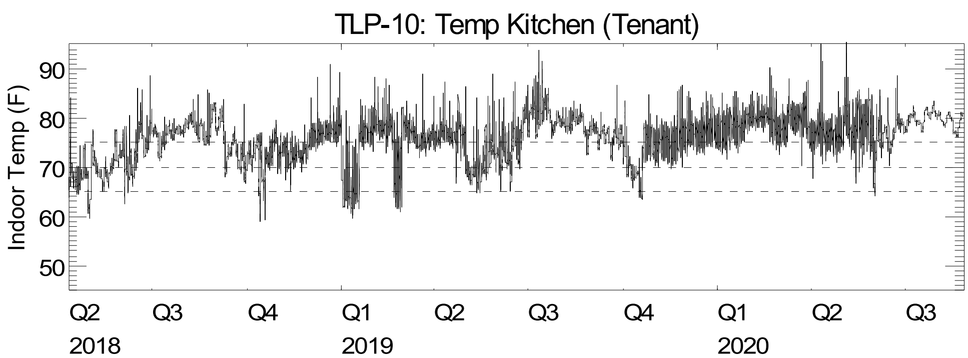


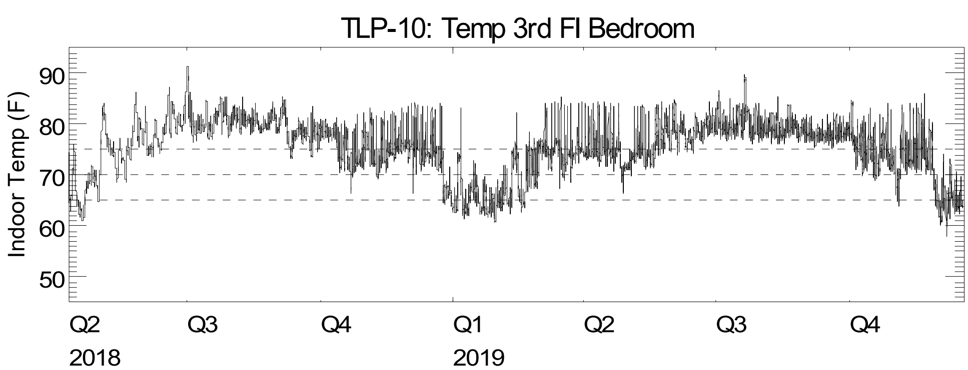
Figure 10. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 11.







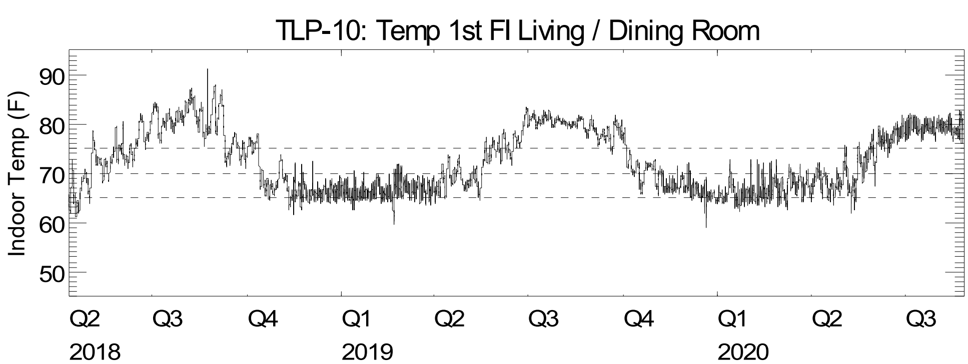


Figure 11. Plot of Space Temperatures at Various Indoor Locations

Site 12 Savings Analysis

This two-family house includes a 1,628 sq ft apartment on the 2nd and 3rd floors occupied by the owner (12.1) and the 814 sq ft apartment on the 1st floor (12.2) occupied by a tenant. The apartments are separately metered for both gas and electric. Each apartment originally had its own gas boiler with conventional baseboard radiation. Two electric heat pumps with a total capacity of 4 tons were added to the 2nd floor apartment (12.1). One 2-ton heat pump was installed in the 1st floor apartment (12.2). The gas boilers remained in place to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on April 12, 2018 to collect data at 15-minute intervals.

The house also had weatherization improvements (air sealing, wall insulation) proposed that were projected to save a total of 285 therms per year. We have allocated 190 therms per year of savings to apartment 12.1 and 95 therms per year of savings to apartment 12.2. Table 1 shows that the final envelope improvements had less impact than originally expected.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage of heated area from 5,789 CFM50 to 4,300 CFM50. SAVINGS: $178 (123 therms)	Reduce overall air leakage of heated area from 5,789 CFM50 to 4,710 CFM50. ADJUSTED SAVINGS: ~89 therms
1st ,2nd and 3rd Floor Walls Insulation	Upgrade 376 square feet of existing 1st floor wall area to R-13. Upgrade 784 square feet of existing 2nd and 3rd floor wall area to R-13. SAVINGS: $238 (163 therms)	Upgrade 638 square feet of existing wall to Gyp Bd, 2x4 16" OC, 3.5" Cellulose, 0.75" Wood, 4" Brick, R-13 ADJUSTED SAVINGS: ~90 therms
Front bay windows 1st and 2nd floors		Remove wall below windows, spray foam and insulate. Remove wall above window 12" section or less, spray foam and insulate. Install sheetrock.
DHW Blowdown Pipe 1st and 2nd Floors	Improve the following condition uncovered during dhw blowdown pipe 1st floor : DHW Blowdown Pipe missing	Improve the following condition uncovered during dhw blowdown pipe 1st floor : DHW Blowdown Pipe missing

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units. A flip-flop test was attempted in February 2018, but fuel readings were collected at the beginning and end of the period.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

Site 12.1

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)
Dec-17	40%	503.4	300.4	203.1
Jan-18	100%	1,088.2	601.6	486.6
Feb-18	100%	260.9	132.3	128.6
Mar-18	100%	478.7	221.2	257.6
Apr-18	100%	234.2	105.2	129.0
May-18	100%	255.9	113.0	142.9
Jun-18	100%	315.4	131.9	183.5
Jul-18	100%	513.3	272.8	240.5
Aug-18	100%	507.4	257.6	249.8
Sep-18	100%	279.7	145.6	134.0
Oct-18	100%	213.1	104.1	109.0
Nov-18	100%	318.1	137.2	180.9
Dec-18	100%	390.9	139.3	251.6
Jan-19	100%	657.4	213.1	444.2
Feb-19	100%	276.3	113.1	163.2
Mar-19	43%	92.2	45.7	46.5
Annual	100%	4,855.8	2,361.8	2,494.0
Summer (Jun-Sep)		1,615.8	807.9	807.8
Winter (Oct-May)		3,240.0	1,553.9	1,686.2

Site 12.2

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)
Dec-17	40%	356.6	356.6
Jan-18	100%	816.1	816.1
Feb-18	100%	254.2	254.2
Mar-18	100%	445.5	445.5
Apr-18	100%	268.7	268.7
May-18	100%	105.3	105.3
Jun-18	100%	101.7	101.7
Jul-18	100%	138.5	138.5
Aug-18	100%	182.0	182.0
Sep-18	100%	133.0	133.0
Oct-18	100%	173.9	173.9
Nov-18	100%	336.0	336.0
Dec-18	100%	308.2	308.2
Jan-19	100%	479.0	479.0
Feb-19	100%	402.8	402.8
Mar-19	43%	189.0	189.0
Annual	100%	3,263.1	3,263.1
Summer (Jun-Sep)		555.2	555.2
Winter (Oct-May)		2,707.9	2,707.9

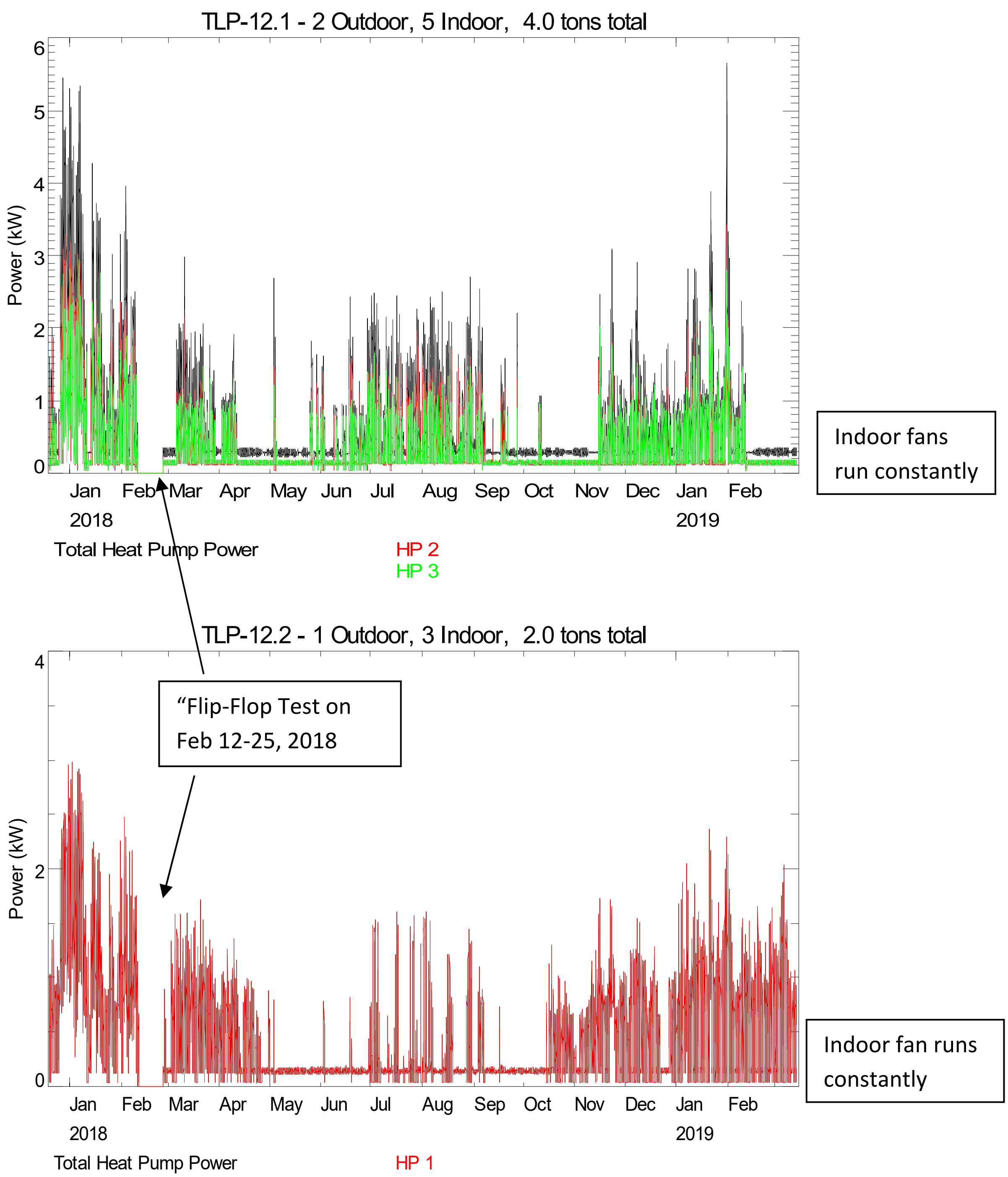
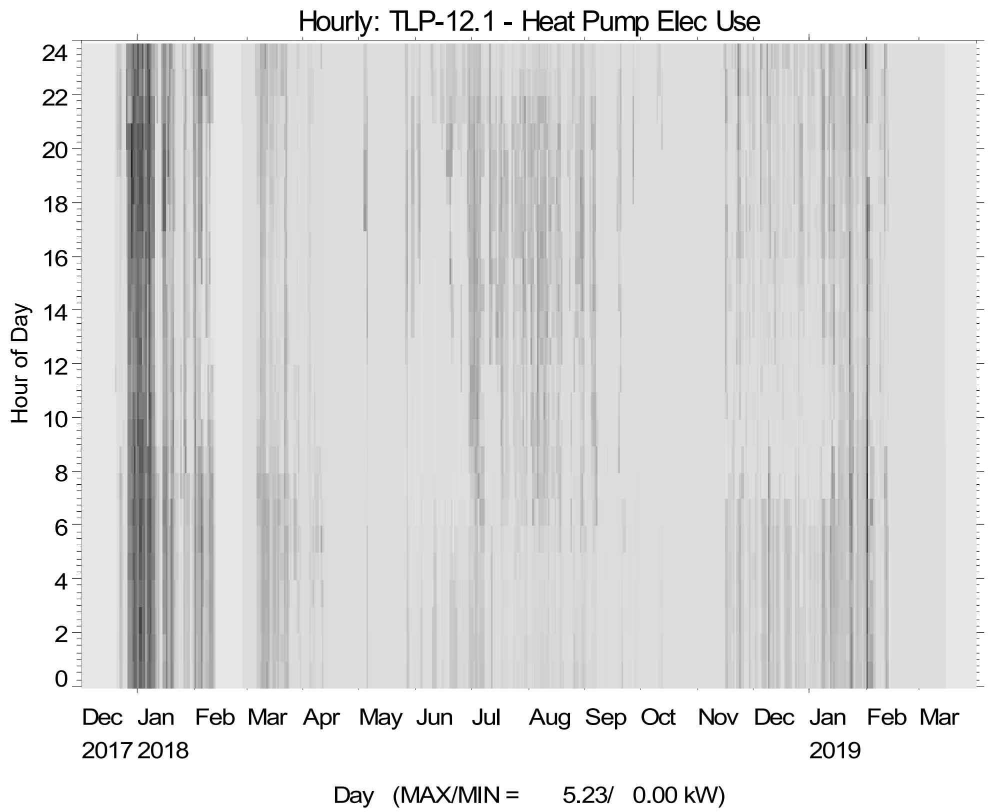


Figure 1. Plot of Power Use for All Heat Pumps at Site



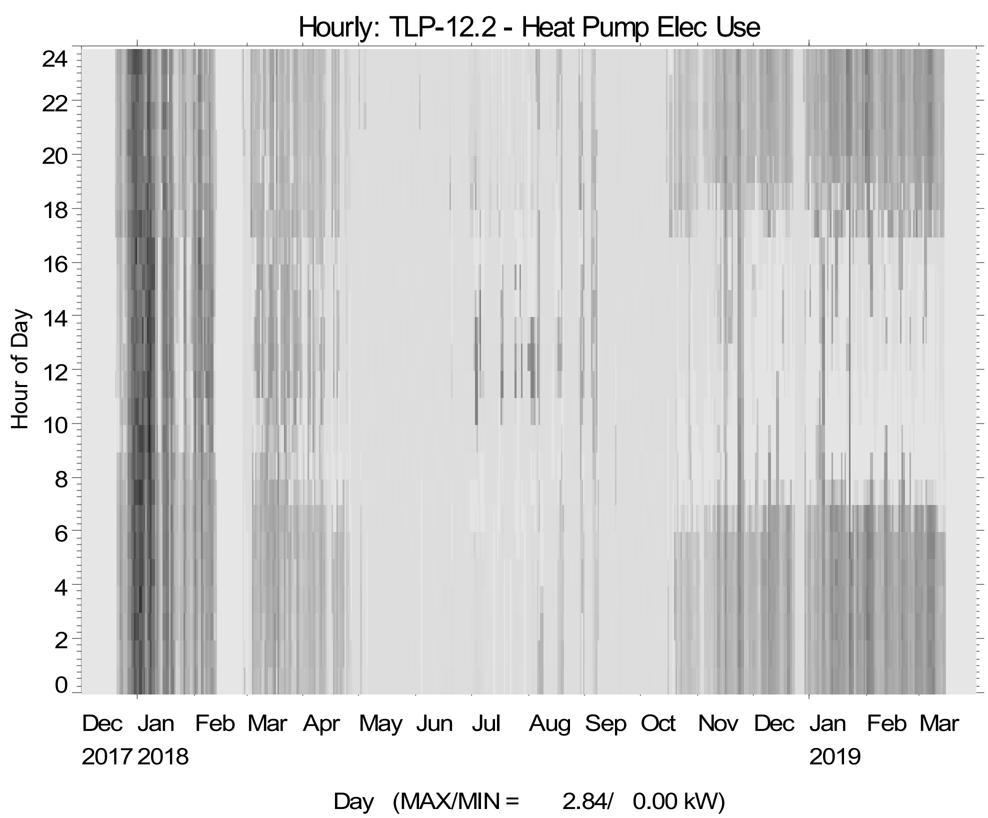
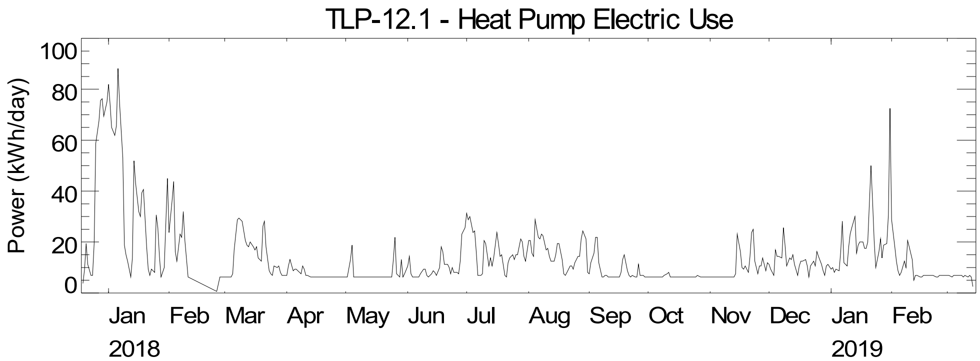


Figure 2. Shade Plot of Total Heat Pump Power

Figure 3 shows the daily energy use of the all the heat pumps.



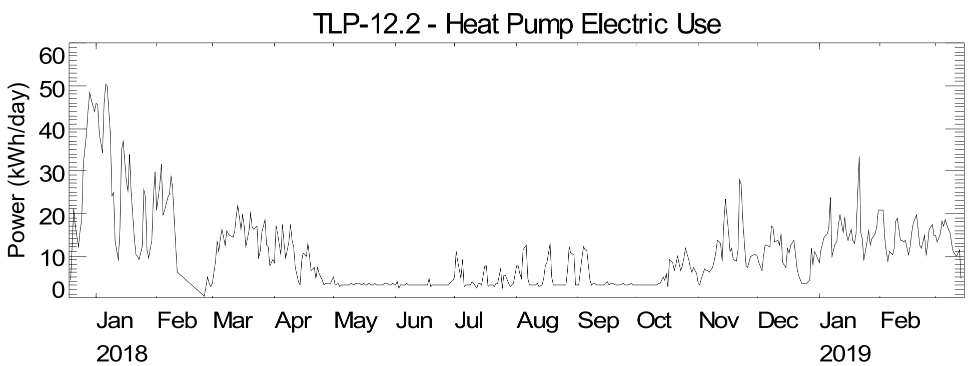
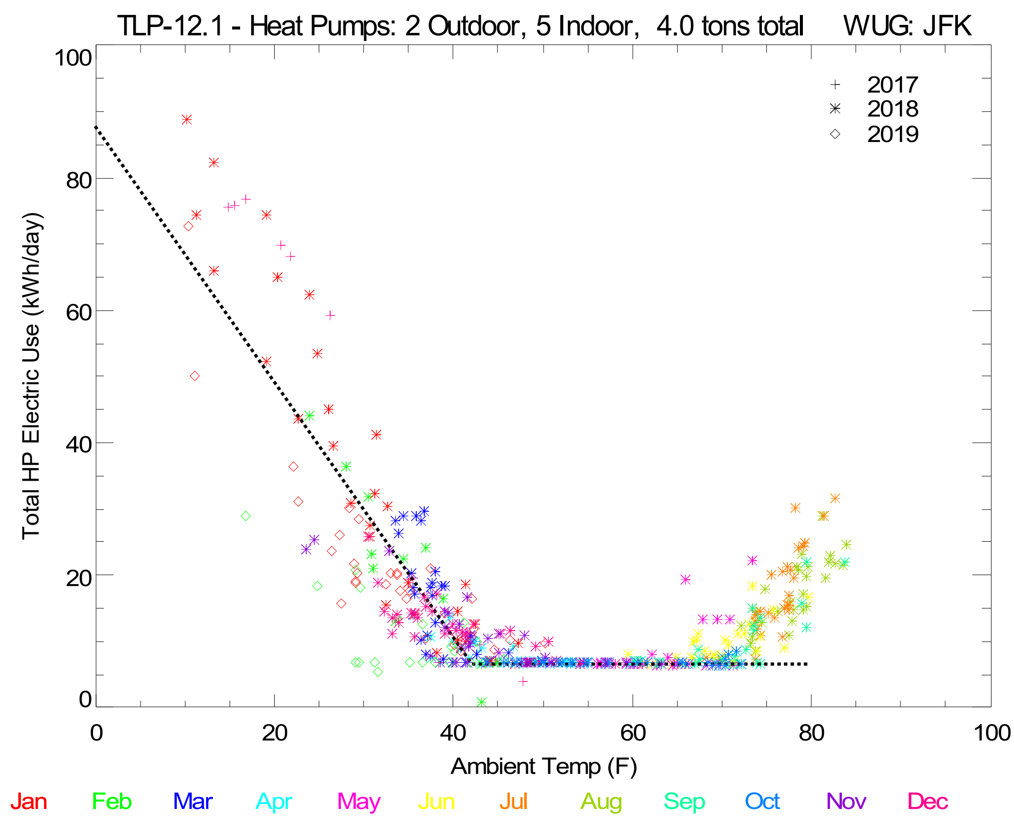


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.



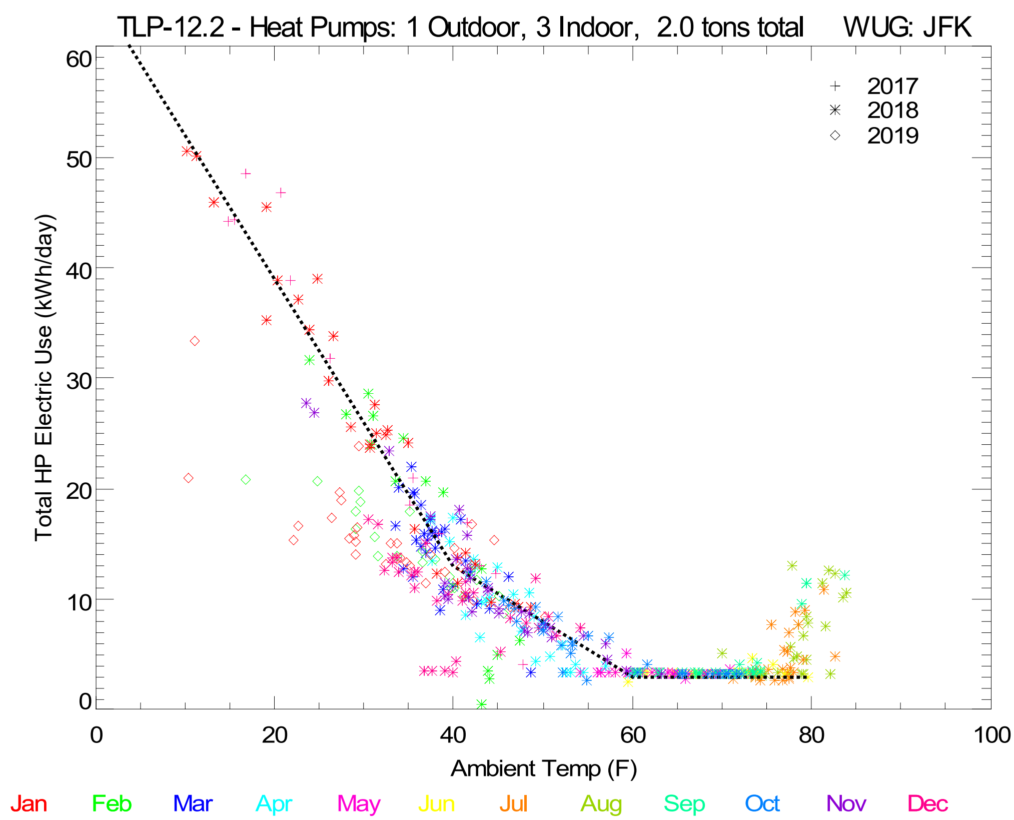
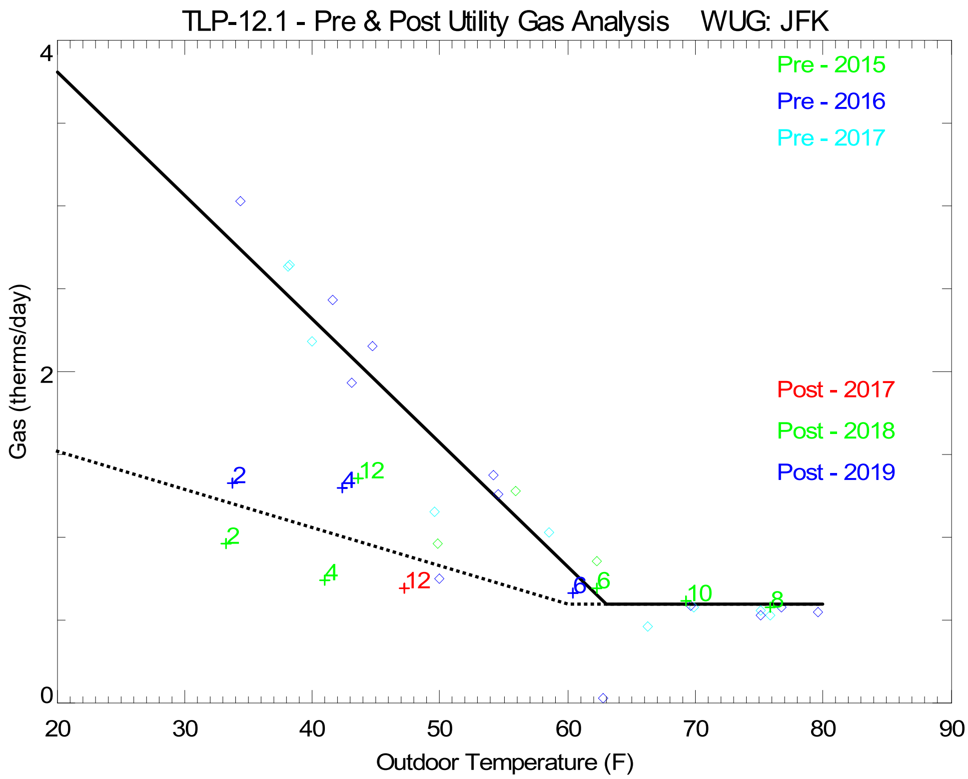


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. The dotted line is the best fit to the post retrofit data, determined by ignoring the two circled points from February and March 2019. The post-retrofit monthly readings were determined to include estimated and actual readings, so we converted the data to be actual readings over each two month period.

The ASHPs were turned off for several days (2/12/2018 to 2/25/2018) and the boiler was used to heat the house. This "flip-flop" test allowed us to estimate the energy savings associated with the envelope improvements alone. DID THIS TEST REALLY HAPPEN??



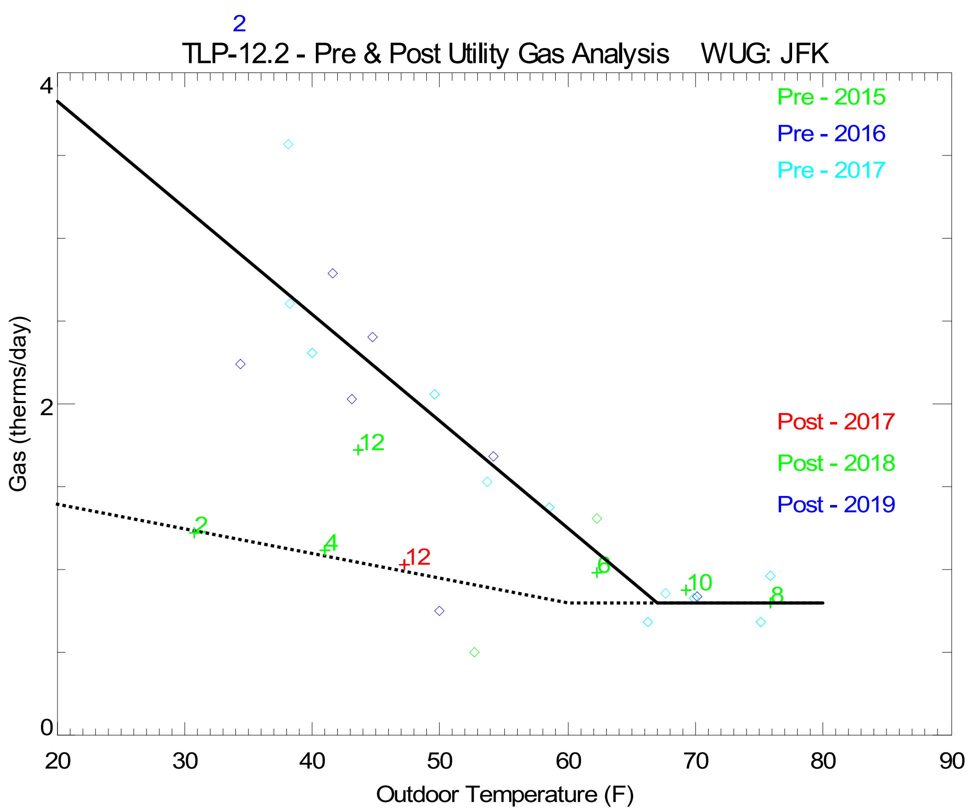


Figure 5. Trend of Gas Use With Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

Annual Savings Analysis

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK) - Site 12.1

SITE:	TLP-12.1	WEATHER:	New_York
FUEL:	Gas		
Floor Area	1628		

$	0.20	per kWh
$	1.403	per therm

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	7.4	2.6	140.5	2.6	0.8	10.3	31.8	
-22.5	0	7.0	2.5	130.9	2.5	0.8	9.8	29.7	
-17.5	0	6.6	2.4	121.3	2.4	0.8	9.3	27.6	
-12.5	0	6.2	2.3	111.6	2.3	0.8	8.8	25.5	
-7.5	0	5.9	2.2	102.0	2.2	0.8	8.2	23.4	
-2.5	0	5.5	2.0	92.3	2.0	0.8	7.7	21.3	
2.5	0	5.1	1.9	82.7	1.9	0.9	7.2	19.2	
7.5	11	4.7	1.8	73.0	1.8	0.9	6.7	17.1	
12.5	22	4.4	1.7	63.4	1.7	0.9	6.1	15.1	
17.5	101	4.0	1.6	53.8	1.6	1.0	5.6	13.0	
22.5	167	3.6	1.5	44.1	1.5	1.1	5.1	10.9	
27.5	247	3.3	1.3	34.5	1.3	1.2	4.6	8.8	
32.5	475	2.9	1.2	24.8	1.2	1.5	4.0	6.7	
37.5	855	2.5	1.1	15.2	1.1	2.0	3.5	4.6	
42.5	708	2.1	1.0	6.5	1.0	3.9	3.0	2.7	
47.5	608	1.8	0.9	6.5	0.9	3.0	2.5	2.5	
52.5	880	1.4	0.8	6.5	0.8	2.1	1.9	2.4	
57.5	750	1.0	0.7	6.5	0.7	1.2	1.4	2.2	
62.5	814	0.6	0.6	6.5	0.6	0.1	0.9	2.1	
67.5	723	0.6	0.6	6.5	0.6	0.0	0.8	2.1	
72.5	751	0.6	0.6	6.5	0.6	0.0	0.8	2.1	

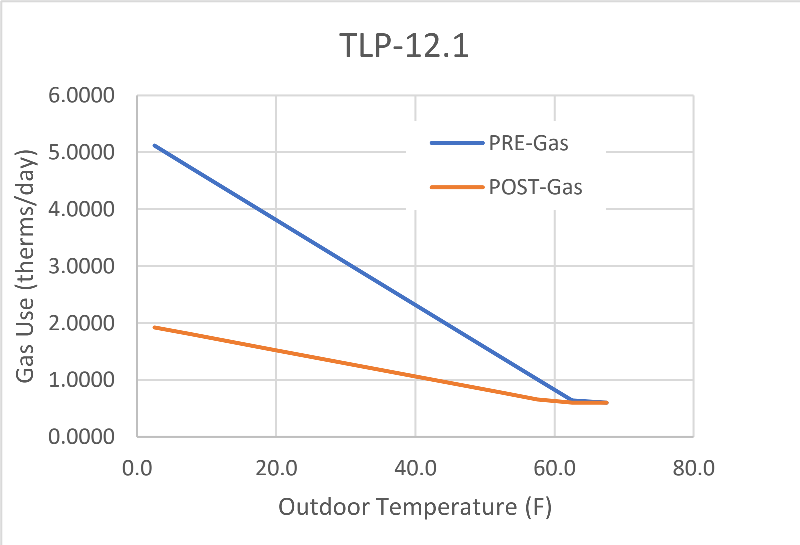
Table 4. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK) - Site 12.2

SITE: **TLP-12.2** WEATHER: **New_York** $ 0.20 per kWh

FUEL: **Gas** $ 1.403 per therm

Floor Area **814**

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	6.9	2.1	100.8	2.1	1.1	9.7	23.1	
-22.5	0	6.6	2.0	94.3	2.0	1.1	9.2	21.7	
-17.5	0	6.2	2.0	87.8	2.0	1.1	8.8	20.3	
-12.5	0	5.9	1.9	81.3	1.9	1.1	8.3	18.9	
-7.5	0	5.6	1.8	74.8	1.8	1.1	7.9	17.5	
-2.5	0	5.3	1.7	68.3	1.7	1.2	7.4	16.1	
2.5	0	5.0	1.7	61.8	1.7	1.2	7.0	14.7	
7.5	11	4.6	1.6	55.3	1.6	1.2	6.5	13.3	
12.5	22	4.3	1.5	48.8	1.5	1.3	6.1	11.9	
17.5	101	4.0	1.4	42.3	1.4	1.3	5.6	10.5	
22.5	167	3.7	1.4	35.8	1.4	1.4	5.1	9.1	
27.5	247	3.3	1.3	29.3	1.3	1.6	4.7	7.7	
32.5	475	3.0	1.2	22.8	1.2	1.8	4.2	6.3	
37.5	855	2.7	1.1	16.3	1.1	2.1	3.8	4.8	
42.5	708	2.4	1.1	11.8	1.1	2.5	3.3	3.8	
47.5	608	2.1	1.0	9.3	1.0	2.6	2.9	3.2	
52.5	880	1.7	0.9	6.8	0.9	2.7	2.4	2.6	
57.5	750	1.4	0.8	4.3	0.8	3.0	2.0	2.0	
62.5	814	1.1	0.8	3.0	0.8	2.2	1.5	1.7	
67.5	723	0.8	0.8	3.0	0.8	0.0	1.1	1.7	
72.5	751	0.8	0.8	3.0	0.8	0.0	1.1	1.7	



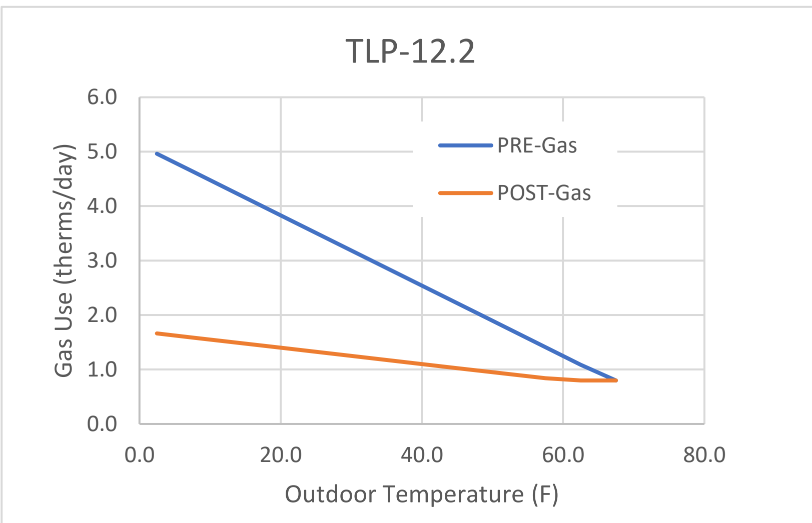
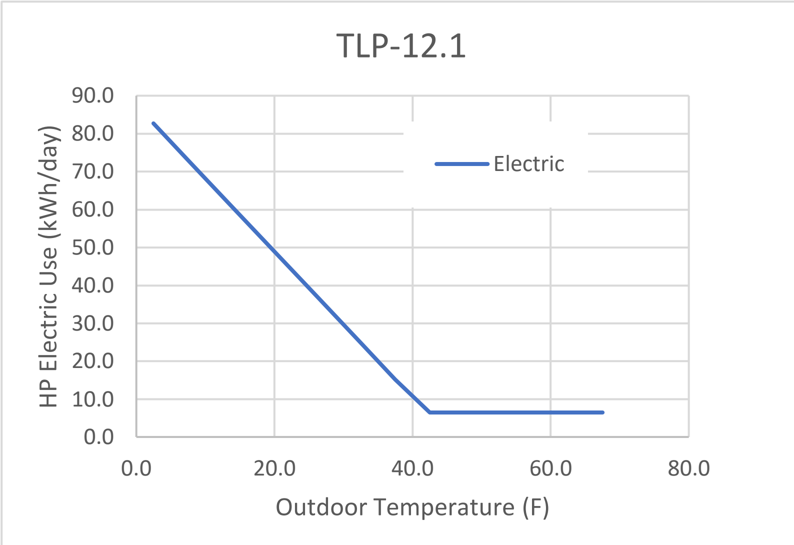


Figure 6. Trend of PRE- and POST-Retrofit Gas Use With Outdoor Temperature for Bin Analysis



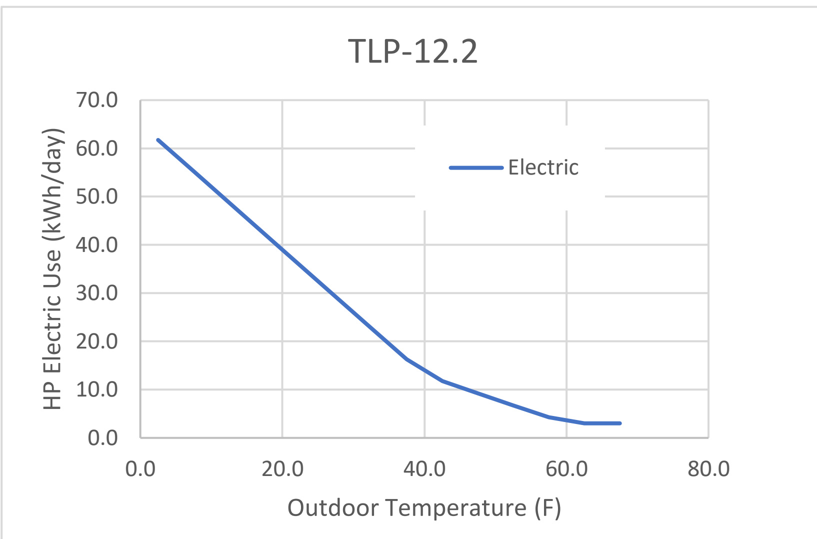


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 5 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 221 and 267 therms per year for all improvements in both apartments. However, if we subtract the gas savings from the envelope improvements – assumed to be two thirds in apartment 12.1 and one third to apartment 12.2 – the fuel savings attributable to the heat pumps is 101 and 208 therms per year in 12.1 and 12.2. The heat pumps are estimated to use 1,503 and 2,185 kWh per year, excluding the indoor supply fan use since these occupants chose to run the fans continuously throughout the year. From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 1.5 and 2.1.

Table 5. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Exclude HP Fan Power

Heating Only TLP-12.1	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Gas (therms/yr)	298	78	119	221	101
HP Electric (kWh/yr)		1,503		(1,503)	
Total Heating Costs	$ 418	$ 409	$ 167	$ 9	$ (158)
Implied Seasonal COP				3.3	1.5

Summary Statistics

0.18	Htg therms per sq ft per year
14.5	Htg MBtu per sq ft per year
74%	Reduction in Htg Fuel Use
3,240	Measured HP Electric (kWh/yr)
216%	of typical year kWh

Exclude HP Fan Power

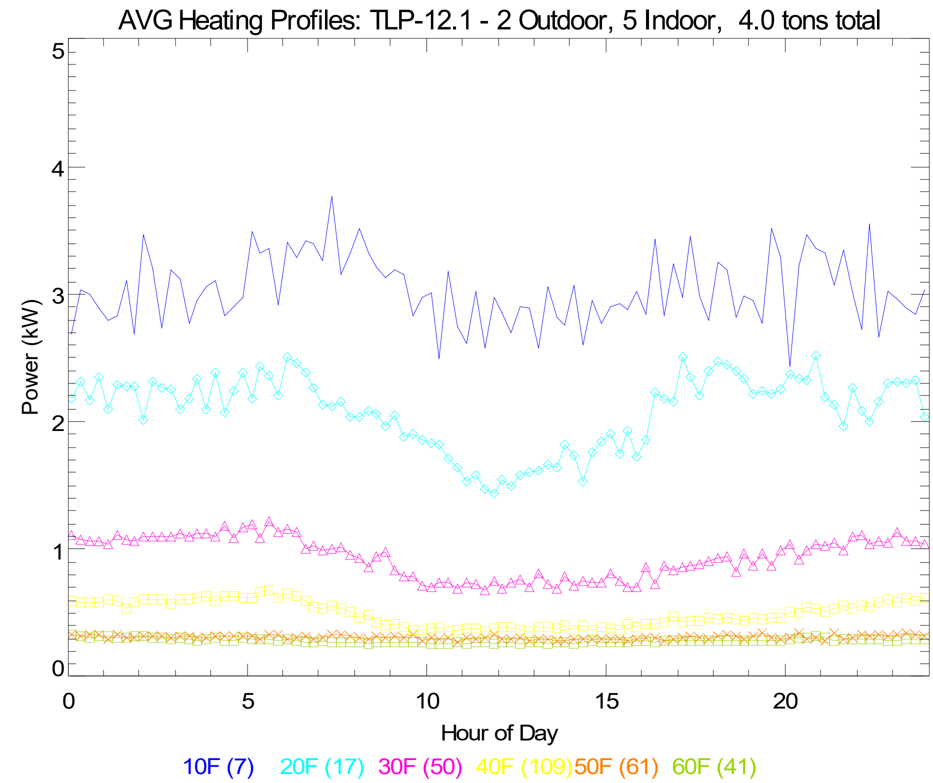
Heating Only TLP-12.2	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Gas (therms/yr)	318	51	60	267	208
HP Electric (kWh/yr)		2,185		(2,185)	
Total Heating Costs	$ 446	$ 508	$ 84	$ (62)	$ (145)
Implied Seasonal COP				2.7	2.1

Summary Statistics

0.39	Htg therms per sq ft per year
30.9	Htg MBtu per sq ft per year
84%	Reduction in Htg Fuel Use
2,708	Measured HP Electric (kWh/yr)
124%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.



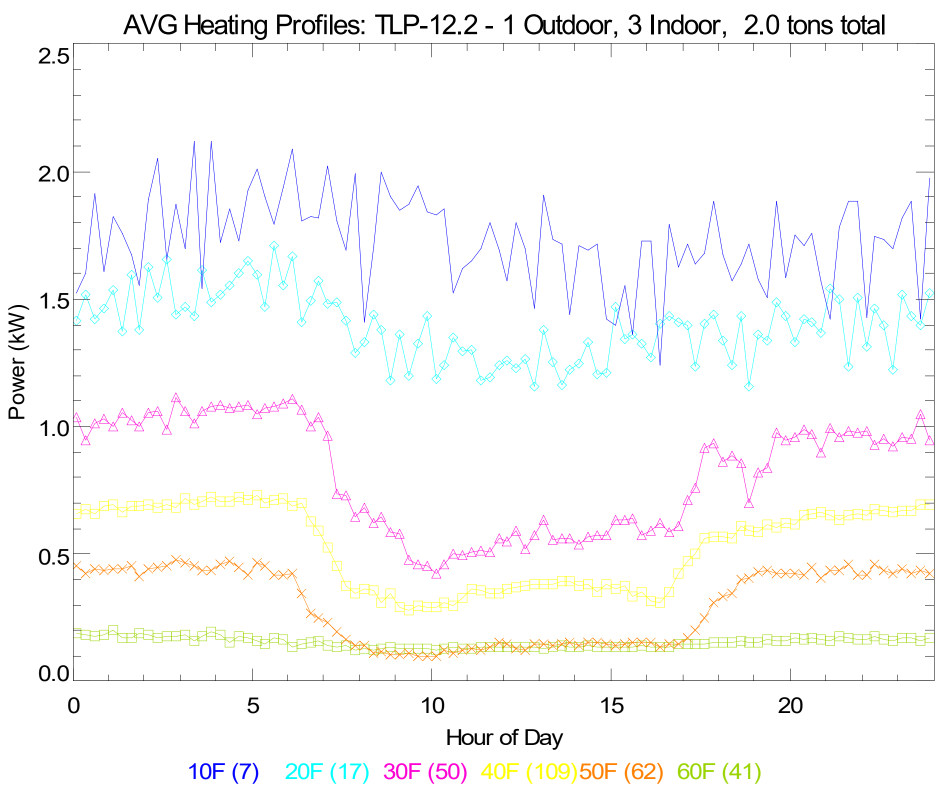
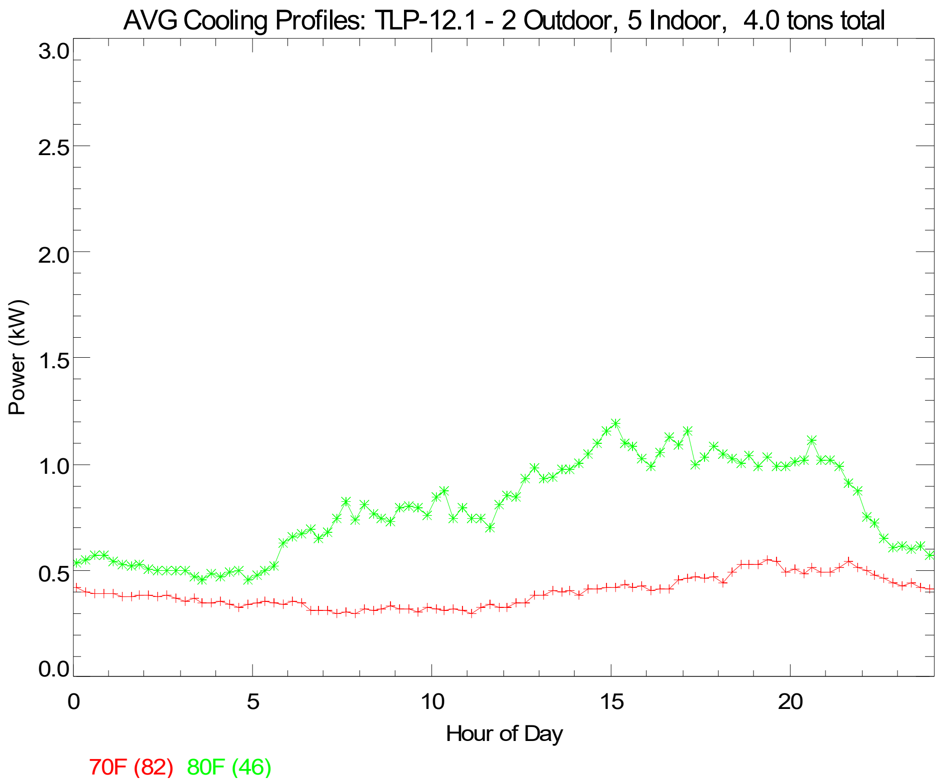


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)



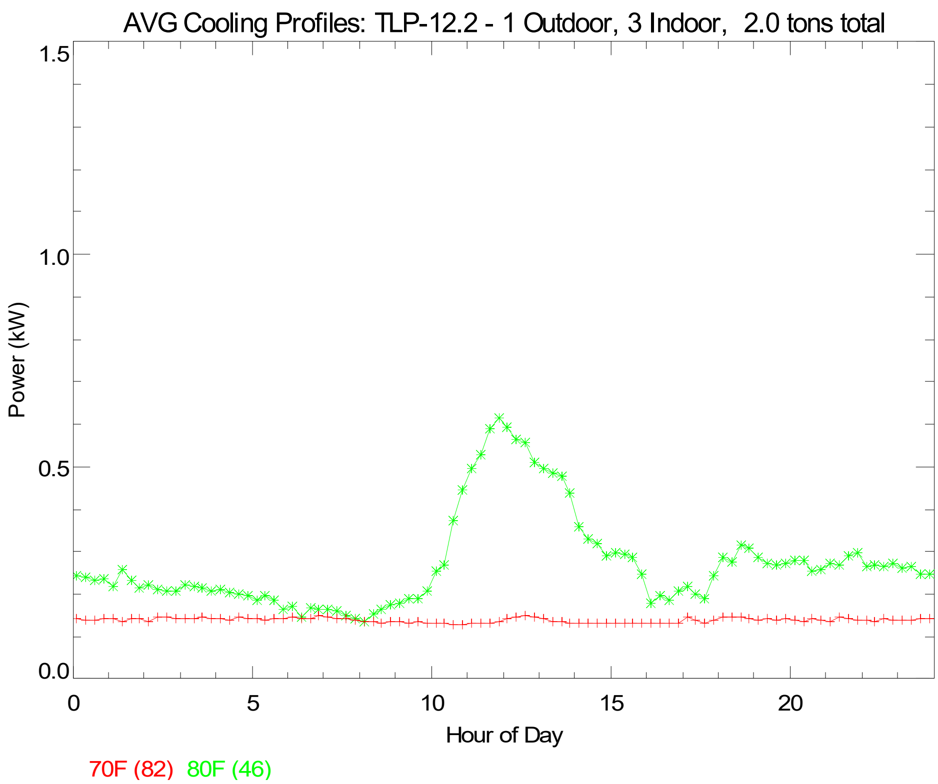
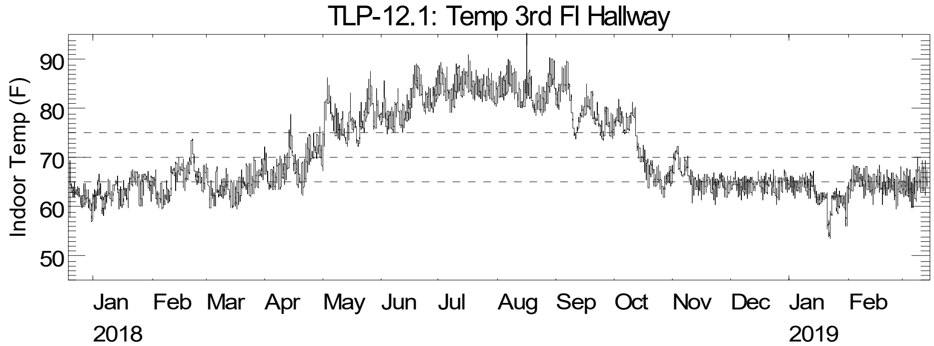
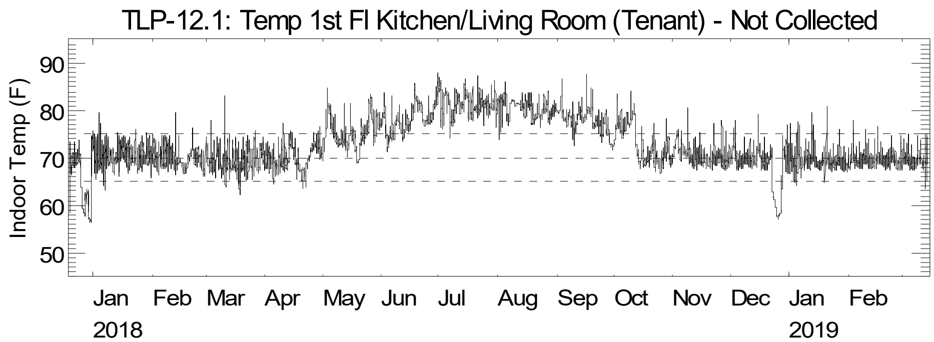


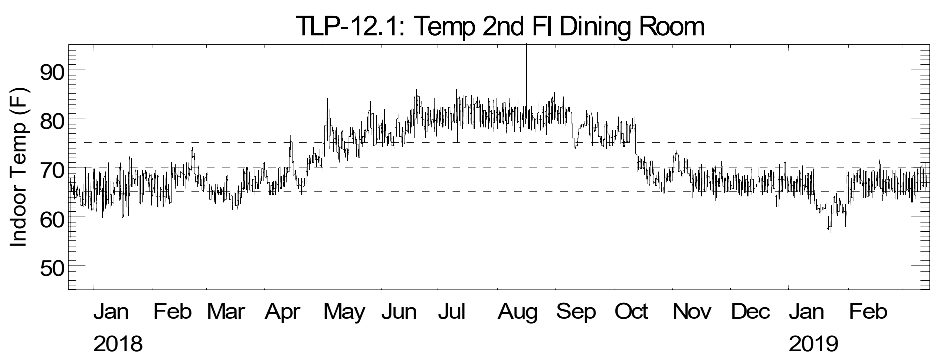
Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.







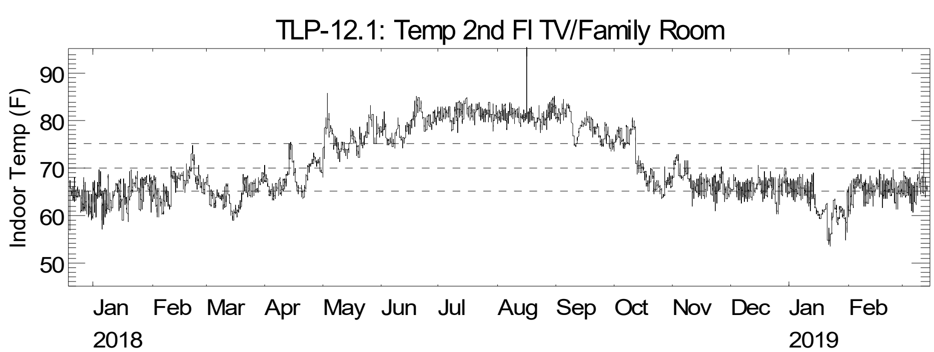


Figure 10. Plot of Space Temperatures at Various Indoor Locations for TLP12.1

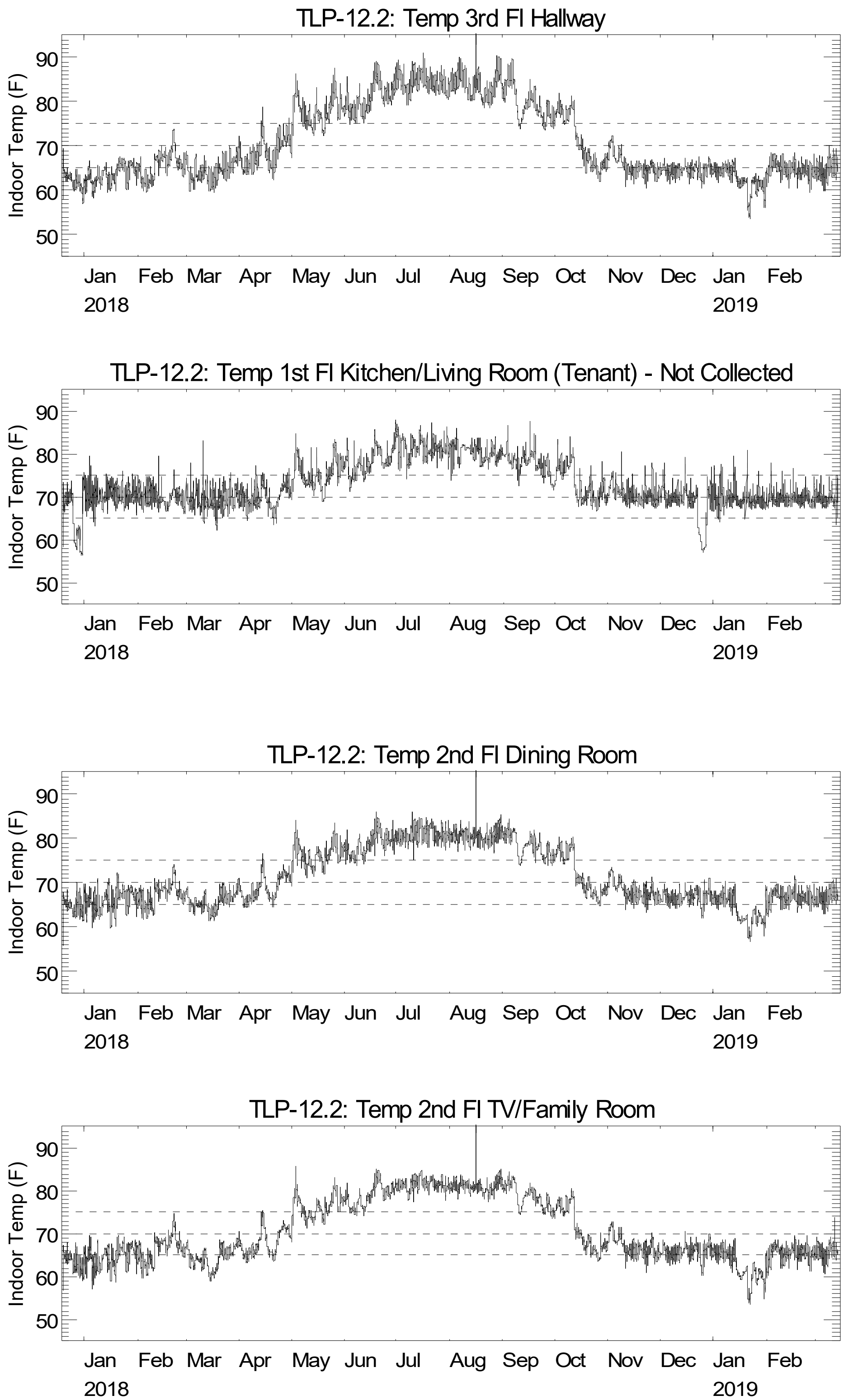


Figure 11. Plot of Space Temperatures at Various Indoor Locations for TLP12.2

Site 14 Savings Analysis

This 2,483 sq ft single-family home originally used an oil boiler with conventional baseboard radiation. Three electric heat pumps with a total capacity of 7 tons were added to the home in mid-2018. The oil boiler was removed. Monitoring equipment was installed on August 15, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, insulation) proposed that were projected to save 451 gallons of oil per year. The actual project saved 384 gallons per year. Table 1 compares the proposed and implemented envelope measures.

Table 1. Summary List of Proposed and Final Envelope Savings

Measure	**Proposed Details**	**Final Details**
Air Sealing	Reduce overall air leakage of heated area from 6680 CFM50 to 4500 CFM50 SAVINGS: $396 (143 gallons)	Reduce overall air leakage of heated area from 6680 CFM50 to **5520** CFM50 ADJUSTED SAVINGS: ~76 gallons
1st and 2nd Floor Walls	Upgrade 2,112 sq ft of wall area to R13	Completed
Rim Joist	Upgrade 132 square feet of existing rim joist to 2" High Density Foam, 1.5" Wood, 0.5" Wood Siding, R-15	Completed
Attic Joist	Upgrade 132 square feet of existing rim joist to 2" High Density Foam, 1.5" Wood, 0.5" Wood Siding, R-15	Completed
All Insulation	SAVINGS: $854 (308 gallons)	Same

Table 2 summarizes the energy use of the heat pumps across the period. Heat pump energy use was much higher in the first year than in the second year, mainly due to extended unoccupied periods. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps. The data imply the family goes on vacation in December and January each year.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	HP3 (kWh)
Aug-18	50%	242.5	75.9	86.8	79.8
Sep-18	100%	216.3	91.4	38.4	86.4
Oct-18	100%	885.1	496.6	267.4	121.0
Nov-18	100%	1,706.0	742.7	748.2	215.1
Dec-18	100%	1,651.7	174.8	1,170.5	306.3
Jan-19	100%	2,375.7	746.4	1,472.0	157.3
Feb-19	100%	2,123.7	697.8	1,251.5	174.5
Mar-19	100%	1,878.7	519.0	1,096.6	263.1
Apr-19	100%	677.8	196.7	398.8	82.4
May-19	100%	139.5	21.0	115.4	3.1
Jun-19	100%	-	-	-	-
Jul-19	100%	-	-	-	-
Aug-19	100%	118.6	37.4	45.3	36.0
Sep-19	100%	49.2	14.7	12.9	21.6
Oct-19	100%	263.4	122.1	80.0	61.3
Nov-19	100%	1,407.8	491.9	609.5	306.4
Dec-19	100%	648.3	211.1	300.7	136.5
Jan-20	100%	1,152.5	423.1	718.2	11.2
Feb-20	100%	1,743.6	566.0	1,154.6	23.0
Mar-20	100%	1,221.0	417.3	775.1	28.6
Apr-20	100%	898.1	310.5	557.9	29.8
May-20	100%	312.5	127.3	141.3	44.0
Jun-20	100%	127.0	39.8	48.1	39.1
Jul-20	100%	307.2	130.3	144.5	32.4
Aug-20	82%	182.2	84.0	63.3	34.8
Annual	100%	11,773.1	3,723.8	6,604.1	1,445.2
Summer (Jun-Sep)		334.9	128.8	83.7	122.4
Winter (Oct-May)		11,438.2	3,595.0	6,520.4	1,322.8

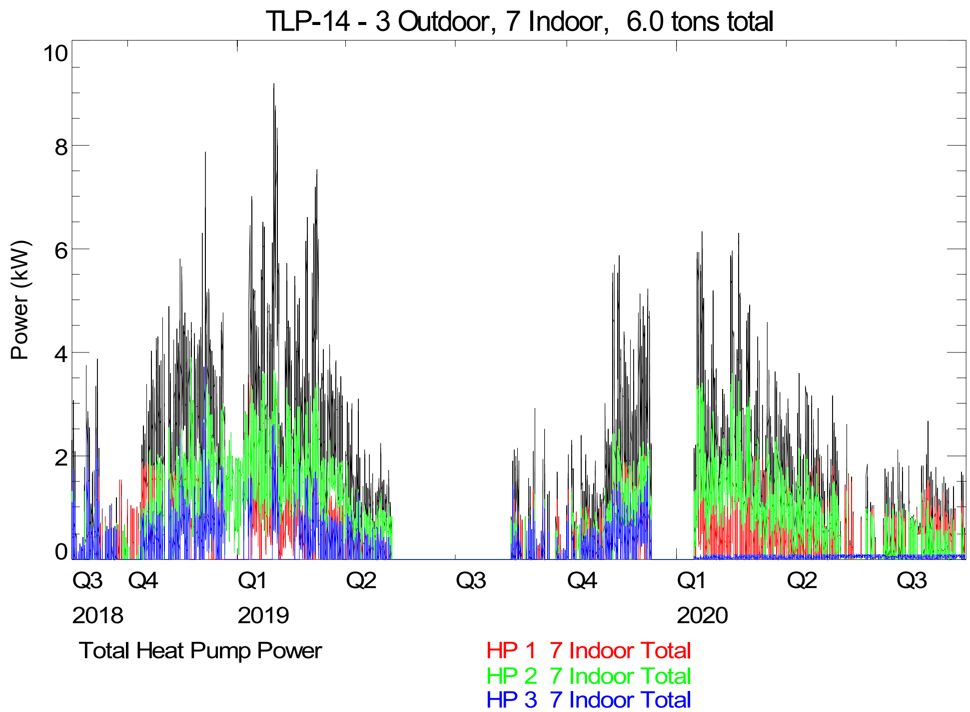


Figure 1. Plot of Power Use for All Heat Pumps at Site

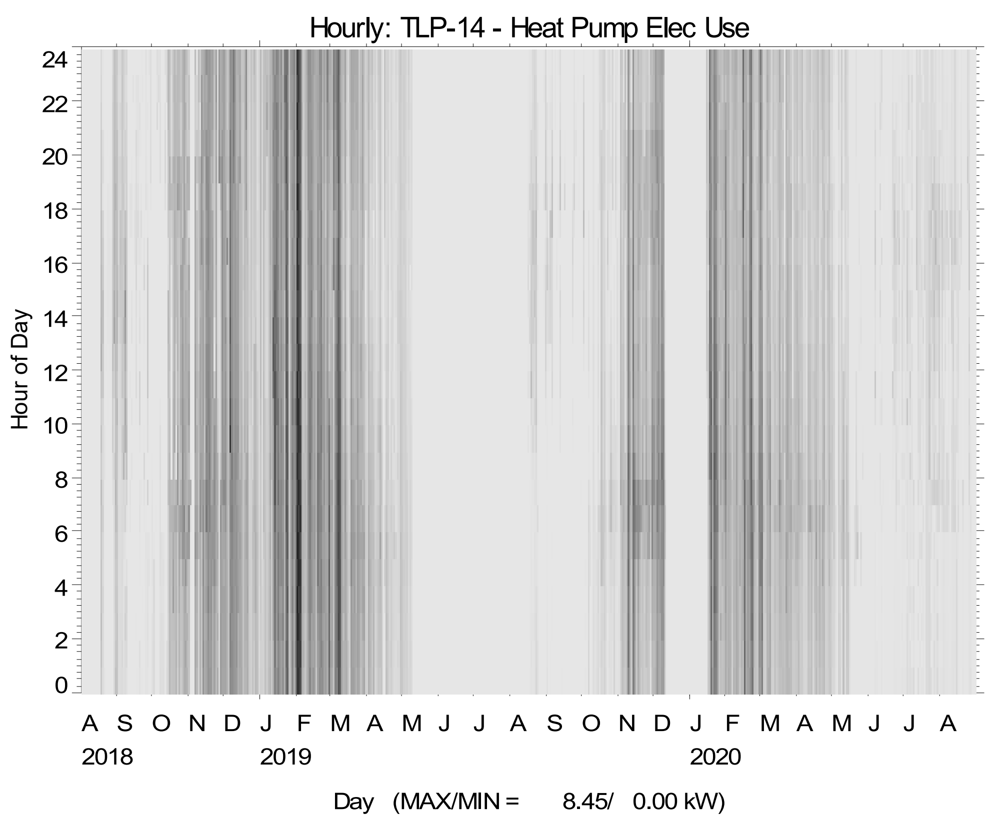


Figure 2. Shade Plot of Total Heat Pump Power

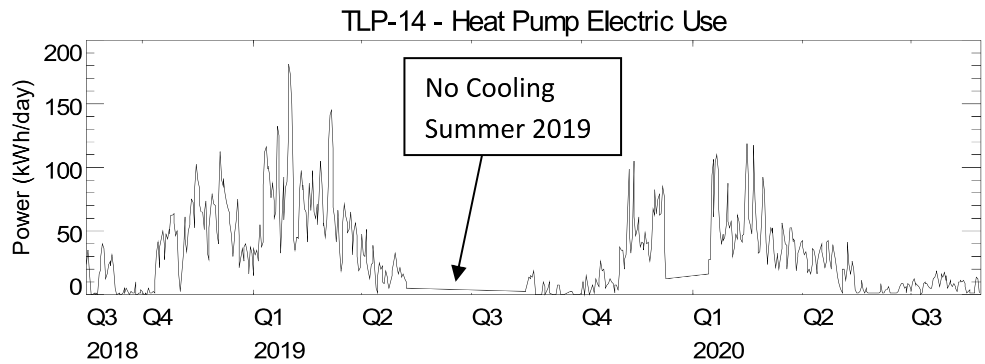


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.

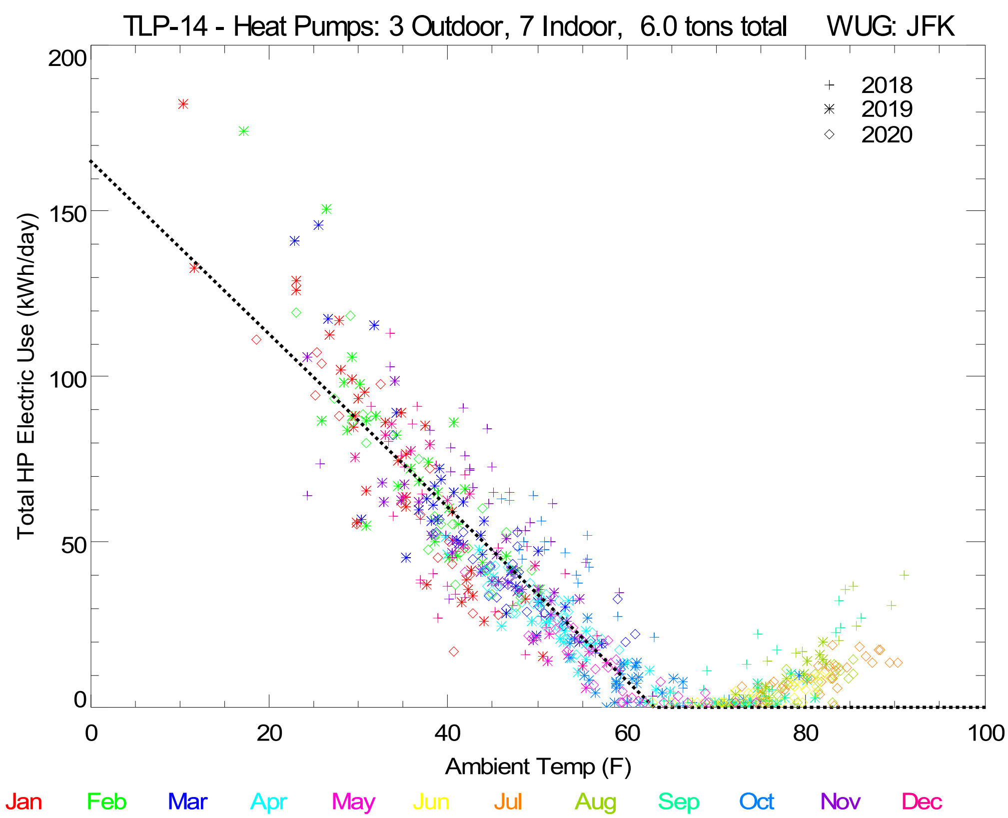


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. There is no post-retrofit data since the boiler was removed. In the analysis we assume the same baseline summer use as in the pre-retrofit period.

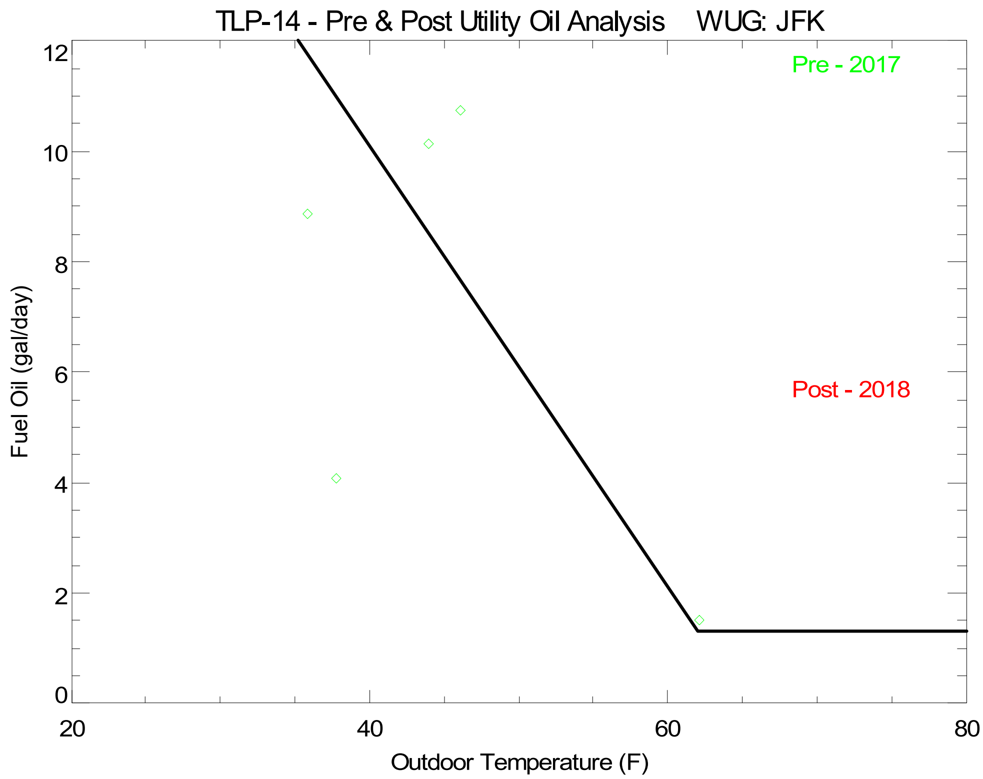


Figure 5. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

Annual Savings Analysis

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-14** WEATHER: **New_York** $ 0.20 per kWh

FUEL: **Oil** $ 2.447 per gal

Floor Area **2185** Boiler Removed

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	37.0	0.0	237.0	1.3	4.0	90.6	50.6	0.0
-22.5	0	35.0	0.0	223.9	1.3	4.0	85.7	48.0	0.0
-17.5	0	33.0	0.0	210.8	1.3	4.0	80.9	45.3	0.0
-12.5	0	31.0	0.0	197.7	1.3	4.0	76.0	42.7	0.0
-7.5	0	29.0	0.0	184.6	1.3	4.0	71.1	40.1	0.0
-2.5	0	27.1	0.0	171.5	1.3	4.0	66.2	37.5	0.0
2.5	0	25.1	0.0	158.5	1.3	4.0	61.3	34.9	0.1
7.5	11	23.1	0.0	145.4	1.3	4.0	56.4	32.3	0.1
12.5	22	21.1	0.0	132.3	1.3	4.0	51.5	29.6	0.1
17.5	101	19.1	0.0	119.2	1.3	3.9	46.7	27.0	0.1
22.5	167	17.1	0.0	106.1	1.3	3.9	41.8	24.4	0.1
27.5	247	15.1	0.0	93.0	1.3	3.9	36.9	21.8	0.1
32.5	475	13.1	0.0	79.9	1.3	3.9	32.0	19.2	0.1
37.5	855	11.1	0.0	66.8	1.3	3.9	27.1	16.5	0.1
42.5	708	9.1	0.0	53.7	1.3	3.8	22.2	13.9	0.1
47.5	608	7.1	0.0	40.6	1.3	3.8	17.3	11.3	0.2
52.5	880	5.1	0.0	27.5	1.3	3.7	12.5	8.7	0.3
57.5	750	3.1	0.0	14.4	1.3	3.3	7.6	6.1	0.4
62.5	814	1.3	0.0	1.3	1.3	0.0	3.2	3.4	1.0
67.5	723	1.3	0.0	0.0	1.3	0.0	3.2	3.2	1.0
72.5	751	1.3	0.0	0.0	1.3	0.0	3.2	3.2	1.0

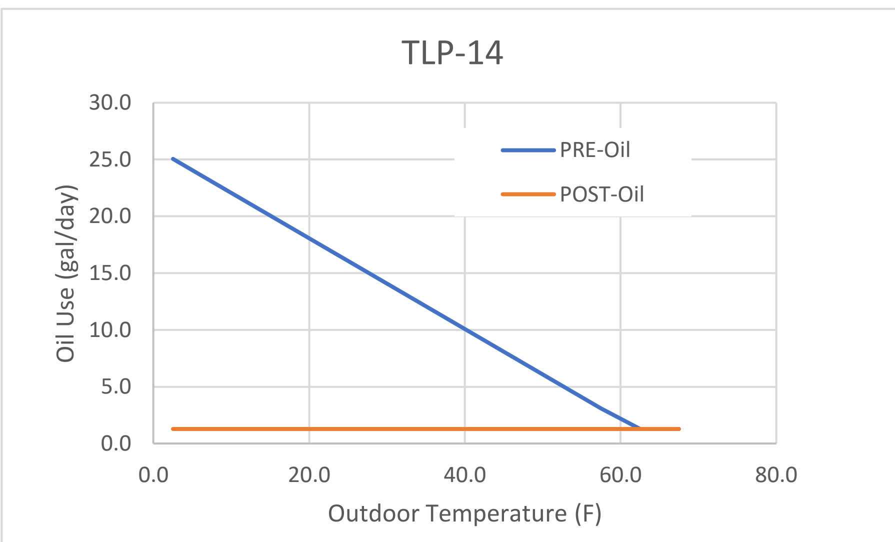


Figure 6. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

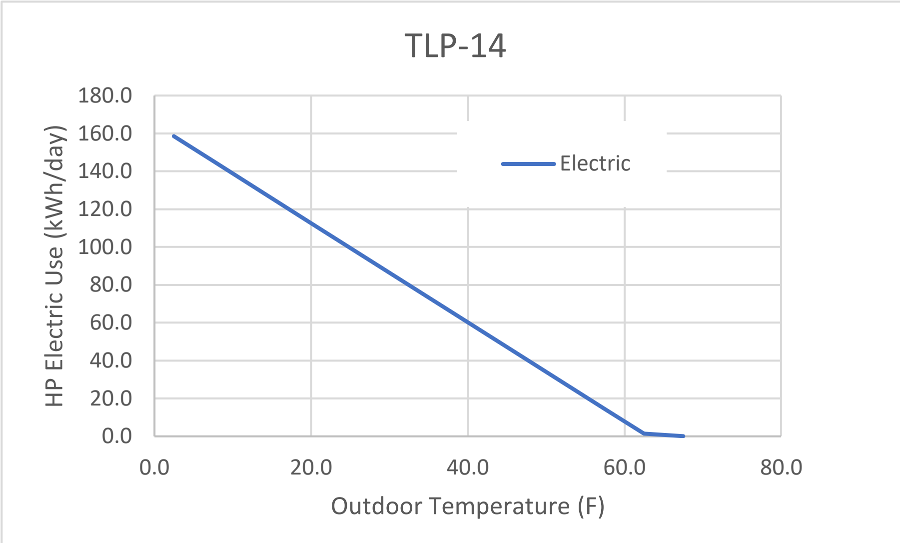


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 1,507 gallons per year for all improvements. However, if we subtract the oil savings from the envelope improvements, the fuel savings attributable to the heat pumps is 1,123 gallons per year. The heat pumps are estimated to use 10,460 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.8.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-14	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	1,507	-	384	1,507	1,123
HP Electric (kWh/yr)		10,460		(10,460)	
Total Heating Costs	$ 3,689	$ 2,092	$ 941	$ 1,597	$ 656
Implied Seasonal COP				3.8	2.8

Summary Statistics	
0.69	Htg gal per sq ft per year
80.6	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
11,438	Measured HP Electric (kWh/yr)
109%	of typical year kWh

<u>Average Heat Pump Demand Profiles</u>

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

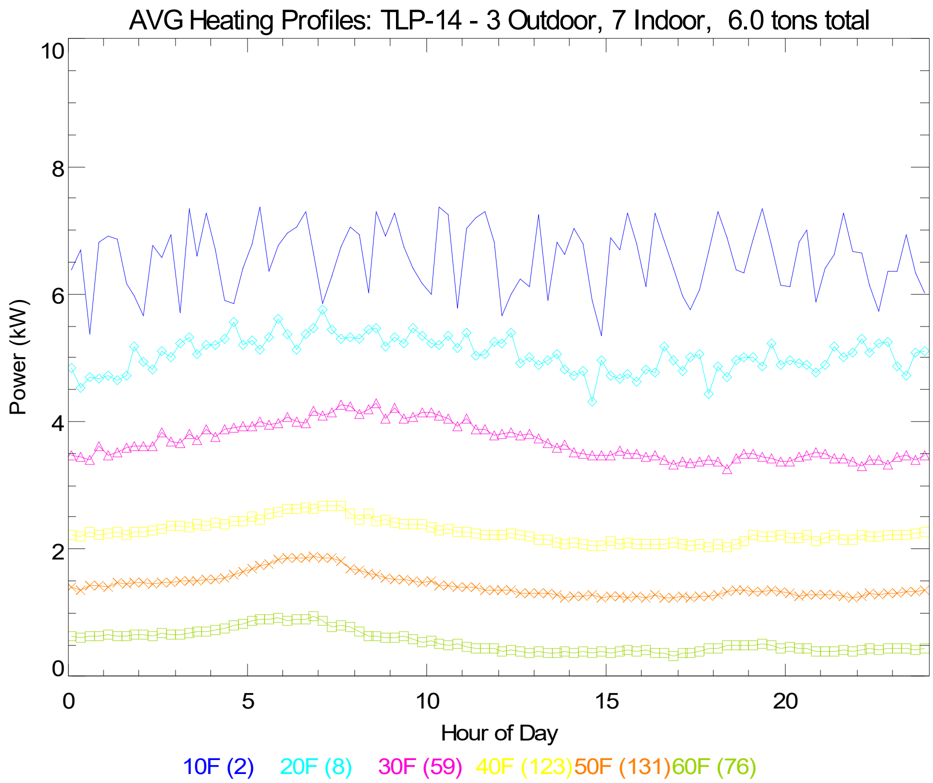


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

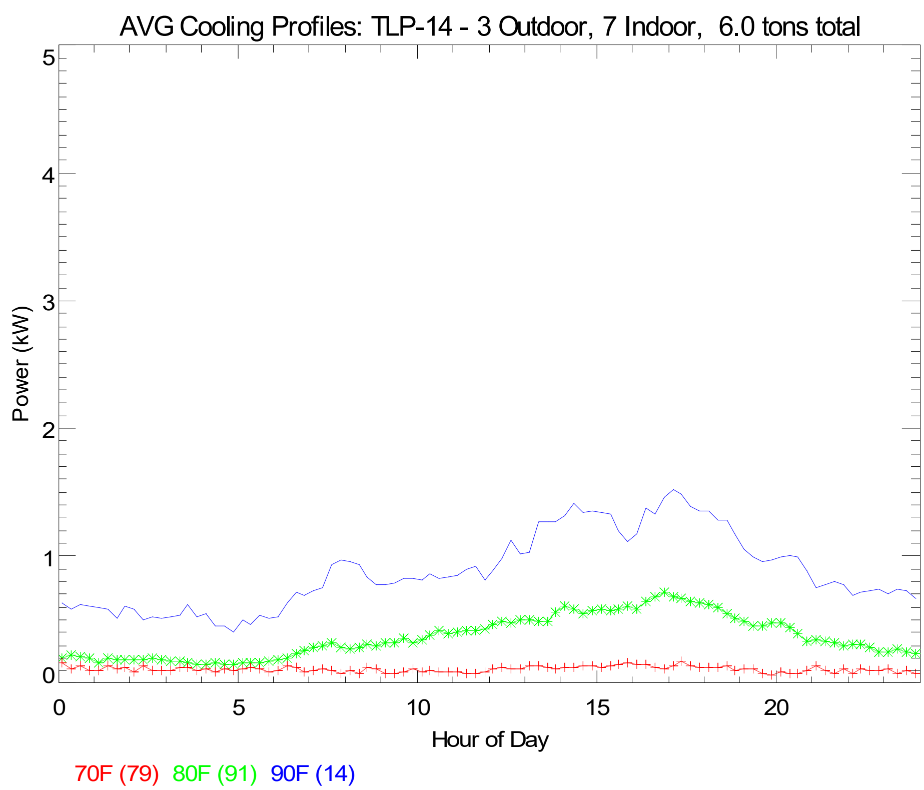


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

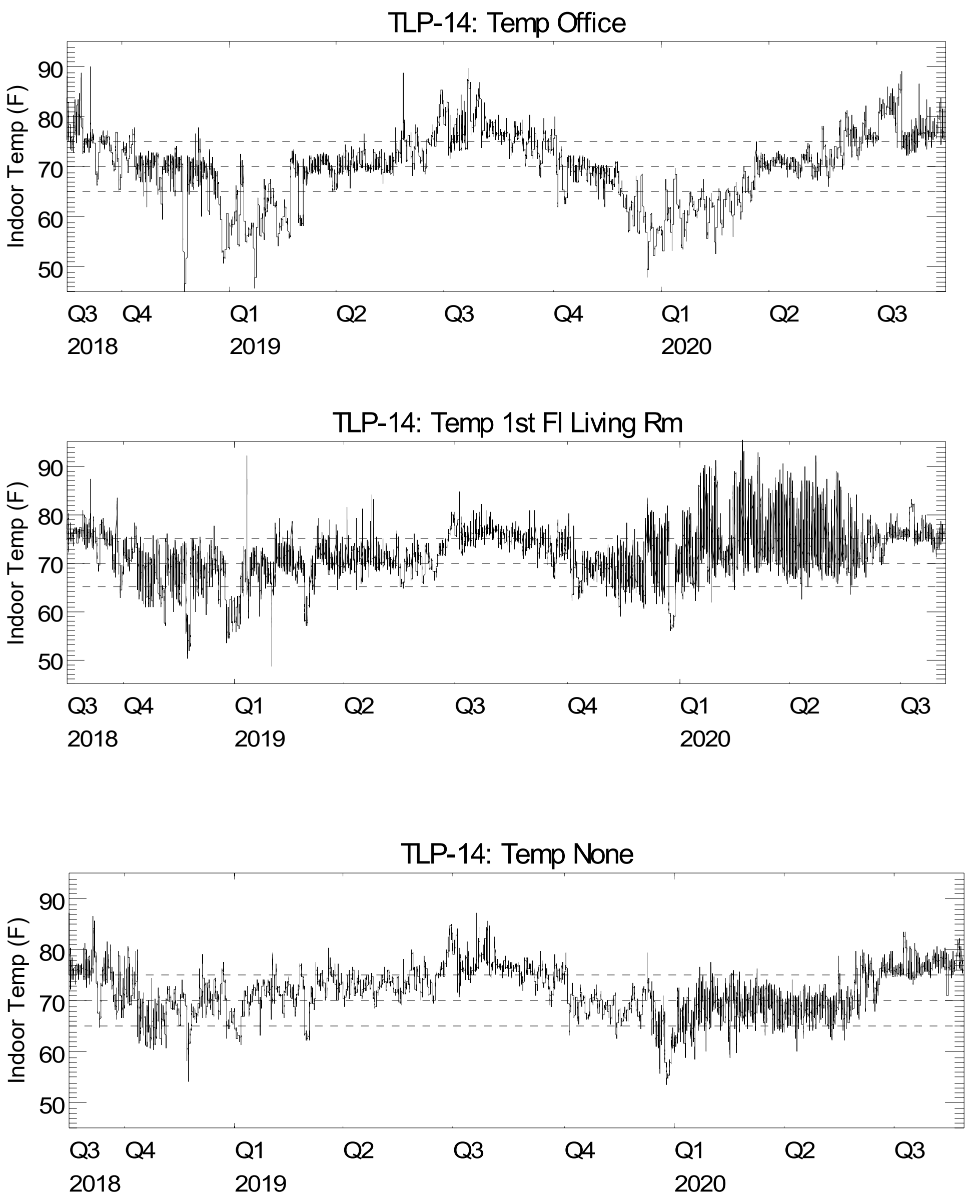


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 18 Savings Analysis

This 2950 sq ft multi-family home originally used an oil boiler with conventional baseboard radiation. The building is a recently completed gut rehab. Four electric heat pumps with a total capacity of 8 tons were added to the home in the summer 2020. The oil boiler was removed. Monitoring equipment was first installed in March 2019, though the data were not useful until August 2020 when the project completed. Table 1 compares the proposed and final envelope measures, as per the design report. It is not clear if all of the work described in the November 2017 report was competed—or if even more envelope improvements were completed as part of the multi-year gut rehab project.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage of heated area from 12,684 cfm to 8500 cfm SAVINGS: $761 (275 gallons)	Uncertain
Insulation	Extensive insulation added as part of gut rehab SAVINGS: $465 (168 gallons)	Uncertain
All	SAVINGS: $1226 (443 gallons)	Uncertain

Table 2 summarizes the energy use of the heat pumps across the period. The heat pumps were measured for a total of 10 months. While not all of the summer data was collected, the data we have showed that the HPs were rarely used for cooling. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units. HP4 was in a tenant area on the garden level and was never used (as confirmed by the homeowners).

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	HP3 (kWh)	HP4 (kWh)
Aug-20	17%	17.6	8.1	6.5	3.0	-
Sep-20	100%	64.5	25.8	31.3	6.1	1.3
Oct-20	100%	3.7	2.1	1.5	-	-
Nov-20	100%	130.9	40.6	57.6	32.6	-
Dec-20	100%	492.2	104.7	235.3	151.6	0.5
Jan-21	100%	855.2	148.7	555.2	151.3	-
Feb-21	100%	699.5	118.0	491.3	90.2	-
Mar-21	100%	361.1	73.6	268.3	19.3	-
Apr-21	100%	35.9	20.3	12.7	2.9	-
May-21	100%	29.1	12.3	11.3	3.7	1.9
Jun-21	9%	0.3	0.3	-	-	-
Jul-21	0%	-	-	-	-	-
Annual	77%	2,690.0	554.5	1,671.0	460.7	3.7
Summer (Jun-Sep)		82.4	34.2	37.8	9.1	1.3
Winter (Oct-May)		2,607.6	520.3	1,633.2	451.6	2.4

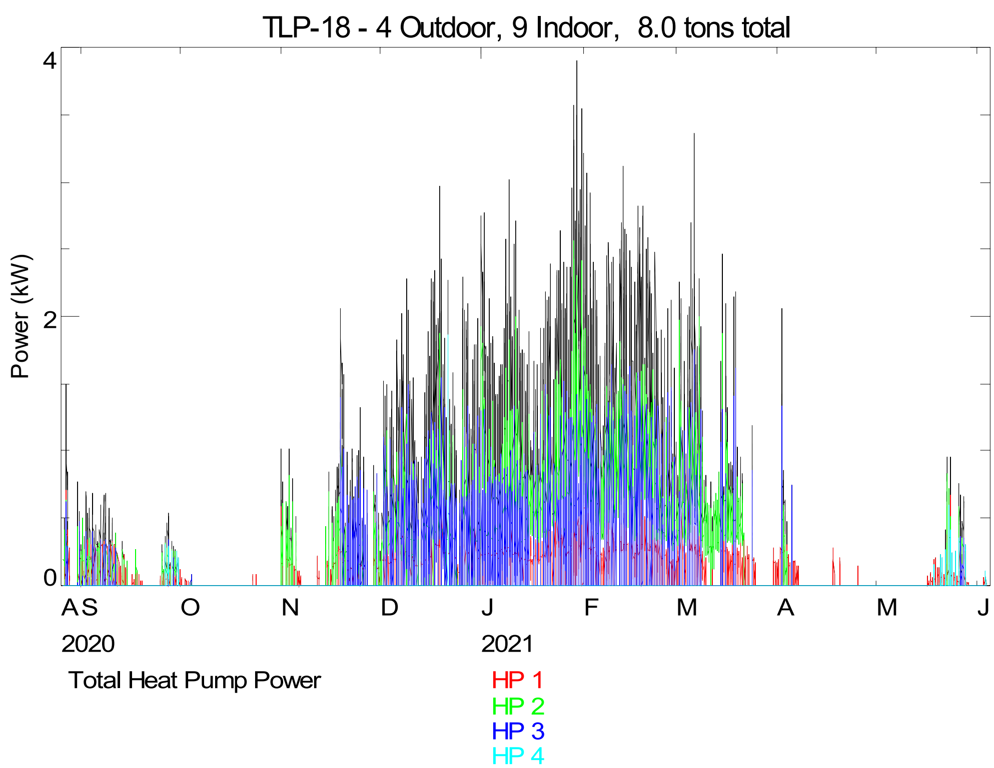


Figure 1. Plot of Power Use for All Heat Pumps at Site

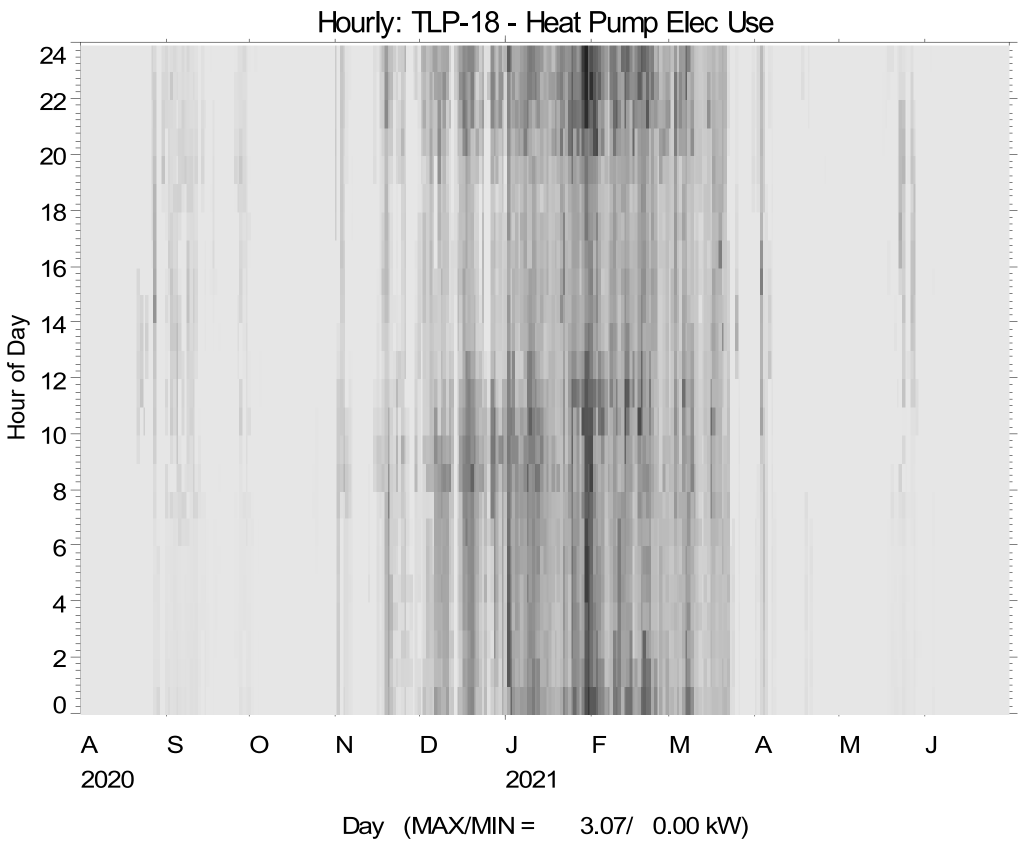


Figure 2. Shade Plot of Total Heat Pump Power

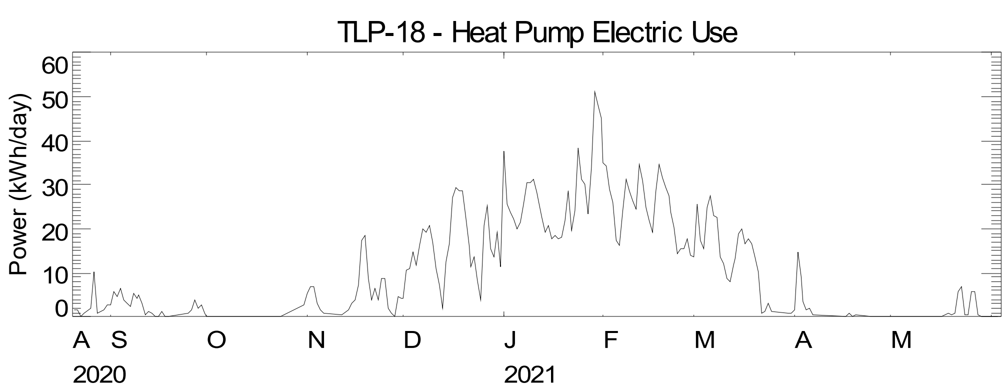


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.

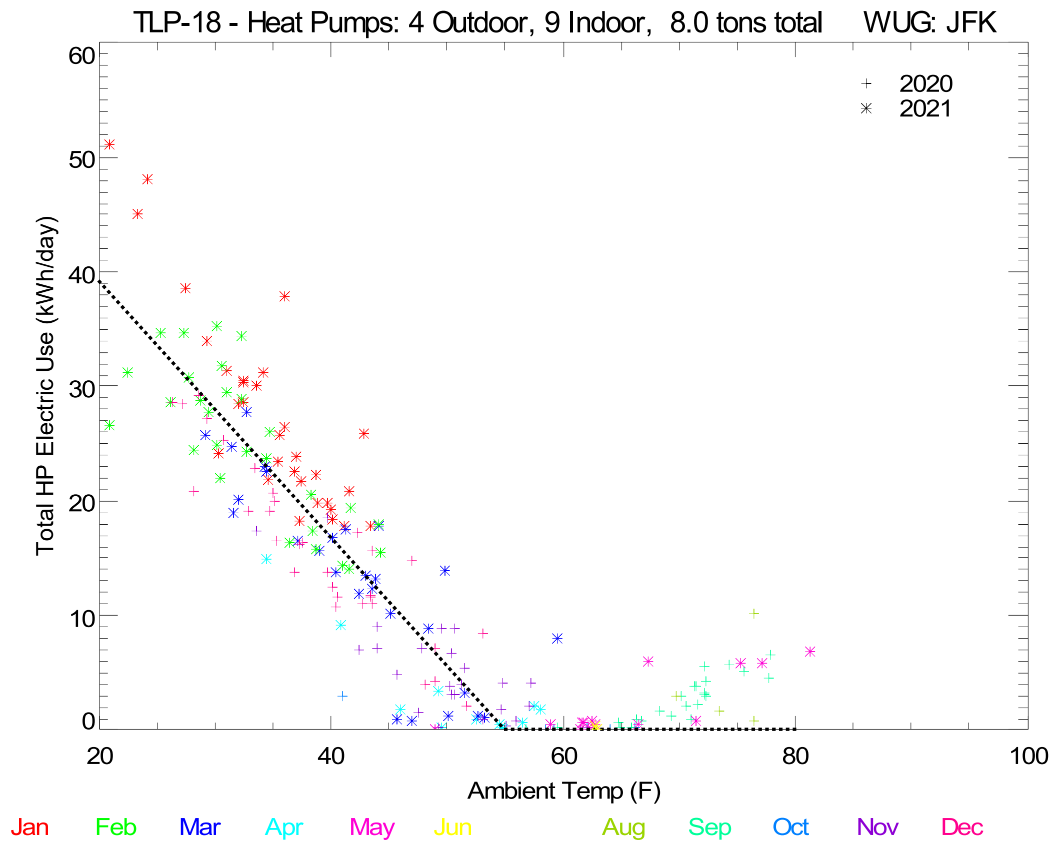


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. There is no post-retrofit data since the boiler was removed. In the analysis we assume the same baseline summer use as in the pre-retrofit period.

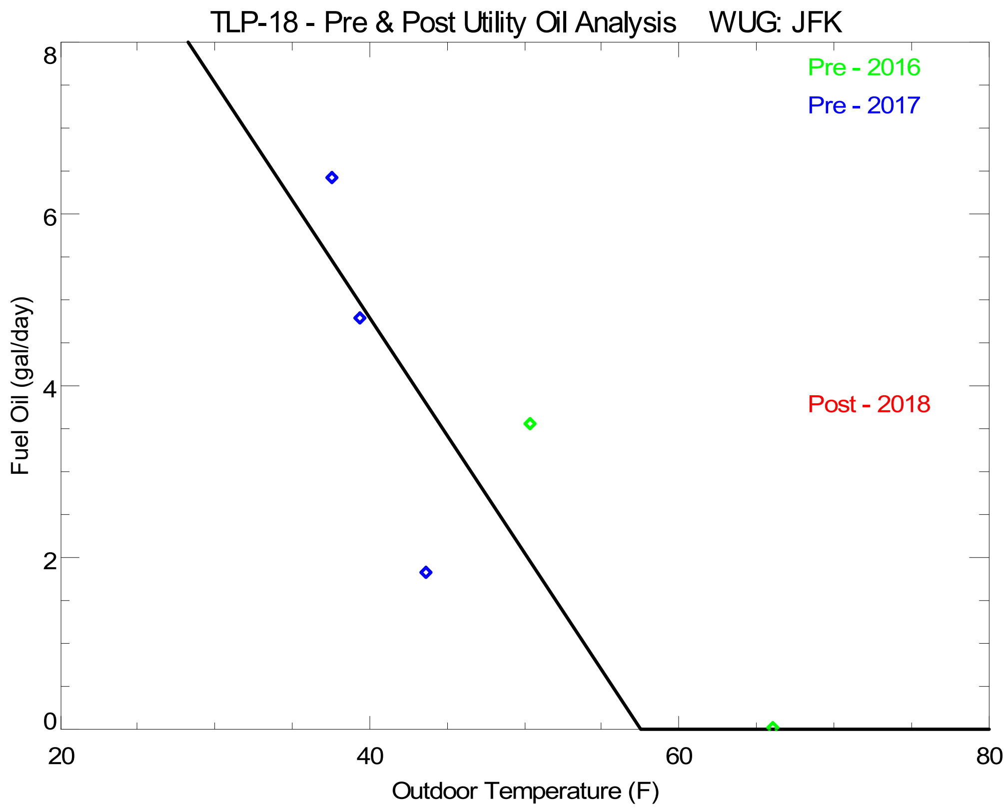


Figure 5. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-18** WEATHER: **New_York** $ 0.20 per kWh

FUEL: **Oil** $ 2.447 per gal

Floor Area **2950**

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	23.3	0.0	92.4	0.0	8.0	57.1	18.5	
-22.5	0	22.0	0.0	86.8	0.0	8.0	53.8	17.4	
-17.5	0	20.6	0.0	81.2	0.0	8.1	50.4	16.2	
-12.5	0	19.2	0.0	75.6	0.0	8.1	47.0	15.1	
-7.5	0	17.8	0.0	70	0.0	8.1	43.7	14.0	
-2.5	0	16.5	0.0	64.4	0.0	8.1	40.3	12.9	
2.5	0	15.1	0.0	58.8	0.0	8.2	37.0	11.8	
7.5	11	13.7	0.0	53.2	0.0	8.2	33.6	10.6	
12.5	22	12.4	0.0	47.6	0.0	8.2	30.2	9.5	
17.5	101	11.0	0.0	42	0.0	8.3	26.9	8.4	
22.5	167	9.6	0.0	36.4	0.0	8.4	23.5	7.3	
27.5	247	8.2	0.0	30.8	0.0	8.5	20.2	6.2	
32.5	475	6.9	0.0	25.2	0.0	8.7	16.8	5.0	
37.5	855	5.5	0.0	19.6	0.0	8.9	13.4	3.9	
42.5	708	4.1	0.0	14	0.0	9.3	10.1	2.8	
47.5	608	2.7	0.0	8.4	0.0	10.4	6.7	1.7	
52.5	880	1.4	0.0	2.8	0.0	15.6	3.4	0.6	
57.5	750	0.0	0.0	0	0.0	0.0	0.0	0.0	
62.5	814	0.0	0.0	0	0.0	0.0	0.0	0.0	
67.5	723	0.0	0.0	0	0.0	0.0	0.0	0.0	

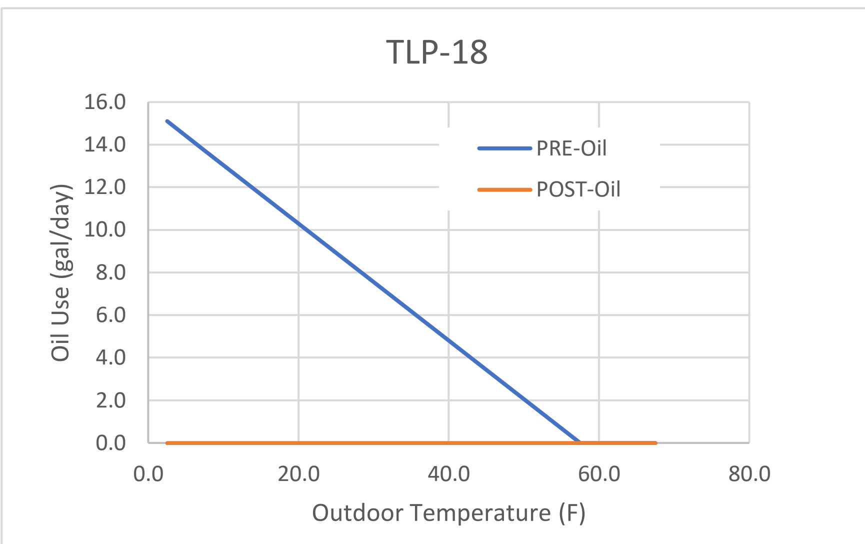


Figure 6. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

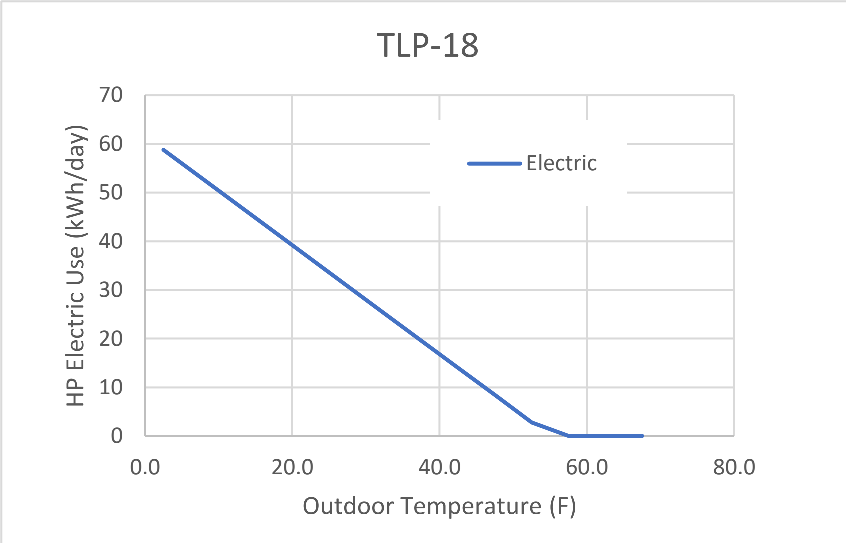


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 788 gallons per year. However, if we subtract the oil savings from the envelope improvements, the fuel savings attributable to the heat pumps is 346 gallons per year. The heat pumps are estimated to use 2,741 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 4.0. This COP is high side of what is plausible. Therefore, we believe that the energy impact of the envelope improvements in this multi-year gut rehab project were under estimated.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-18	**PRE Retrofit**	**POST Retrofit**	**Envelope Savings**	**ASHP & Env Savings**	**ASHP Savings**
Oil (gal/yr)	788	-	443	788	346
HP Electric (kWh/yr)		2,741		(2,741)	
Total Heating Costs	$ 1,929	$ 548	$ 1,083	$ 1,381	$ 298
Implied Seasonal COP				9.1	4.0

Summary Statistics	
0.27	Htg gal per sq ft per year
31.2	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
2,608	Measured HP Electric (kWh/yr)
95%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

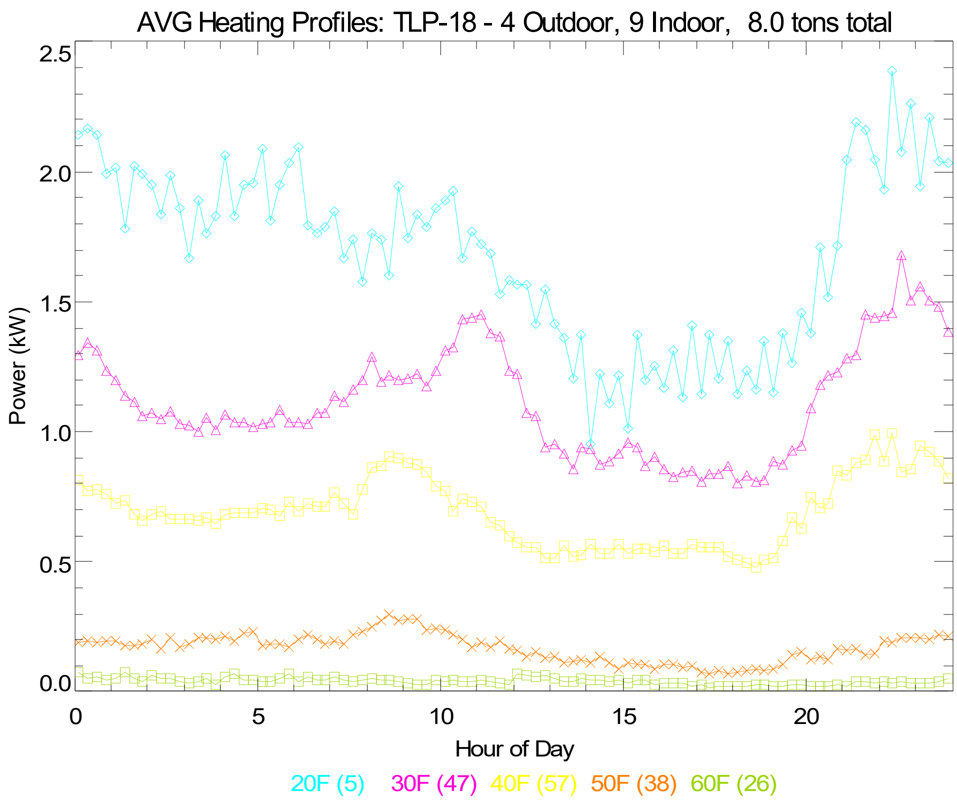


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

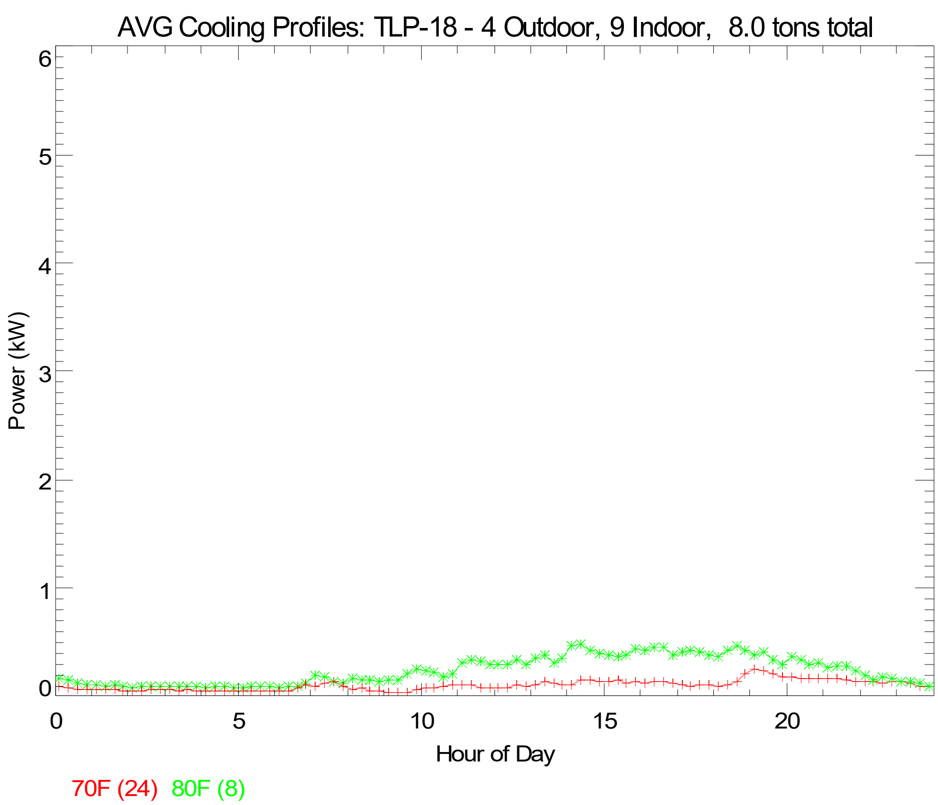


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

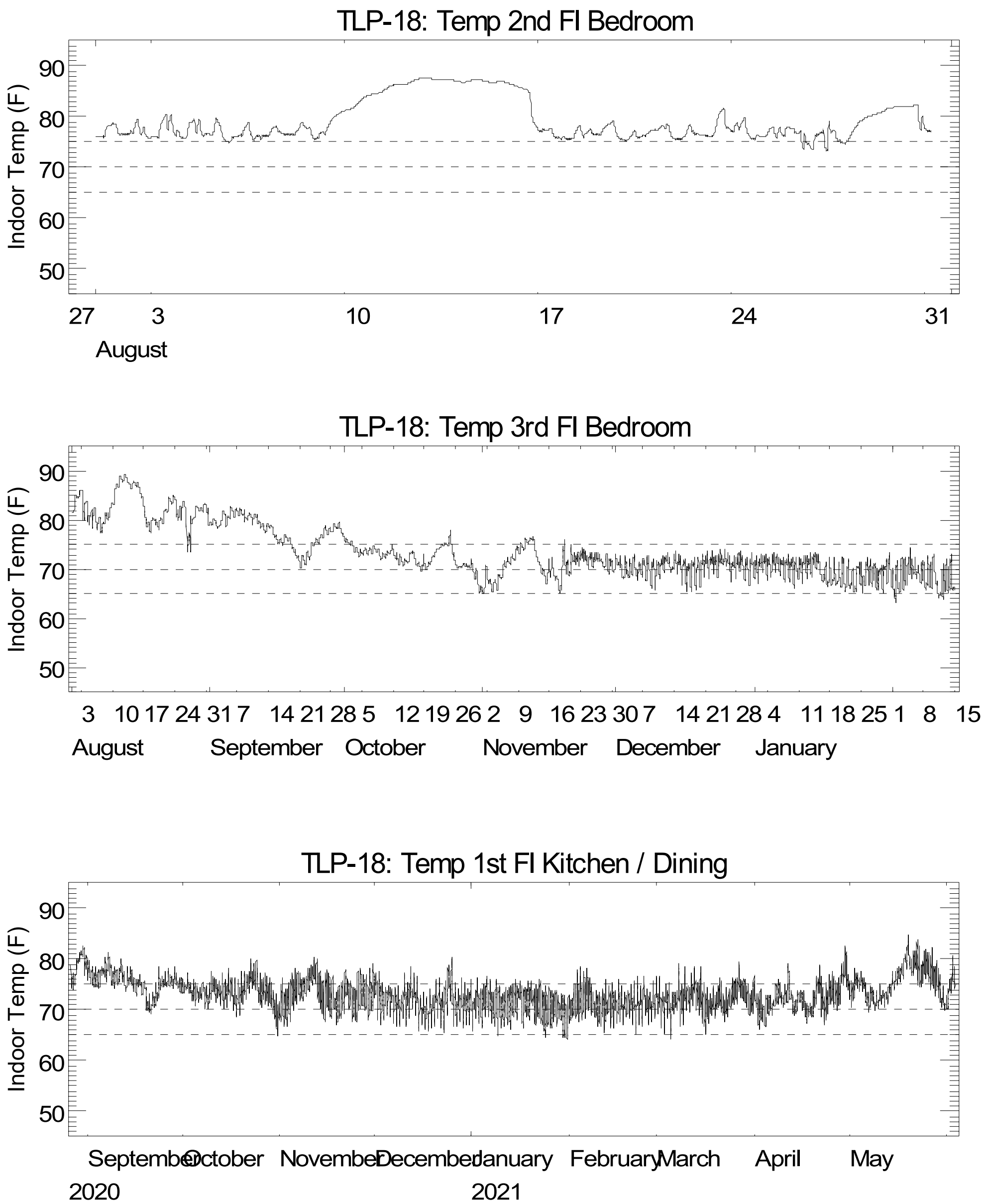


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 19 Savings Analysis

This 1,318 sq ft multi-family home originally used an oil boiler with conventional baseboard radiation. Both apartments are affordable housing rental units. Two electric heat pumps with a total capacity of 4.5 tons were added to the home in early 2018. The oil boiler was removed. Monitoring equipment was installed on April 11, 2018 to collect data at 15-minute intervals. The house did not have any weatherization or envelope improvements.

Table 1 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps.

Table 1. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)
Apr-18	65%	1,061.9	577.4	484.5
May-18	100%	232.7	143.4	89.3
Jun-18	100%	440.1	300.6	139.5
Jul-18	100%	816.4	492.4	324.0
Aug-18	100%	967.7	635.3	332.5
Sep-18	100%	530.7	390.5	140.2
Oct-18	100%	925.1	553.9	371.2
Nov-18	100%	1,751.7	790.4	961.3
Dec-18	100%	2,228.4	888.9	1,339.5
Jan-19	100%	3,582.5	1,684.1	1,898.4
Feb-19	100%	3,024.5	1,281.4	1,743.1
Mar-19	100%	2,791.3	1,320.0	1,471.3
Apr-19	100%	1,599.8	860.7	739.1
May-19	100%	1,075.2	615.2	460.0
Jun-19	11%	39.7	28.2	11.5
Annual	100%	18,890.9	9,341.6	9,549.4
Summer (Jun-Sep)		2754.9	1818.8	936.2
Winter (Oct-May)		16,136.0	7,522.8	8,613.2

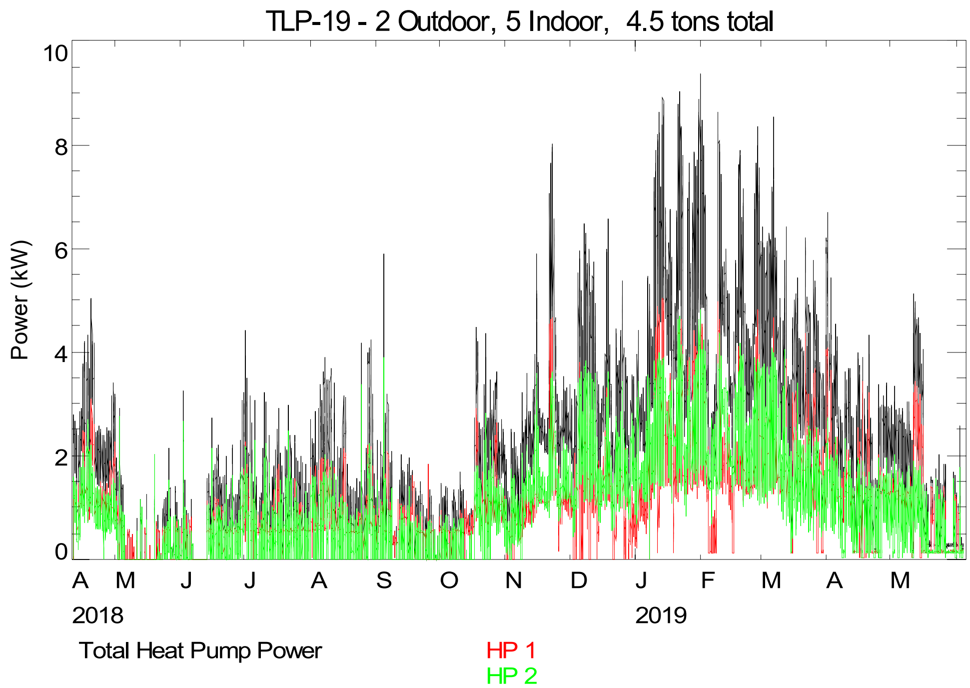


Figure 1. Plot of Power Use for All Heat Pumps at Site

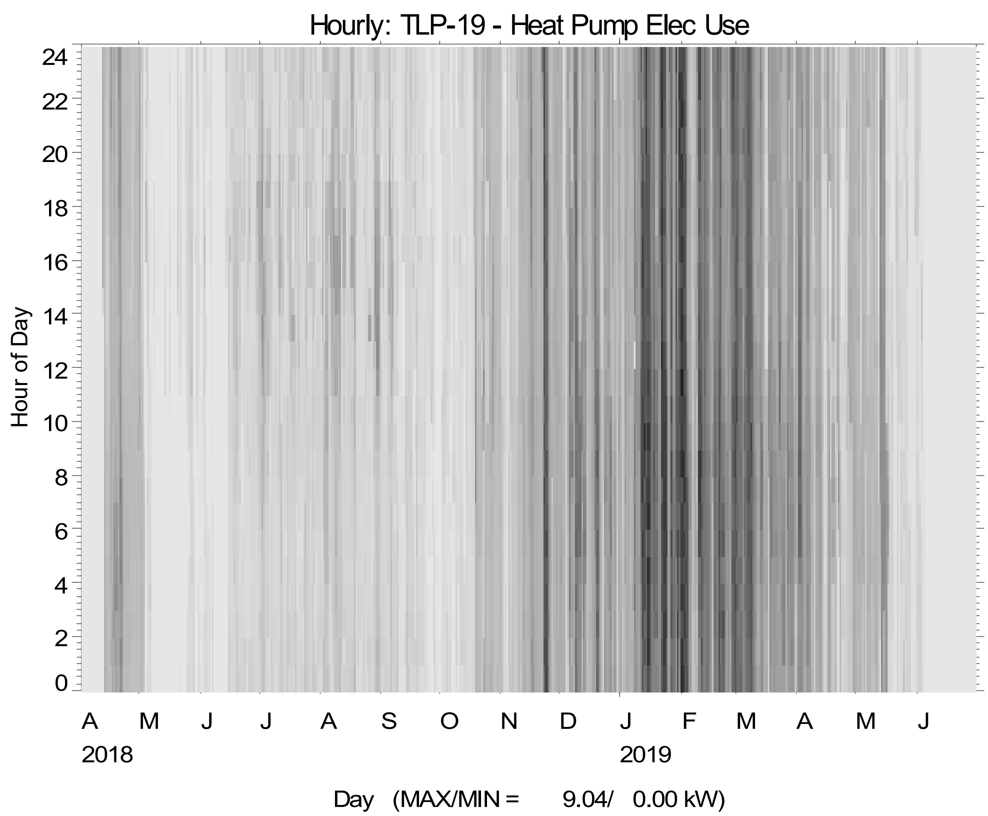


Figure 2. Shade Plot of Total Heat Pump Power

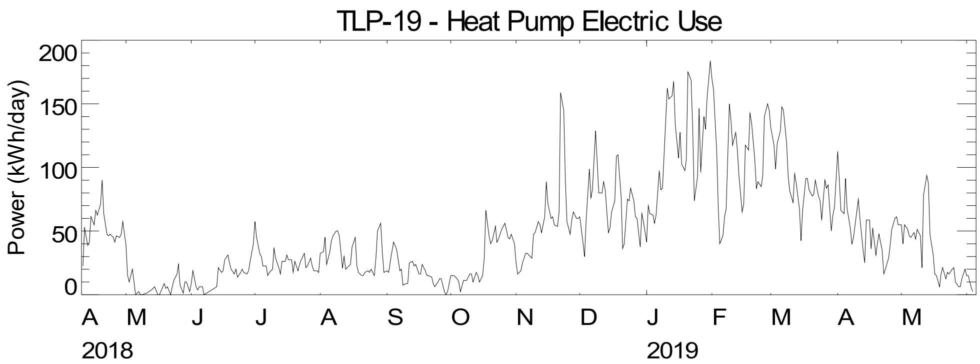


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.

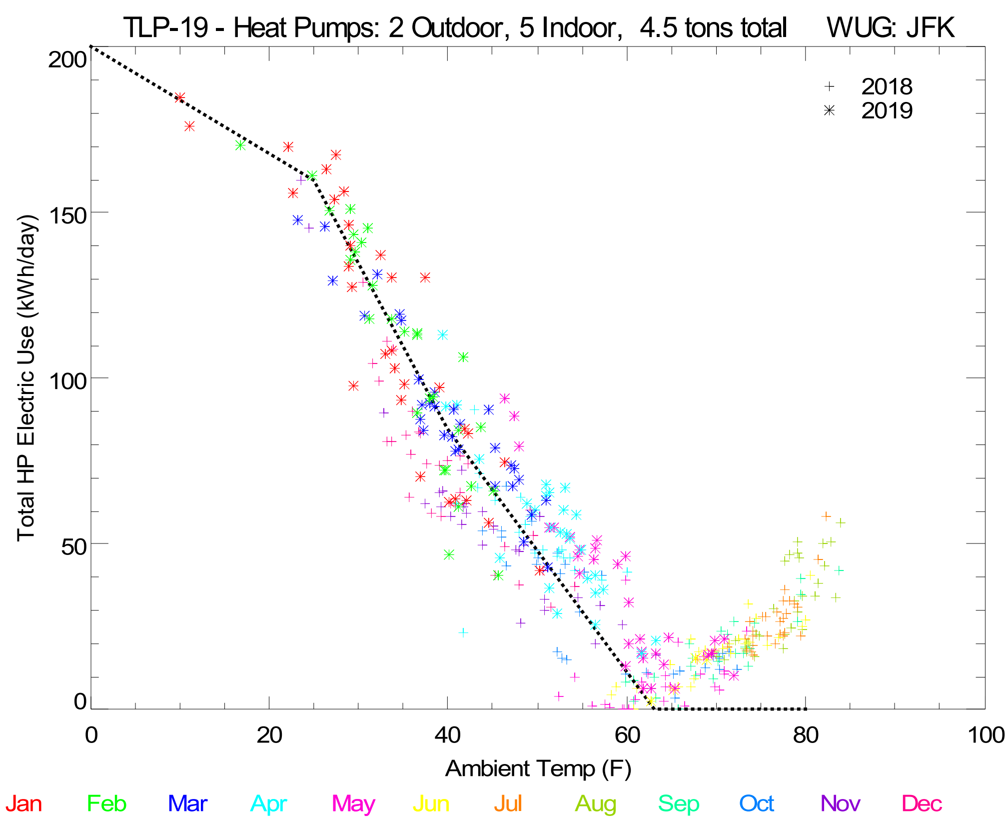


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. There is no post-retrofit data since the boiler was removed. In the analysis we assume the same baseline summer use as in the pre-retrofit period.

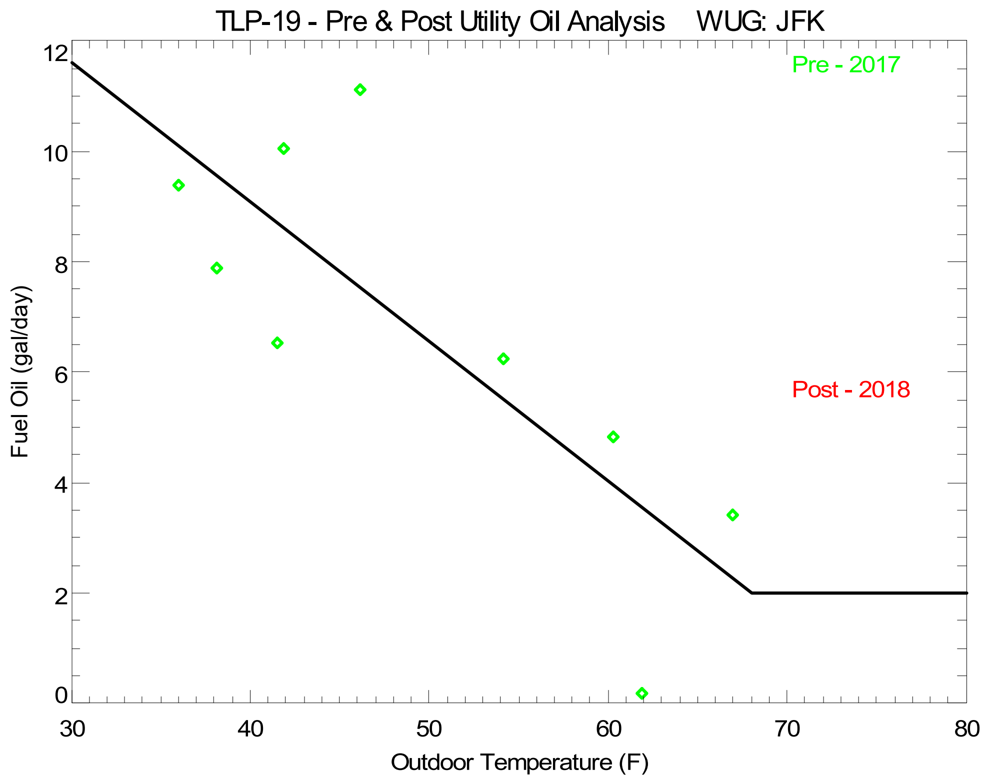


Figure 5. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 2. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-19** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Oil** $ 2.447 per gal

Floor Area **1318**

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	26.1	0.0	244.0	2.0	3.1	63.9	53.7	0.1
-22.5	0	24.9	0.0	236.0	2.0	3.1	60.8	52.1	0.1
-17.5	0	23.6	0.0	228.0	2.0	3.0	57.8	50.5	0.1
-12.5	0	22.3	0.0	220.0	2.0	2.9	54.7	48.9	0.1
-7.5	0	21.1	0.0	212.0	2.0	2.9	51.6	47.3	0.1
-2.5	0	19.8	0.0	204.0	2.0	2.8	48.5	45.7	0.1
2.5	0	18.5	0.0	196.0	2.0	2.7	45.4	44.1	0.1
7.5	11	17.3	0.0	188.0	2.0	2.6	42.3	42.5	0.1
12.5	22	16.0	0.0	180.0	2.0	2.5	39.2	40.9	0.1
17.5	101	14.8	0.0	172.0	2.0	2.4	36.1	39.3	0.1
22.5	167	13.5	0.0	164.0	2.0	2.2	33.0	37.7	0.1
27.5	247	12.2	0.0	147.5	2.0	2.2	29.9	34.4	0.2
32.5	475	11.0	0.0	122.5	2.0	2.3	26.8	29.4	0.2
37.5	855	9.7	0.0	97.5	2.0	2.5	23.7	24.4	0.2
42.5	708	8.4	0.0	75.8	2.0	2.7	20.7	20.0	0.2
47.5	608	7.2	0.0	57.3	2.0	2.9	17.6	16.4	0.3
52.5	880	5.9	0.0	38.8	2.0	3.2	14.5	12.7	0.3
57.5	750	4.7	0.0	20.3	2.0	4.1	11.4	9.0	0.4
62.5	814	3.4	0.0	1.8	2.0	23.9	8.3	5.3	0.6
67.5	723	2.1	0.0	0.0	2.0	99.0	5.2	4.9	0.9
72.5	751	2.0	0.0	0.0	2.0	0.0	4.9	4.9	1.0

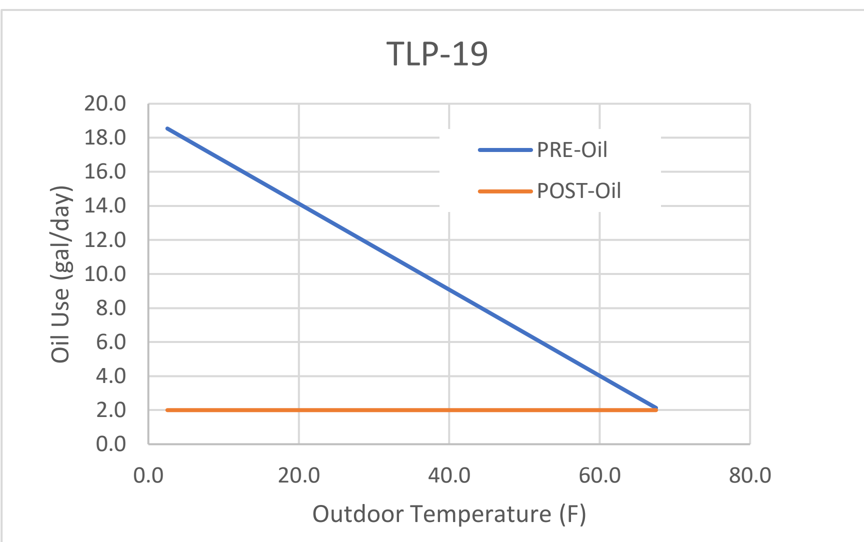


Figure 6. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

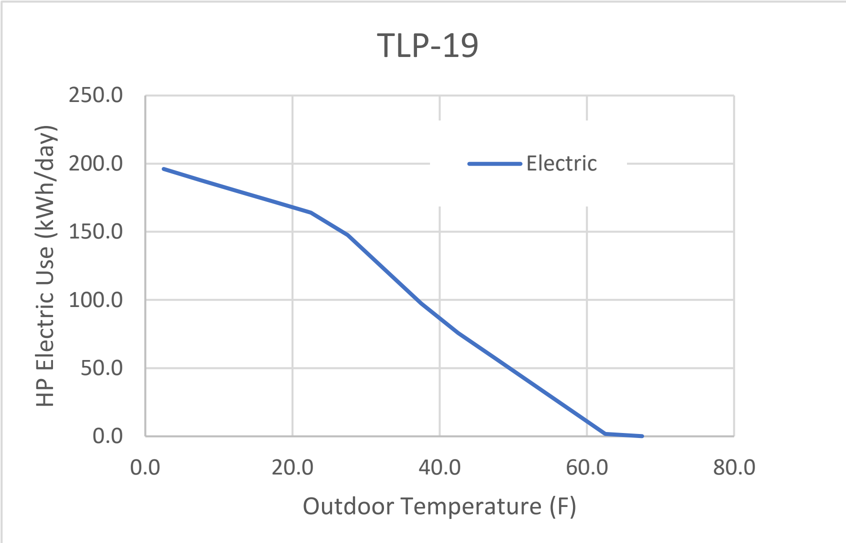


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 3 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 1,309 gallons per year for the heat pump. The heat pumps are estimated to use 15,339 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.7.

Table 3. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-19	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	1,309	-	-	1,309	1,309
HP Electric (kWh/yr)		15,339		(15,339)	
Total Heating Costs	$ 3,204	$ 3,068	$ -	$ 137	$ 137
Implied Seasonal COP				2.7	2.7

Summary Statistics	
0.99	Htg gal per sq ft per year
116.0	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
16,136	Measured HP Electric (kWh/yr)
105%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

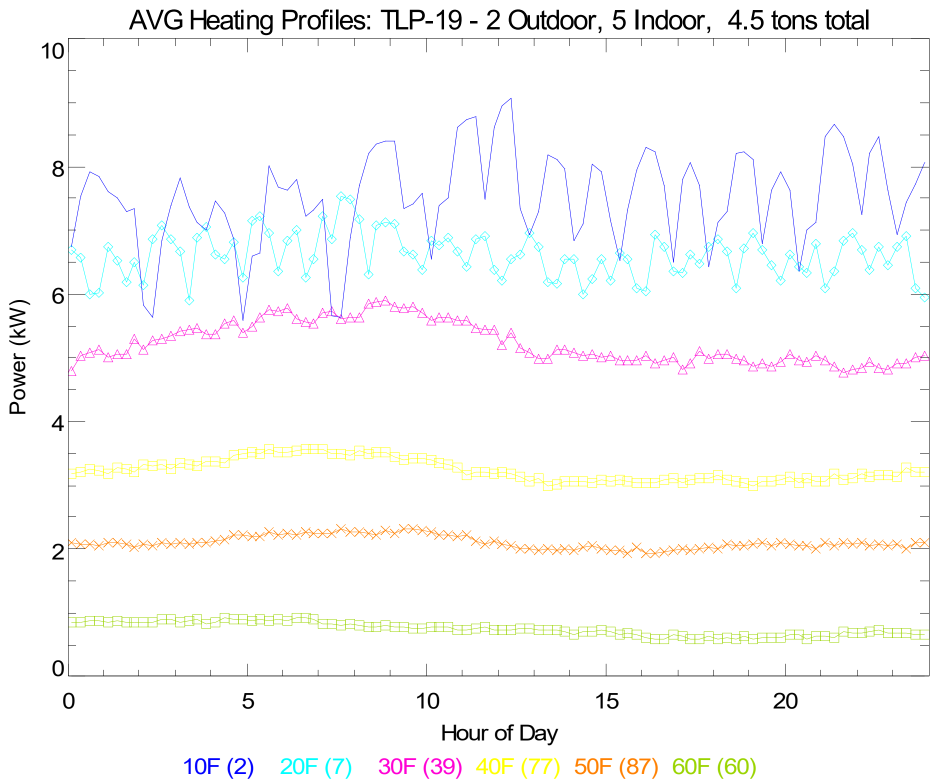


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

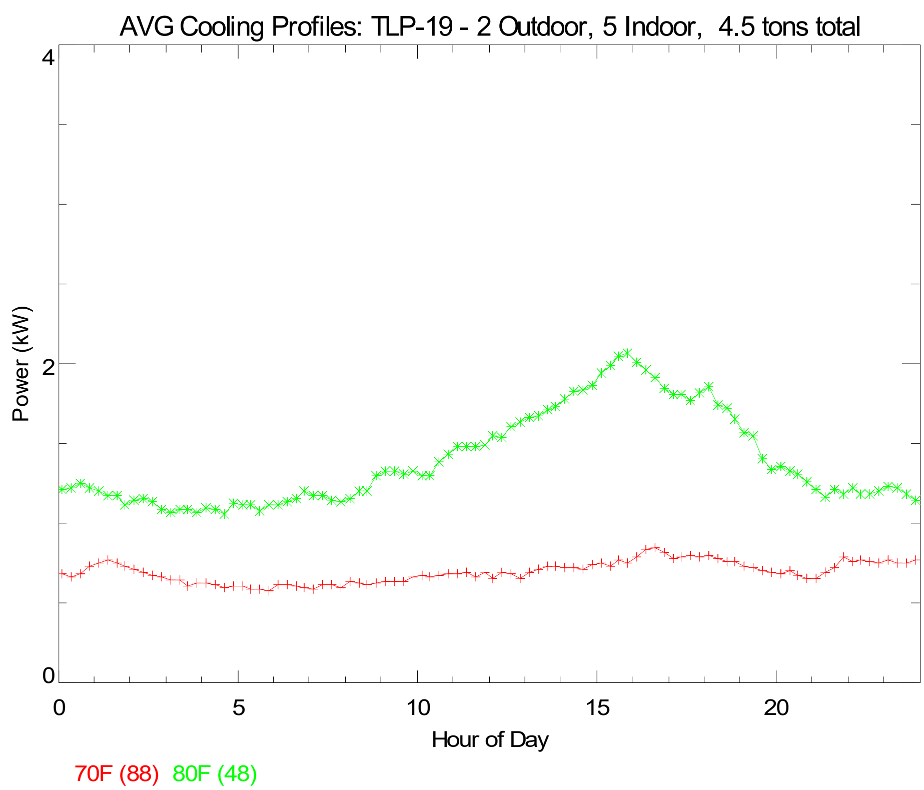


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10. The first floor master bedroom did get colder than expected in the winter period.

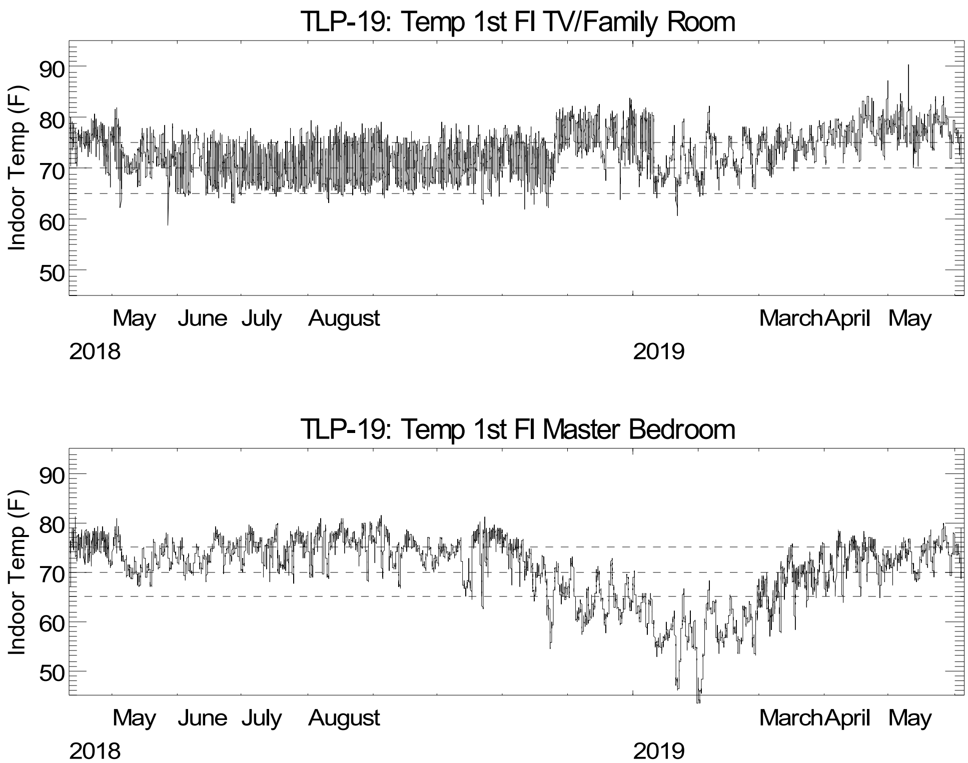


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 21 Savings Analysis

This 1700 sq ft two-family home originally used a gas boiler with conventional baseboard radiation. Two electric heat pumps with a total capacity of 3.3 tons were added to the home in mid 2018. The gas boiler was also upgraded to a high efficiency unit to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on August 16, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, rim joist) implemented that were projected to save 122 therms per year. Table 1 summarizes the proposed envelope measures, which were implemented.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage from 5,670 CFM50 to 4,500 CFM50 SAVINGS: $135 (94 therms)	Completed
Rim Joist	Upgrade 106 sq ft to R15 SAVINGS: $40 (28 therms)	Completed

Table 2 summarizes the energy use of the heat pumps across the period. Note that both HPs were measured as one power channel. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps.

Both Table 1 and Figure 3 show there was almost no heat pump use in the second winter. The occupants apparently decided to switch back to the boiler for heating.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	Boiler (hrs)
Aug-18	50%	278.1	278.1	4.8
Sep-18	100%	325.3	325.3	10.4
Oct-18	100%	455.1	455.1	14.2
Nov-18	100%	1,214.2	1,214.2	65.0
Dec-18	100%	1,412.0	1,412.0	373.8
Jan-19	100%	1,214.9	1,214.9	593.2
Feb-19	100%	1,022.2	1,022.2	522.2
Mar-19	100%	1,061.2	1,061.2	460.0
Apr-19	100%	345.5	345.5	181.8
May-19	100%	183.0	183.0	69.7
Jun-19	100%	299.4	299.4	12.6
Jul-19	100%	514.3	514.3	10.1
Aug-19	100%	332.6	332.6	10.7
Sep-19	100%	235.4	235.4	15.4
Oct-19	100%	198.6	198.6	47.0
Nov-19	100%	188.1	188.1	424.7
Dec-19	100%	238.0	238.0	581.1
Jan-20	100%	295.4	295.4	541.2
Feb-20	100%	194.6	194.6	491.2
Mar-20	100%	195.3	195.3	350.5
Apr-20	100%	184.9	184.9	287.2
May-20	100%	185.9	185.9	183.5
Jun-20	100%	386.8	386.8	162.1
Jul-20	100%	548.6	548.6	221.1
Aug-20	83%	511.5	511.5	204.1
Annual	100%	8,379.7	8,379.7	2,323.7
Summer (Jun-Sep)		1,471.6	1,471.6	43.8
Winter (Oct-May)		6,908.1	6,908.1	2,279.9

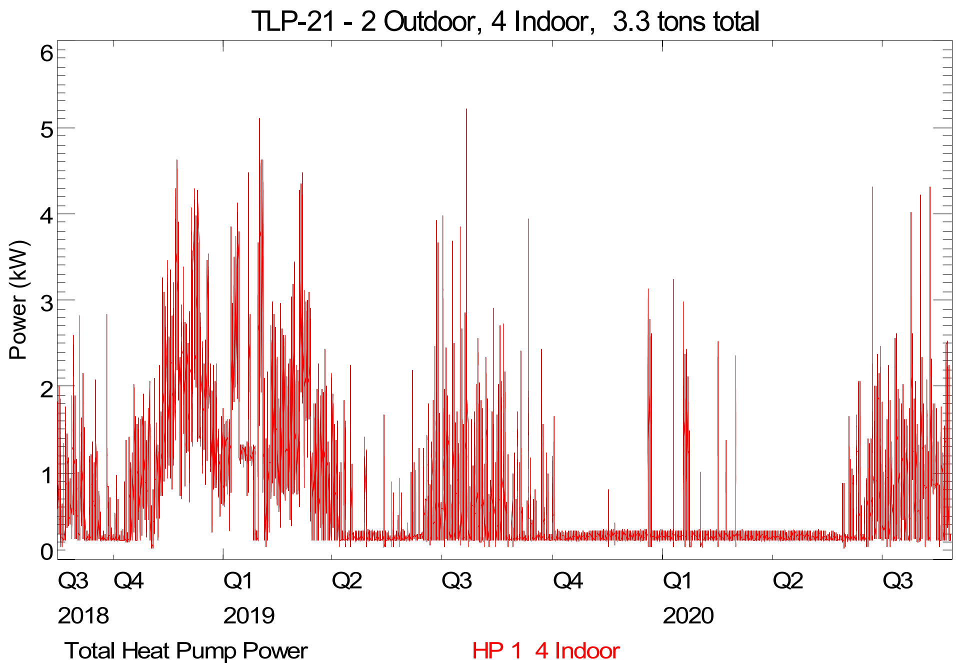


Figure 1. Plot of Power Use for All Heat Pumps at Site

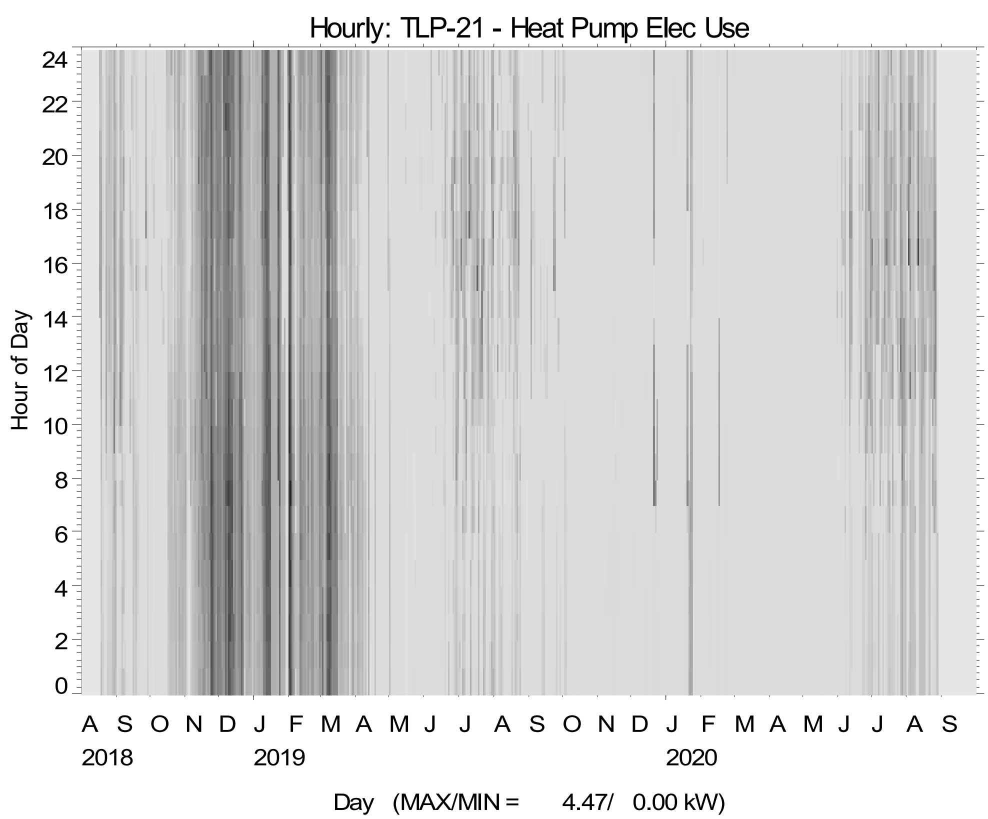


Figure 2. Shade Plot of Total Heat Pump Power

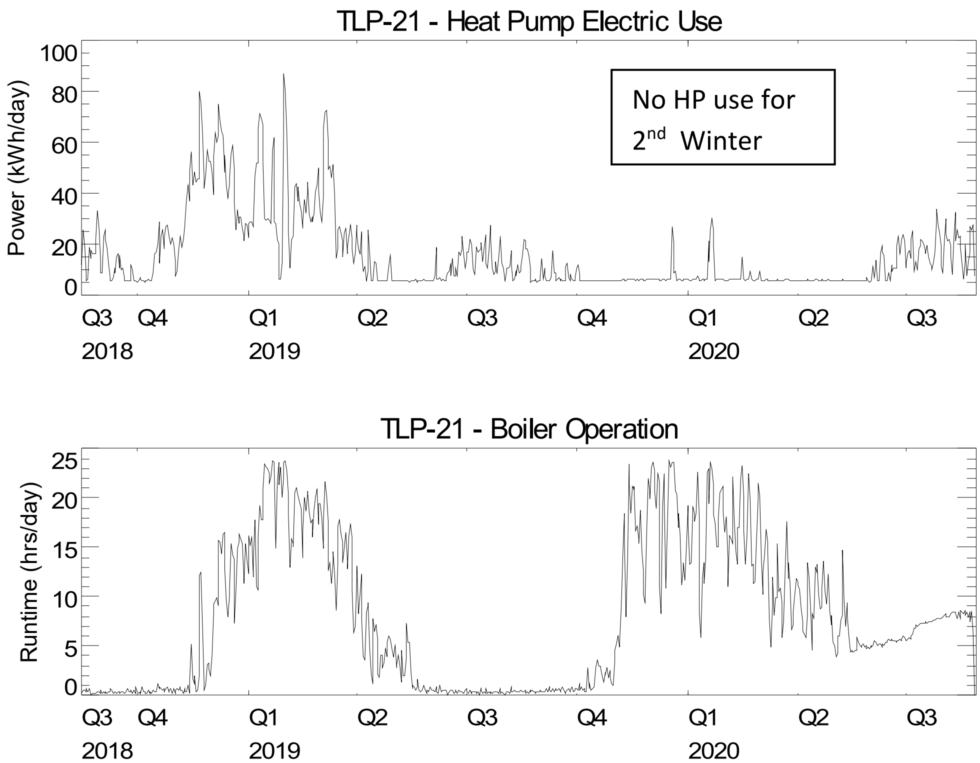


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the JFK. The data for each month are shown with different colors. Different symbol types are used for each year.

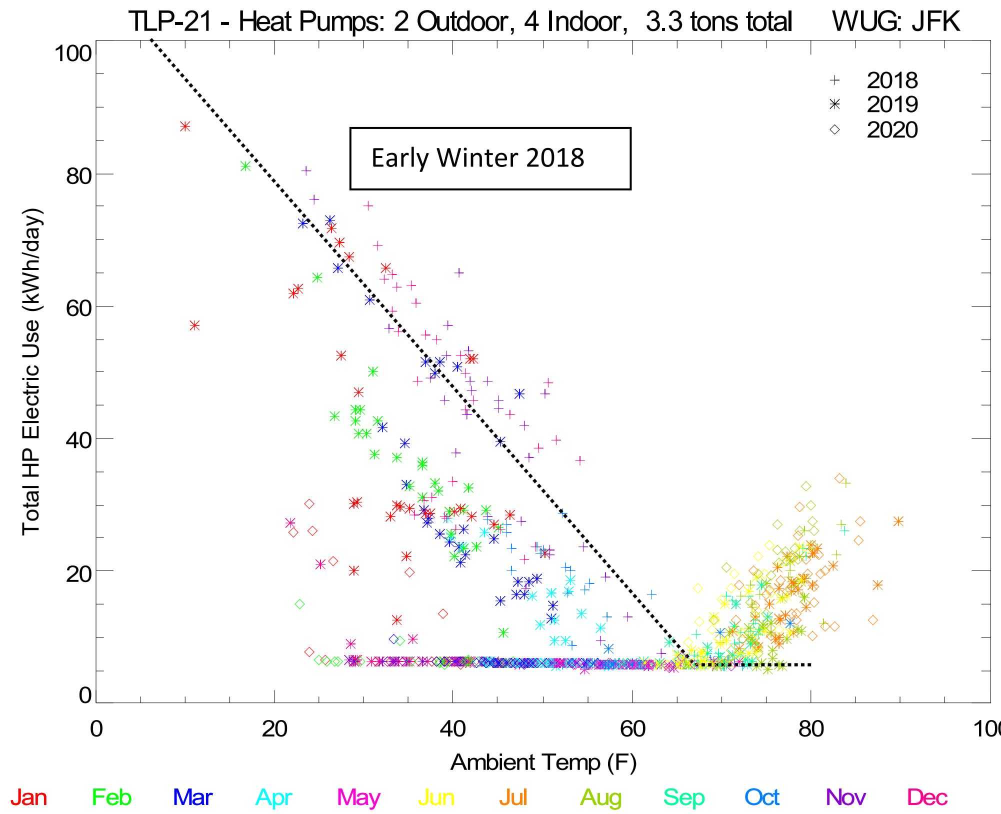


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. The dotted line is the best fit to the post retrofit data from the first few months from the first winter of operation.

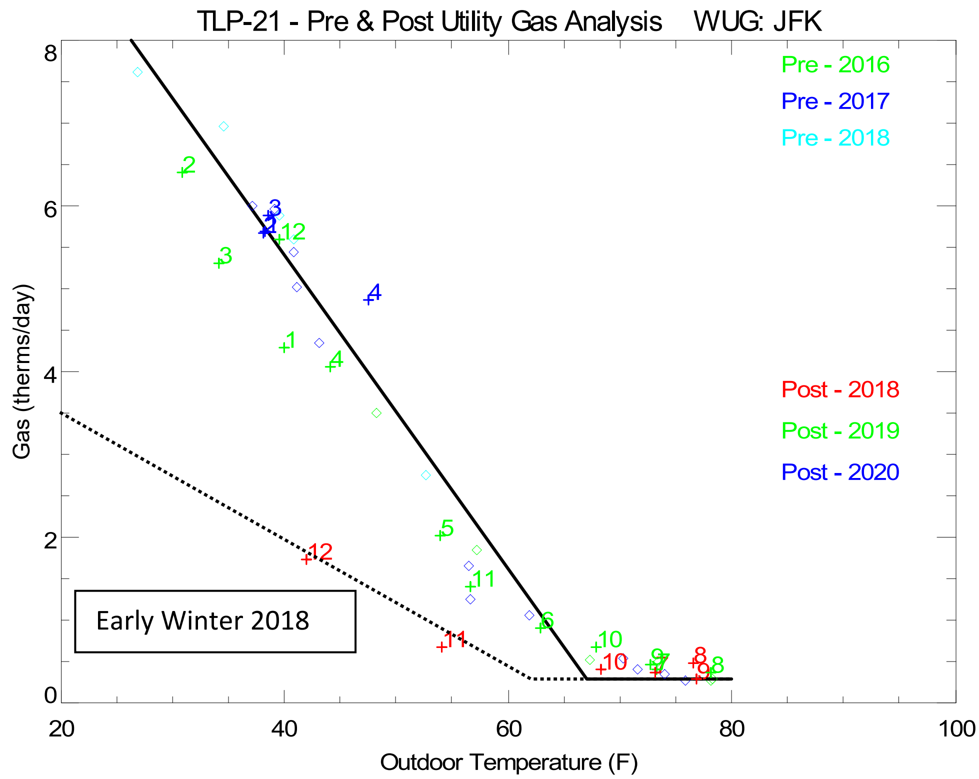


Figure 5. Trend of Gas Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre- and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above (focused on early Winter 2018) were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-21** WEATHER: **New_York** $ 0.20 per kWh

FUEL: **Gas** $ 1.403 per therm

Floor Are: **1700**

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	18.2	7.1	152.7	7.1	2.0	25.5	40.5	
-22.5	0	17.2	6.7	144.9	6.7	2.0	24.2	38.4	
-17.5	0	16.3	6.4	137.2	6.4	2.0	22.9	36.4	
-12.5	0	15.4	6.0	129.4	6.0	2.0	21.5	34.3	
-7.5	0	14.4	5.6	121.6	5.6	2.0	20.2	32.2	
-2.5	0	13.5	5.2	113.9	5.2	2.0	18.9	30.1	
2.5	0	12.5	4.8	106.1	4.8	2.0	17.6	28.0	
7.5	11	11.6	4.5	98.4	4.5	2.0	16.2	25.9	
12.5	22	10.6	4.1	90.6	4.1	2.0	14.9	23.8	
17.5	101	9.7	3.7	82.8	3.7	2.0	13.6	21.7	
22.5	167	8.7	3.3	75.1	3.3	2.0	12.2	19.7	
27.5	247	7.8	2.9	67.3	2.9	2.0	10.9	17.6	
32.5	475	6.8	2.5	59.6	2.5	2.0	9.6	15.5	
37.5	855	5.9	2.2	51.8	2.2	2.0	8.3	13.4	
42.5	708	4.9	1.8	44.0	1.8	2.0	6.9	11.3	
47.5	608	4.0	1.4	36.3	1.4	2.0	5.6	9.2	
52.5	880	3.0	1.0	28.5	1.0	2.0	4.3	7.1	
57.5	750	2.1	0.6	20.7	0.6	2.0	2.9	5.1	
62.5	814	1.2	0.3	13.0	0.3	1.8	1.6	3.0	
67.5	723	0.3	0.3	6.0	0.3	0.0	0.4	1.6	
72.5	751	0.3	0.3	6.0	0.3	0.0	0.4	1.6	

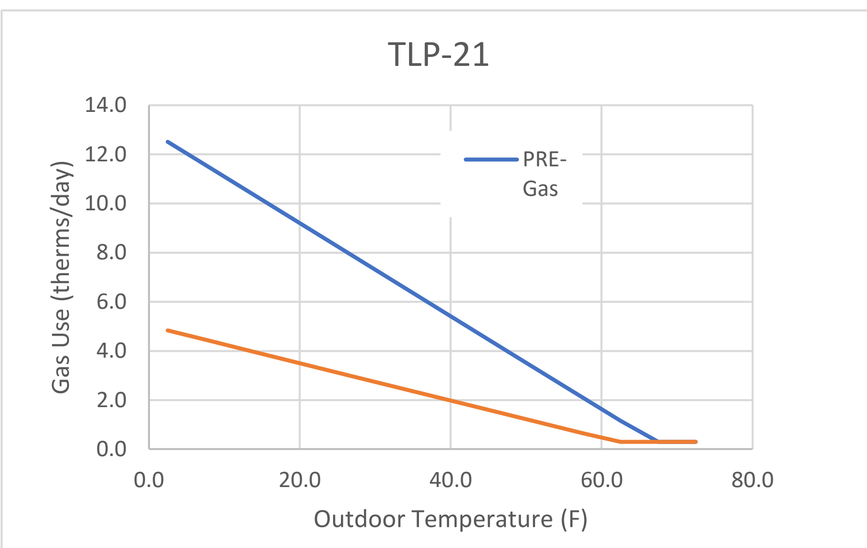


Figure 6. Trend of PRE- and POST-Retrofit Gas Use with Outdoor Temperature for Bin Analysis

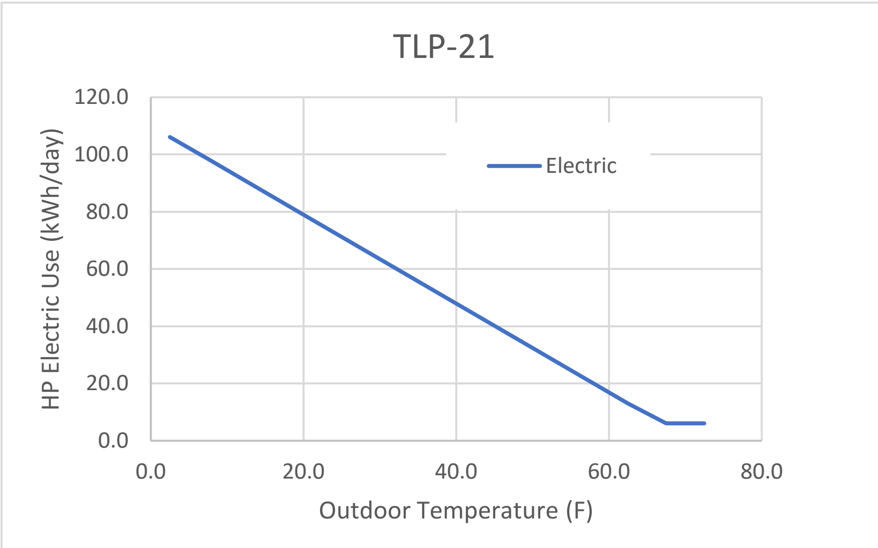


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 647 therms per year for all improvements. However, if we subtract the gas savings from the envelope improvements, the fuel savings attributable to the heat pumps is 525 therms per year. The heat pumps are estimated to use 7,658 kWh per year, excluding fan power for heat pumps. From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 1.9.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Exlcude HP Fan Power

Heating Only TLP-21	**PRE Retrofit**	**POST Retrofit**	**Envelope Savings**	**ASHP & Env Savings**	**ASHP Savings**
Gas (therms/yr)	934	288	122	647	525
HP Electric (kWh/yr)		7,658		(7,658)	
Total Heating Costs	$ 1,311	$ 1,935	$ 171	$ (624)	$ (795)
Implied Seasonal COP				2.3	1.9

Summary Statistics	
0.55	Htg therms per sq ft per year
43.4	Htg MBtu per sq ft per year
69%	Reduction in Htg Fuel Use
6,908	Measured HP Electric (kWh/yr)
90%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

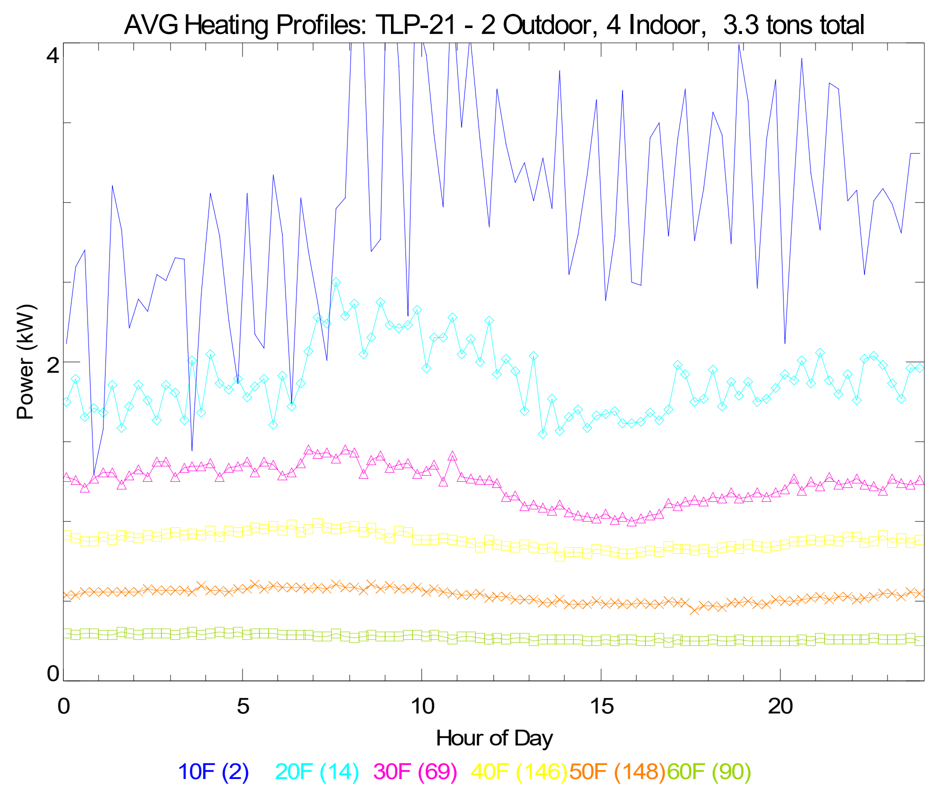


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

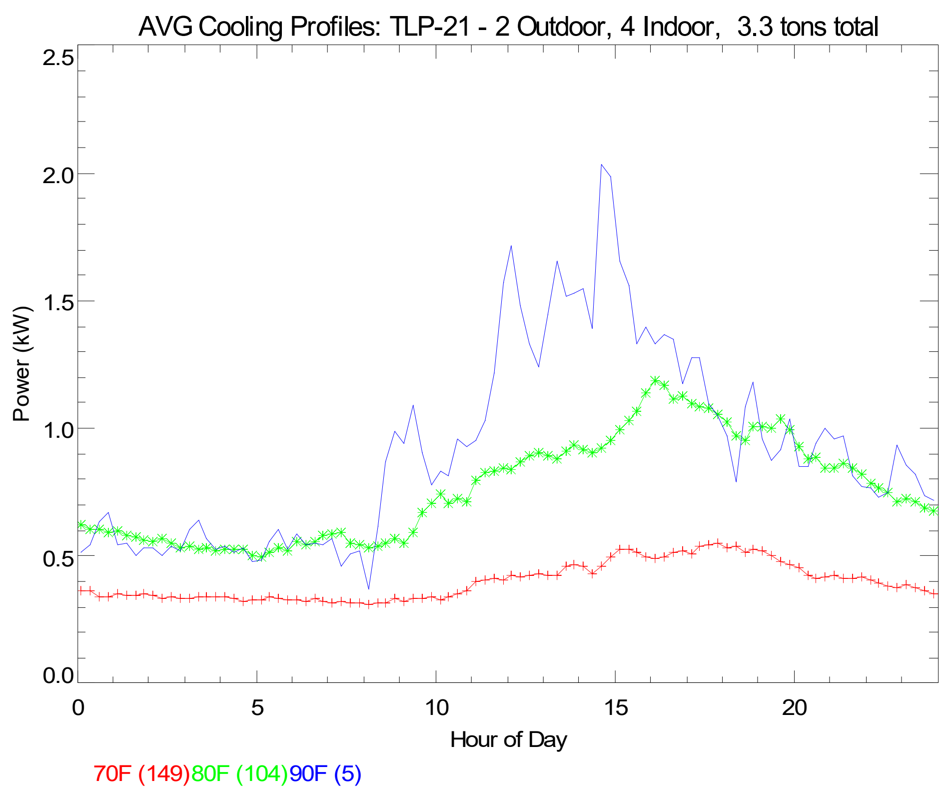


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

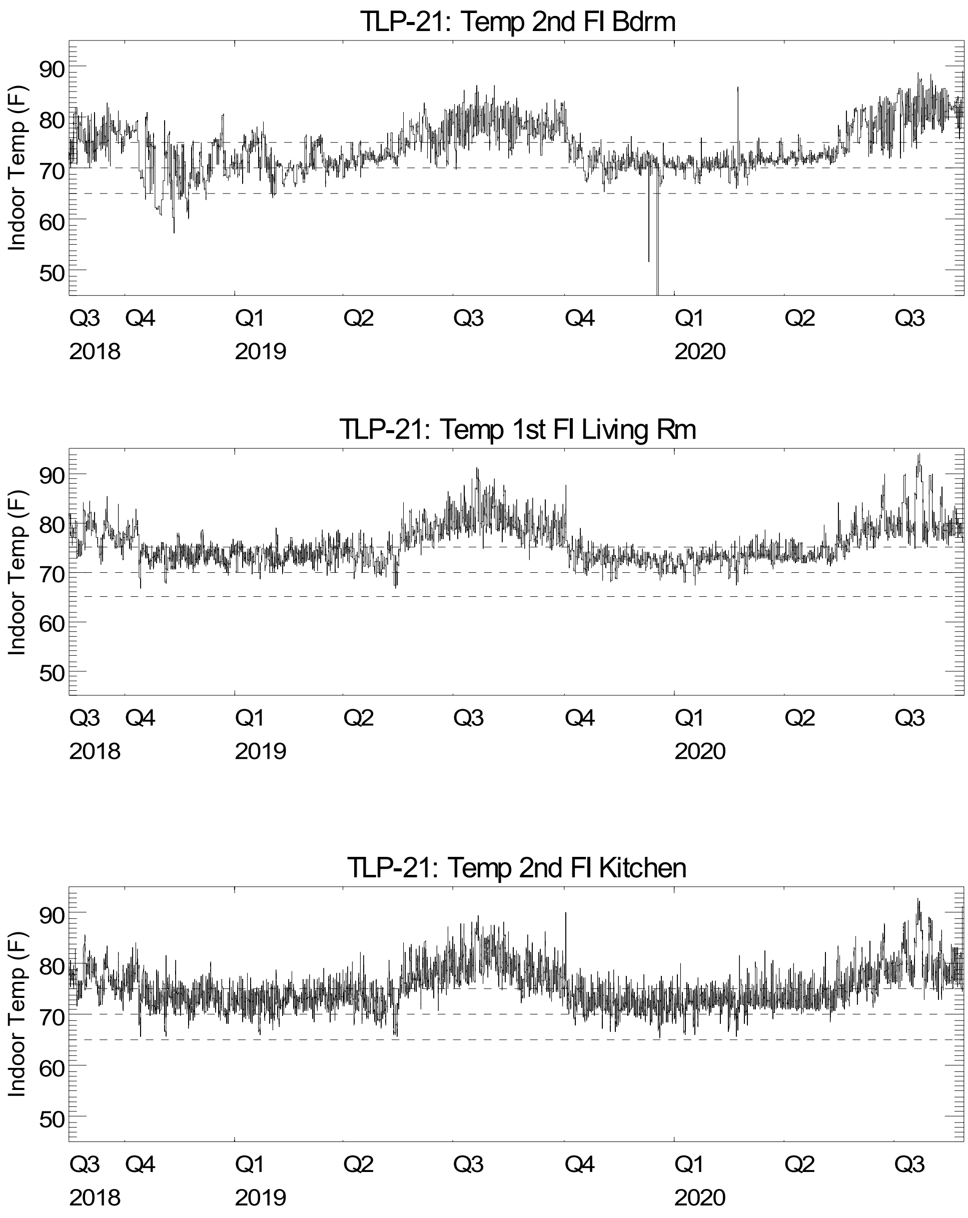


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 23 Savings Analysis

This 2,792 sq ft single-family home originally used an oil boiler with conventional baseboard radiation. Two electric heat pumps with a total capacity of 6 tons were added to the home in early 2018. The oil boiler remained in place as backup and to assist with heating on the coldest days. DHW was switched from the oil boiler to an electric tank. Monitoring equipment was installed on April 10, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, insulation) implemented that were projected to save 351 gallons of oil per year. Table 1 summarizes the proposed envelope measures, which were all implemented.

Table 1. Summary List of Proposed and Final Envelope Savings

Measure	**Proposed Details**	**Final Details**
Air Sealing	Reduce overall air leakage of heated area from 2,373 CFM50 to 1,750 CFM 50 SAVINGS: $92 (23 gallons)	Same
Attic floor & knee wall	Upgrade 709 sq ft of existing ceiling to Gyp Bd, 2x8 16" OC, 8" cellulose, R25	Same
Exterior wall insulation	Upgrade 2,865 sq ft of existing wall to Gyp Bd 2x4 16" OC cellulose, 1" wood, R12	Same
3rd floor sloped ceiling	Upgrade 249 sq ft of existing sloped roof to 2x6 16" OC, 5.5" cellulose, 0.5" wood, asphalt roofing R18	Same
All Insulation	SAVINGS: $1,326 (328 gallons)	Same

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps as well as the runtime for the oil boiler. In March 2019 there was short period where heat pump use dropped and boiler use increased. Otherwise HP use was fairly consistent.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	Boiler (hrs)
Apr-18	69%	145.8	124.0	21.8	0.2
May-18	100%	100.5	52.6	47.8	0.3
Jun-18	100%	279.6	122.6	157.1	-
Jul-18	100%	644.5	318.5	326.0	0.7
Aug-18	100%	701.9	356.2	345.8	-
Sep-18	100%	336.1	144.2	191.9	-
Oct-18	100%	185.8	73.0	112.8	-
Nov-18	100%	590.0	402.4	187.6	2.3
Dec-18	100%	820.2	580.4	239.8	-
Jan-19	100%	1,440.4	1,046.9	393.6	3.0
Feb-19	100%	1,067.6	760.3	307.3	13.3
Mar-19	100%	499.4	346.3	153.2	44.2
Apr-19	100%	126.9	95.2	31.7	-
May-19	100%	65.4	26.3	39.0	-
Jun-19	9%	14.6	0.1	14.5	-
Annual	100%	6,792.9	4,298.6	2,494.6	63.8
Summer (Jun-Sep)		1,962.1	-	-	-
Winter (Oct-May)		4,830.8	4,298.6	2,494.6	63.8

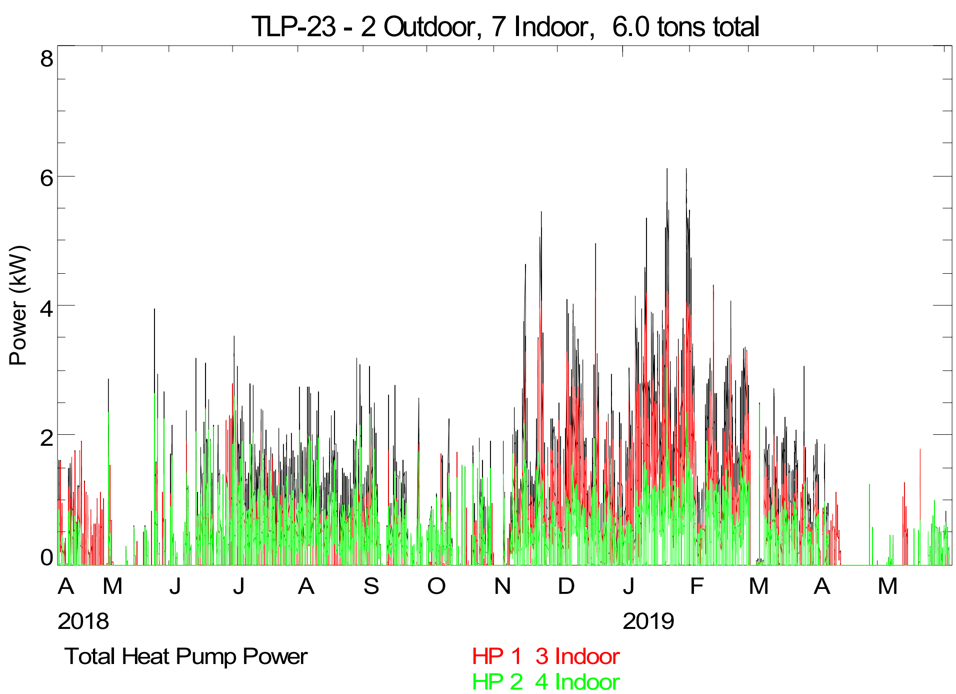


Figure 1. Plot of Power Use for All Heat Pumps at Site

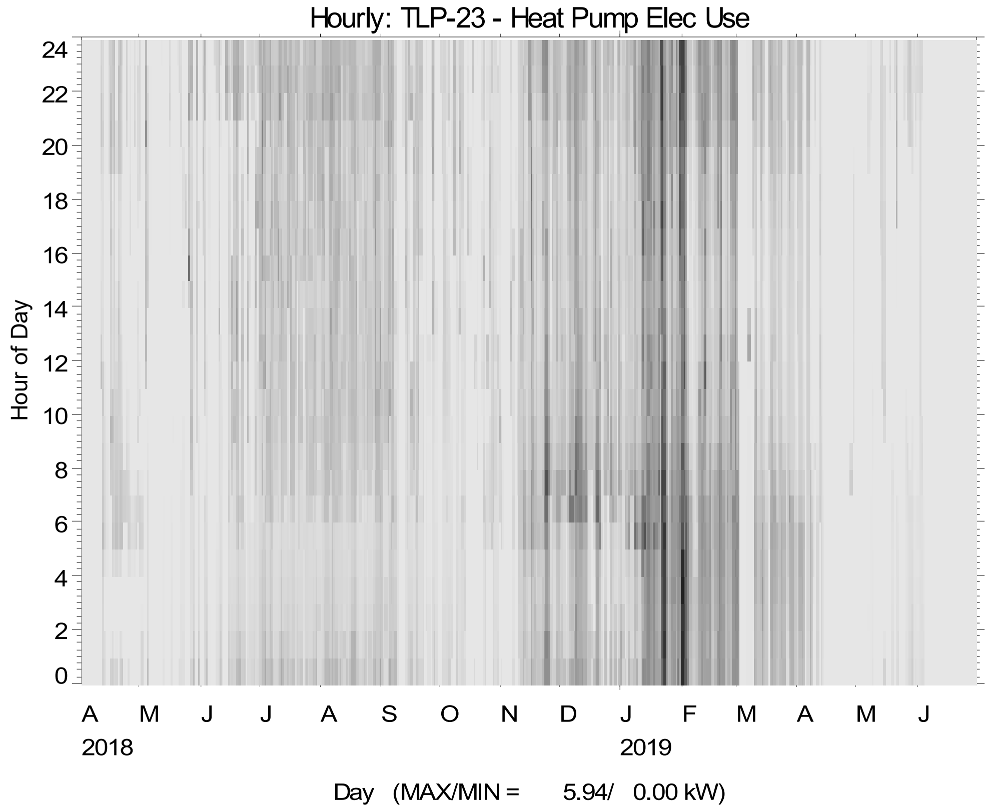


Figure 2. Shade Plot of Total Heat Pump Power

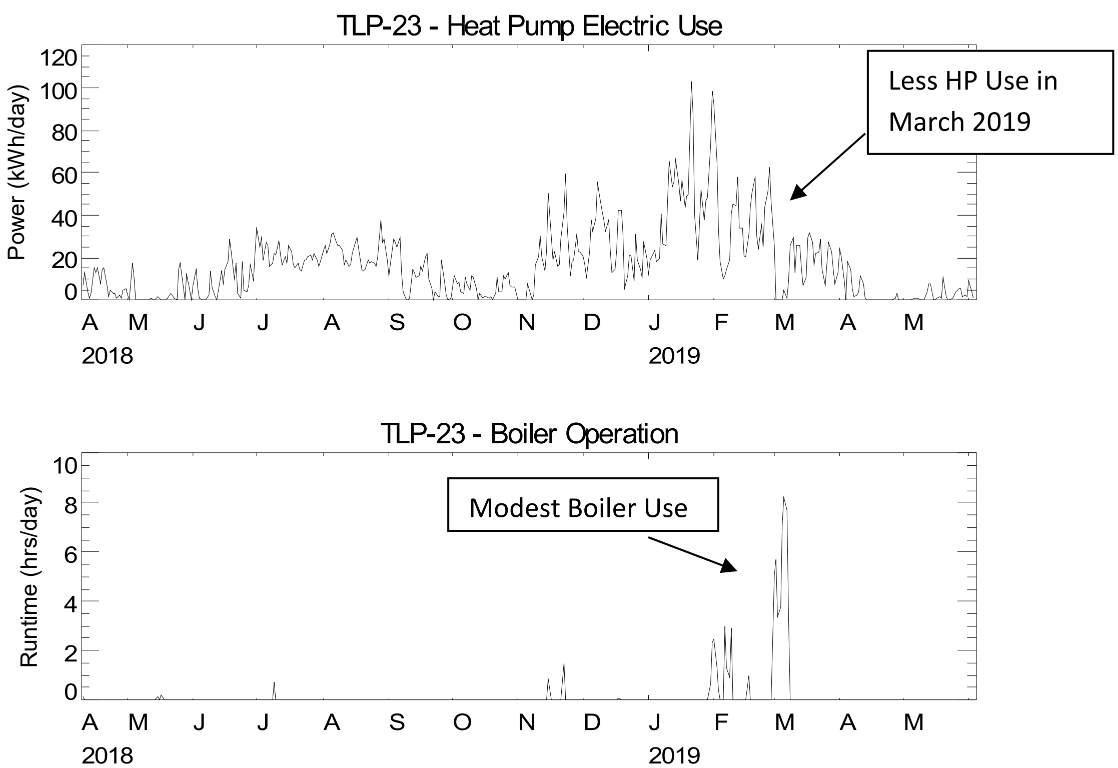


Figure 3. Plot of Daily Total HP Electric Use (and Boiler Operation)

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year.

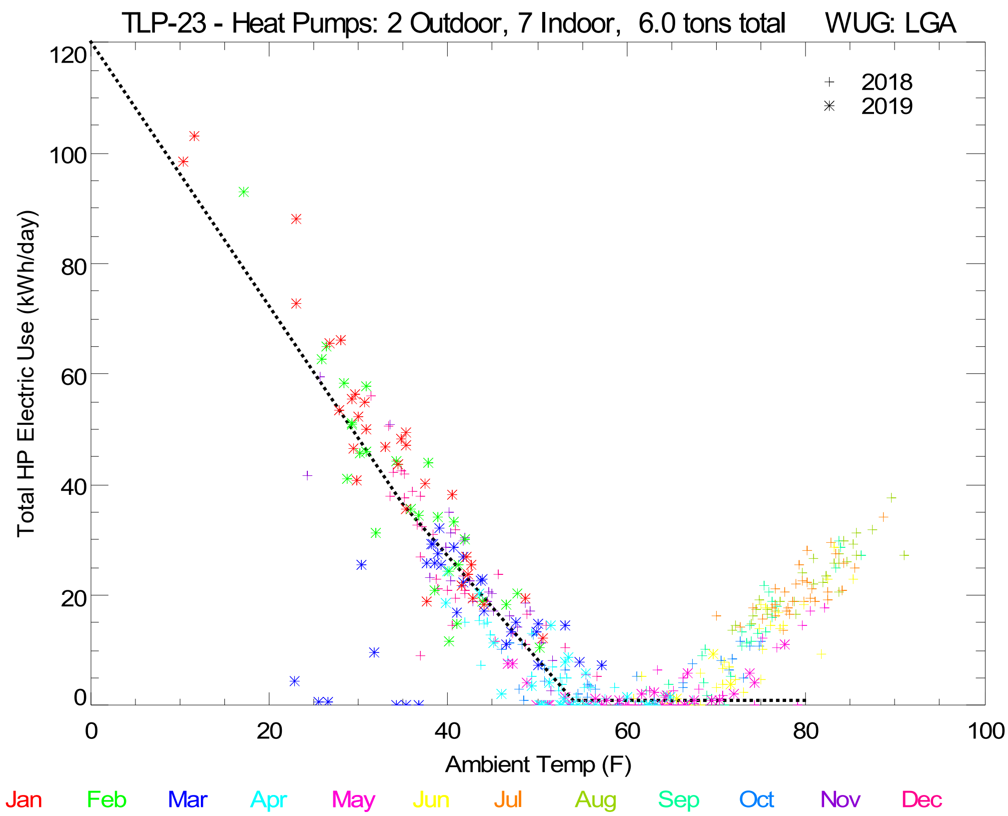


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the correlation between daily boiler runtime and the daily average ambient temperature from LGA. The same colors and symbols were used to represent months and years as described above for Figure 4. A significant change in operation is apparent for March 2019.

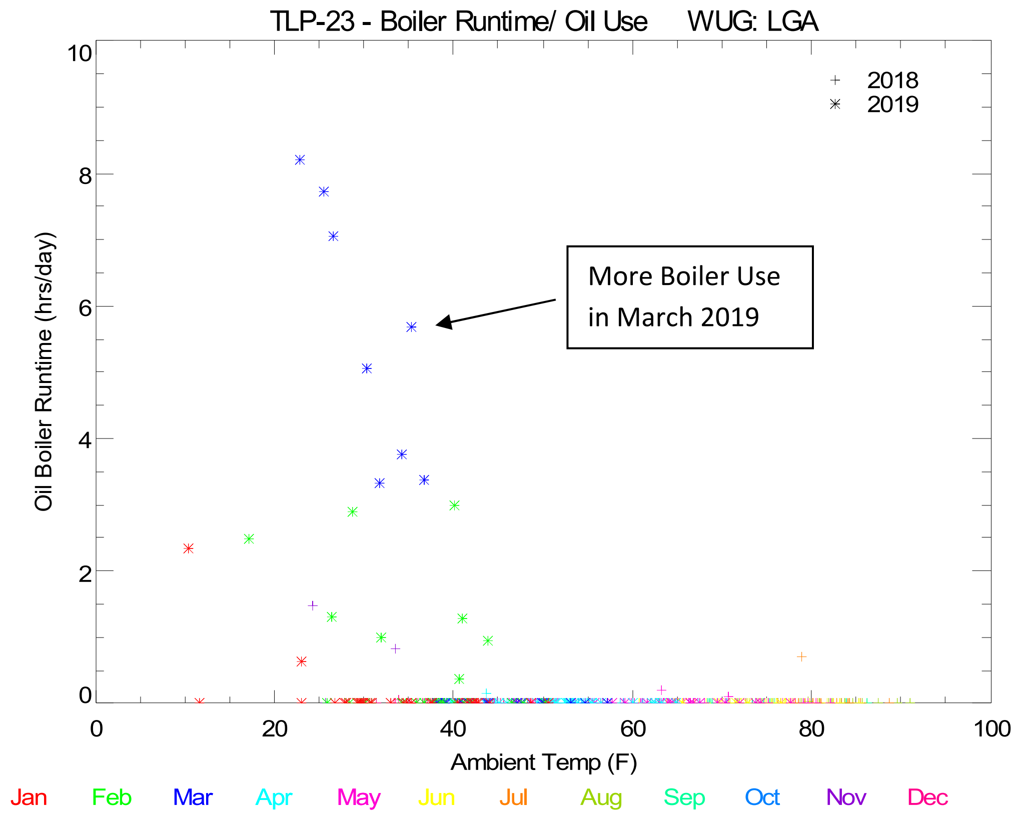


Figure 5. Daily Boiler Runtime versus Outdoor Temperature (from LGA)

Figure 6 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. The data show there was almost no post-retrofit oil consumption in 2018, though the boiler runtime plot (Figure 5) did show boiler operation later in March 2019. DHW was converted to electric at this house, so in the analysis we assume the post retrofit period had same baseline summer use as in the pre-retrofit period.

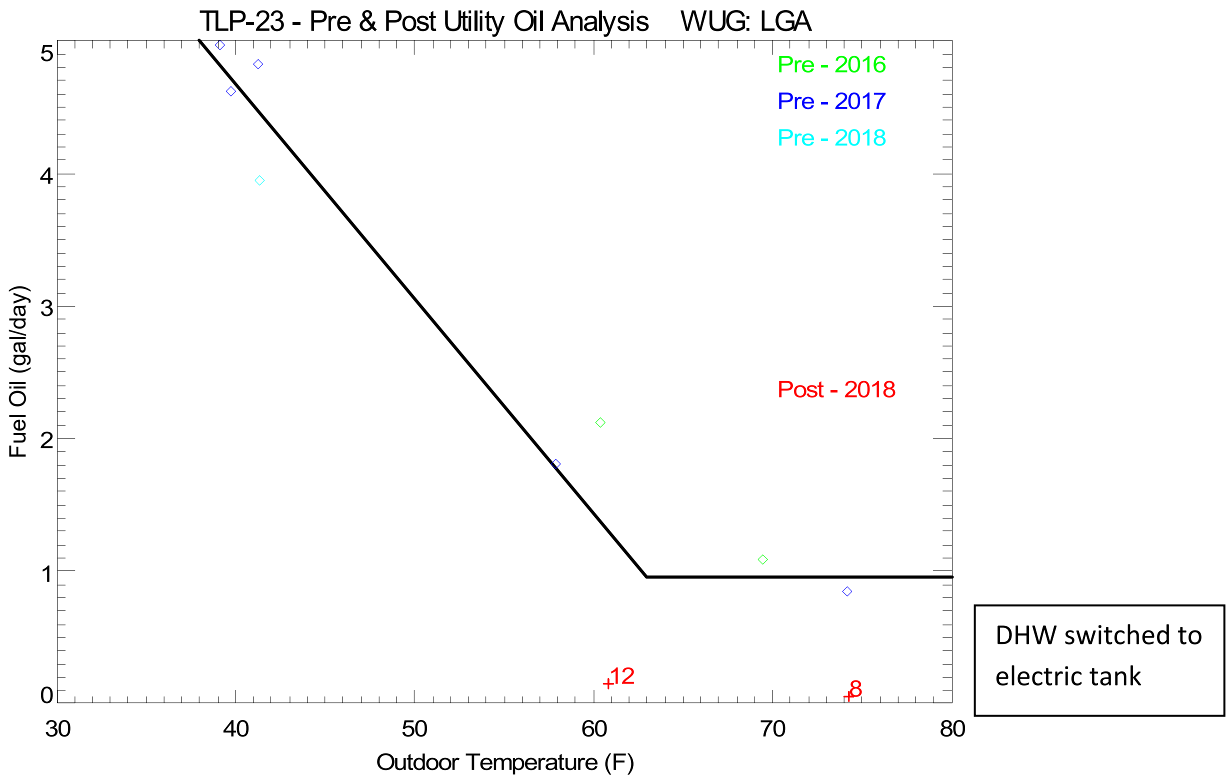


Figure 6. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 7 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 8 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE:	TLP-23	WEATHER:	New_York	$ 0.20	per kWh
FUEL:	Oil			$ 2.447	per gal

Floor Are: 2792

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	15.6	0.0	185.6	1.0	2.2	38.2	39.4	0.1
-22.5	0	14.8	0.0	173.7	1.0	2.3	36.2	37.1	0.1
-17.5	0	14.0	0.0	161.8	1.0	2.3	34.2	34.7	0.1
-12.5	0	13.2	0.0	149.8	1.0	2.3	32.2	32.3	0.1
-7.5	0	12.4	0.0	137.9	1.0	2.4	30.2	29.9	0.1
-2.5	0	11.6	0.0	126.0	1.0	2.4	28.3	27.5	0.1
2.5	0	10.7	0.0	114.0	1.0	2.4	26.3	25.1	0.1
7.5	11	9.9	0.0	102.1	1.0	2.5	24.3	22.7	0.1
12.5	22	9.1	0.0	90.2	1.0	2.6	22.3	20.4	0.1
17.5	101	8.3	0.0	78.3	1.0	2.7	20.3	18.0	0.1
22.5	167	7.5	0.0	66.3	1.0	2.8	18.4	15.6	0.1
27.5	247	6.7	0.0	54.4	1.0	3.0	16.4	13.2	0.1
32.5	475	5.9	0.0	42.5	1.0	3.3	14.4	10.8	0.2
37.5	855	5.1	0.0	31.8	1.0	3.7	12.4	8.7	0.2
42.5	708	4.3	0.0	22.5	1.0	4.2	10.4	6.8	0.2
47.5	608	3.5	0.0	13.1	1.0	5.4	8.5	5.0	0.3
52.5	880	2.6	0.0	3.8	1.0	12.7	6.5	3.1	0.4
57.5	750	1.8	0.0	1.0	1.0	25.4	4.5	2.5	0.5
62.5	814	1.0	0.0	1.0	1.0	2.3	2.5	2.5	0.9
67.5	723	1.0	0.0	1.0	1.0	0.0	2.3	2.5	1.0
72.5	751	1.0	0.0	1.0	1.0	0.0	2.3	2.5	1.0

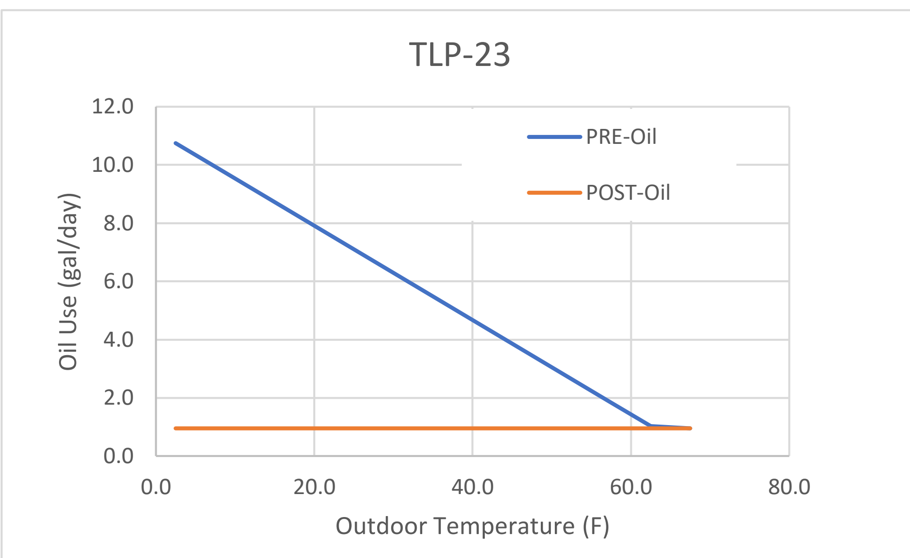


Figure 7. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

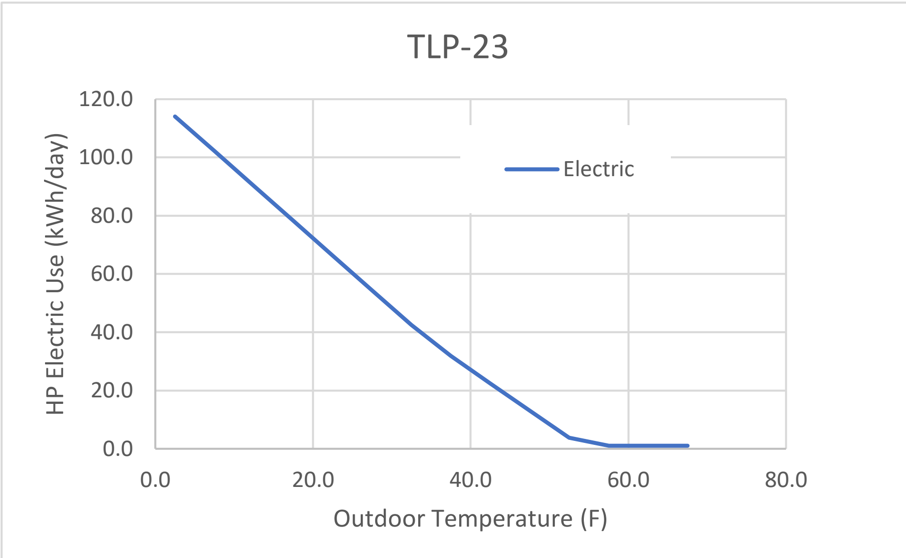


Figure 8. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 646 gallons per year for all improvements. However, if we subtract the oil savings from the envelope improvements, the fuel savings attributable to the heat pumps is 295 gallons per year. The heat pumps are estimated to use 4,685 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 1.8.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-23	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	646	-	351	646	295
HP Electric (kWh/yr)		4,685		(4,685)	
Total Heating Costs	$ 1,582	$ 937	$ 859	$ 645	$ (214)
Implied Seasonal COP				3.9	1.8

Summary Statistics	
0.23	Htg gal per sq ft per year
27.0	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
4,831	Measured HP Electric (kWh/yr)
103%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 9 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 10 shows the same calculation process associated with cooling operation.

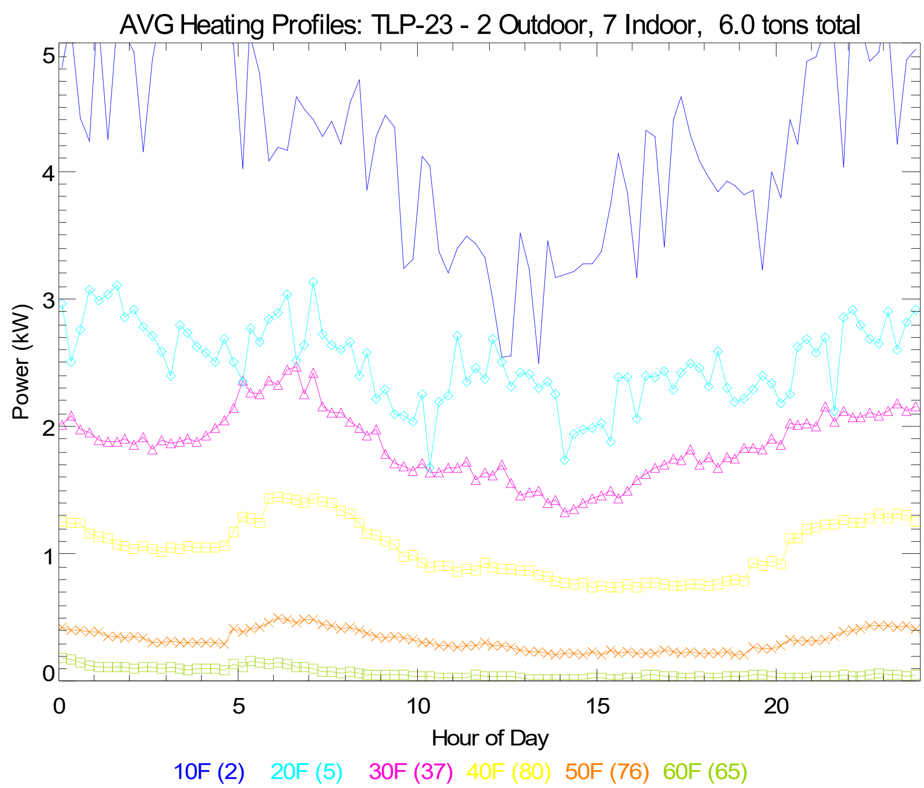


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

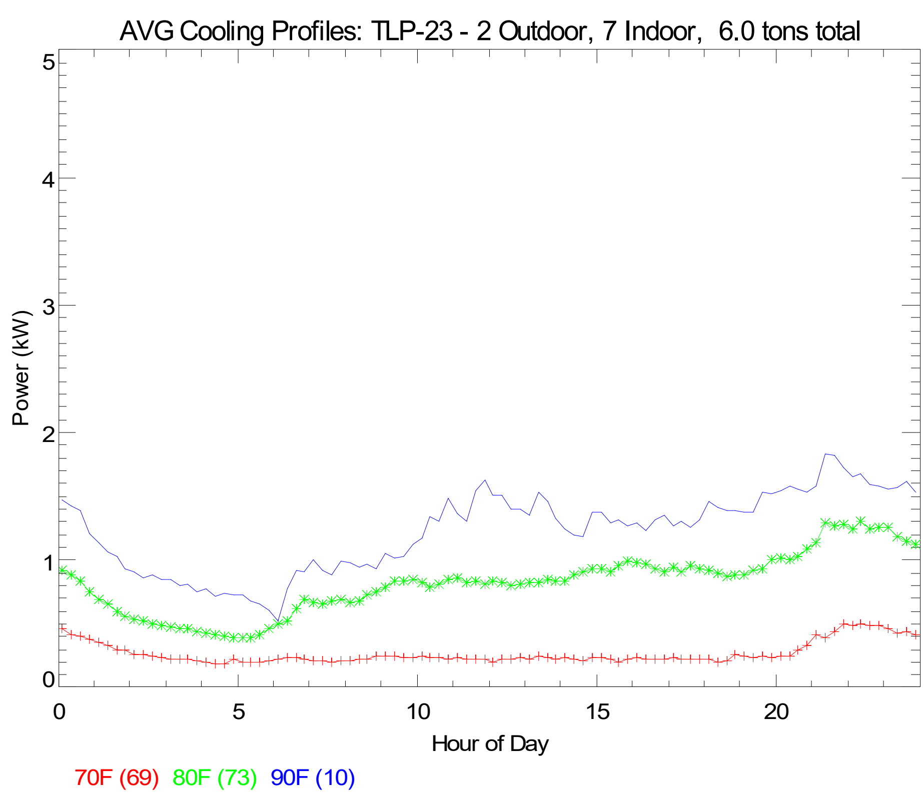


Figure 10. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 11.

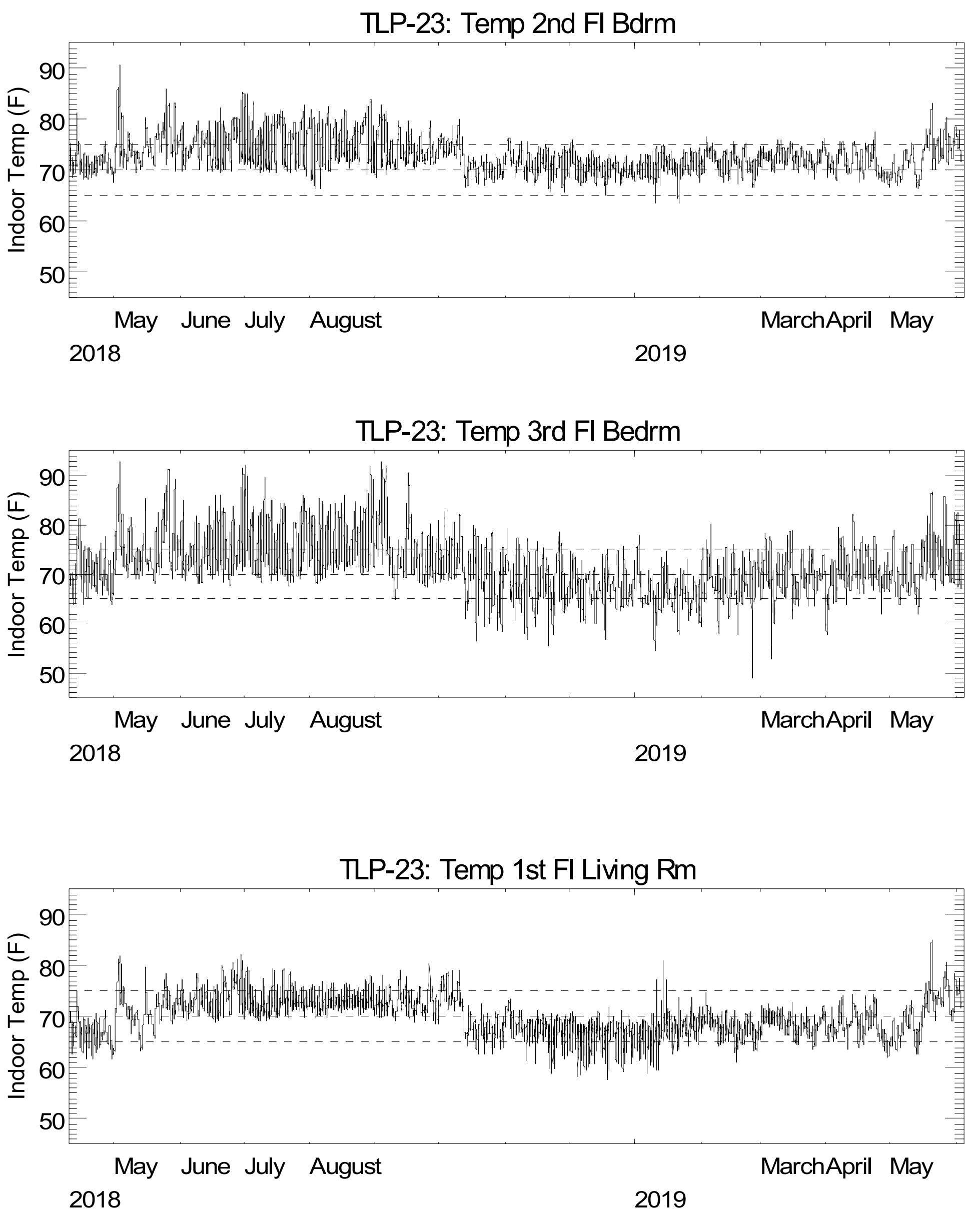


Figure 11. Plot of Space Temperatures at Various Indoor Locations

Site 25 Savings Analysis

This 1,550 sq ft single-family home originally used a gas boiler with conventional baseboard radiation. As part of this project 320 sq ft of living space was added in the basement, to make the total floor area 1,870 sq ft. Two electric heat pumps with a total capacity of 6 tons were added to the home in early 2018. The gas boiler remained in place to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on April 10, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, rim insulation) implemented that were projected to save 149 therms per year. Table 1 summarizes the proposed envelope measures, which were fully implemented.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage of heated area from 4,711 CFM50 to 4,000 CFM 50 SAVINGS: $93 (64 therms)	Completed
Third floor insulation upgrade	Upgrade 304 sqft of existing wall to Gyp Bd, 2x4, 16" OC, 3.5" cellulose, 0.75" wood, 4" brick. R13 Upgrade 513 sqft of existing ceiling to Gyp Bd, 2x6 16" OC, 2" fiberglass, 10" cellulose, R39 SAVINGS: $122 (85 therms)	Completed

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps. The is evidence of constant fan operation over some parts of the winter.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)
Apr-18	68%	314.8	176.5	138.2
May-18	100%	75.5	31.5	44.0
Jun-18	100%	108.2	60.5	47.7
Jul-18	100%	445.2	235.0	210.2
Aug-18	100%	746.0	356.8	389.2
Sep-18	100%	264.2	134.0	130.2
Oct-18	100%	419.6	241.2	178.4
Nov-18	100%	954.6	590.0	364.6
Dec-18	100%	1,375.8	739.7	636.1
Jan-19	100%	1,981.7	1,085.2	896.5
Feb-19	100%	1,761.0	990.5	770.5
Mar-19	100%	1,477.1	780.2	696.9
Apr-19	100%	561.2	195.4	365.8
May-19	100%	315.3	129.3	185.9
Jun-19	100%	489.9	214.8	275.1
Jul-19	100%	960.9	478.9	482.1
Aug-19	40%	310.9	153.0	157.8
Annual	100%	10,170.1	5,440.0	4,730.1
Summer (Jun-Sep)		1,563.6	786.3	777.3
Winter (Oct-May)		8,606.5	4,653.7	3,952.8

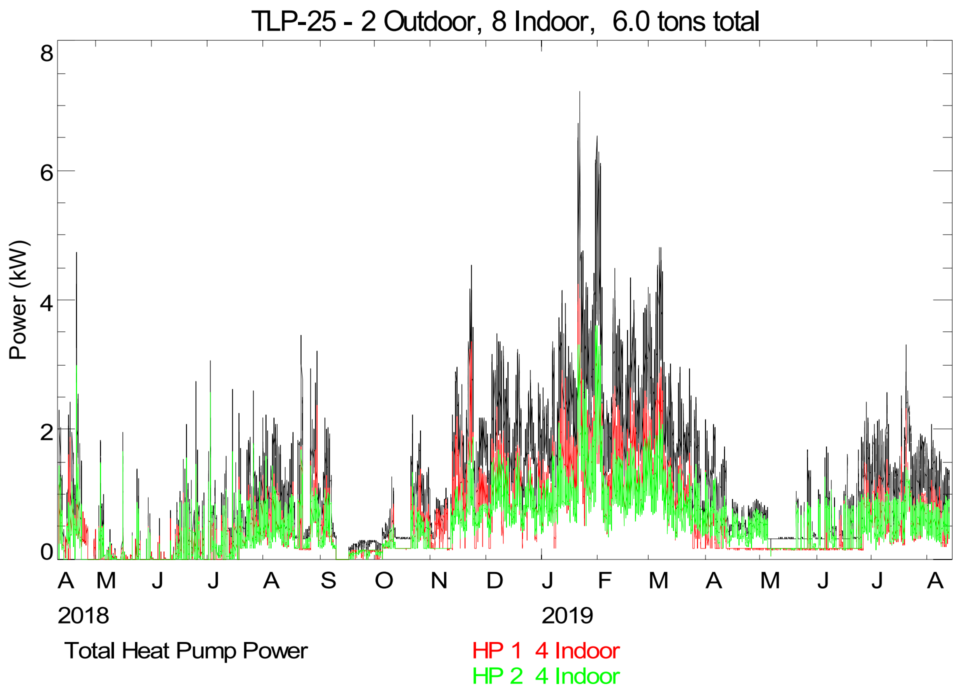


Figure 1. Plot of Power Use for All Heat Pumps at Site

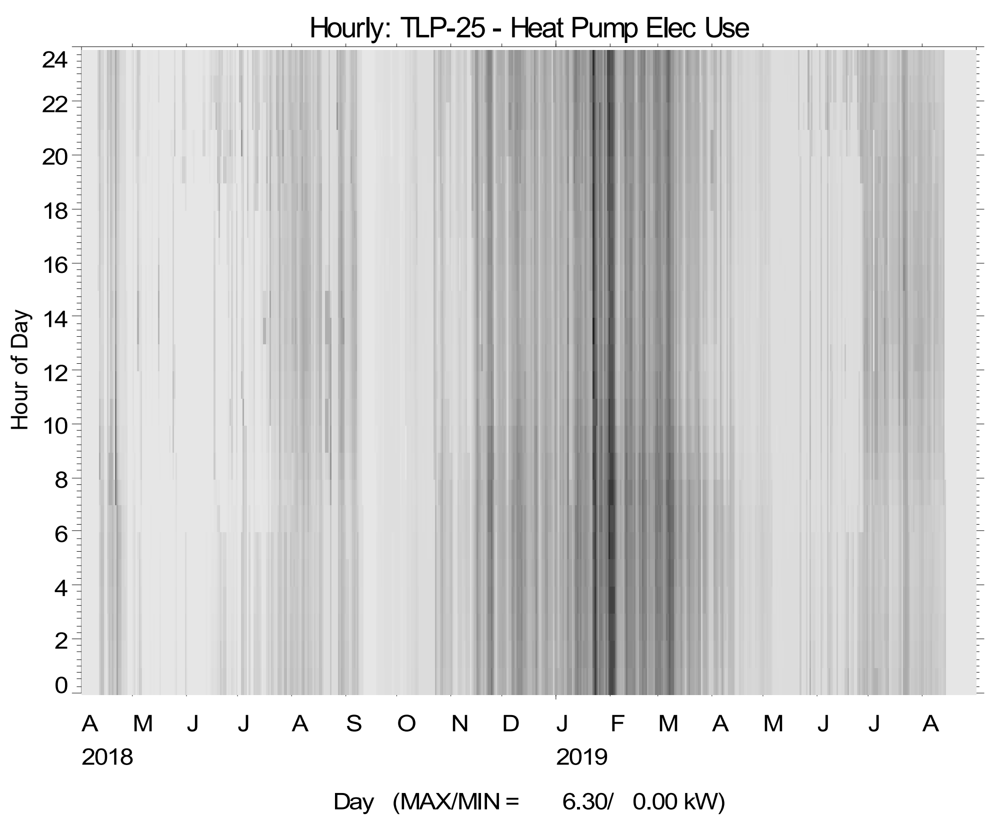


Figure 2. Shade Plot of Total Heat Pump Power

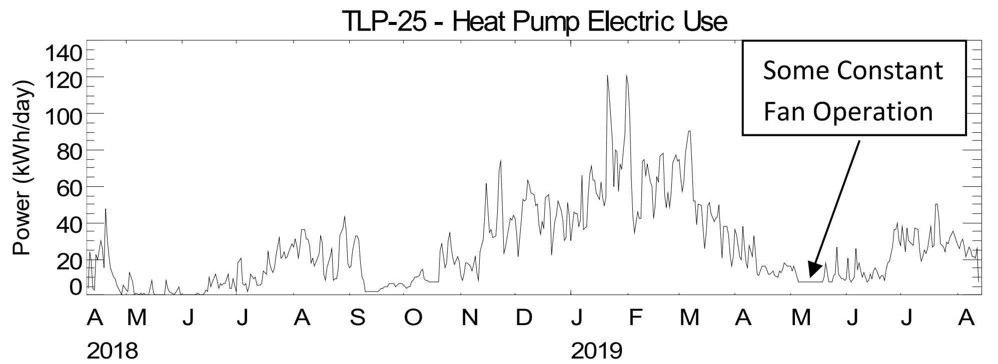


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year.

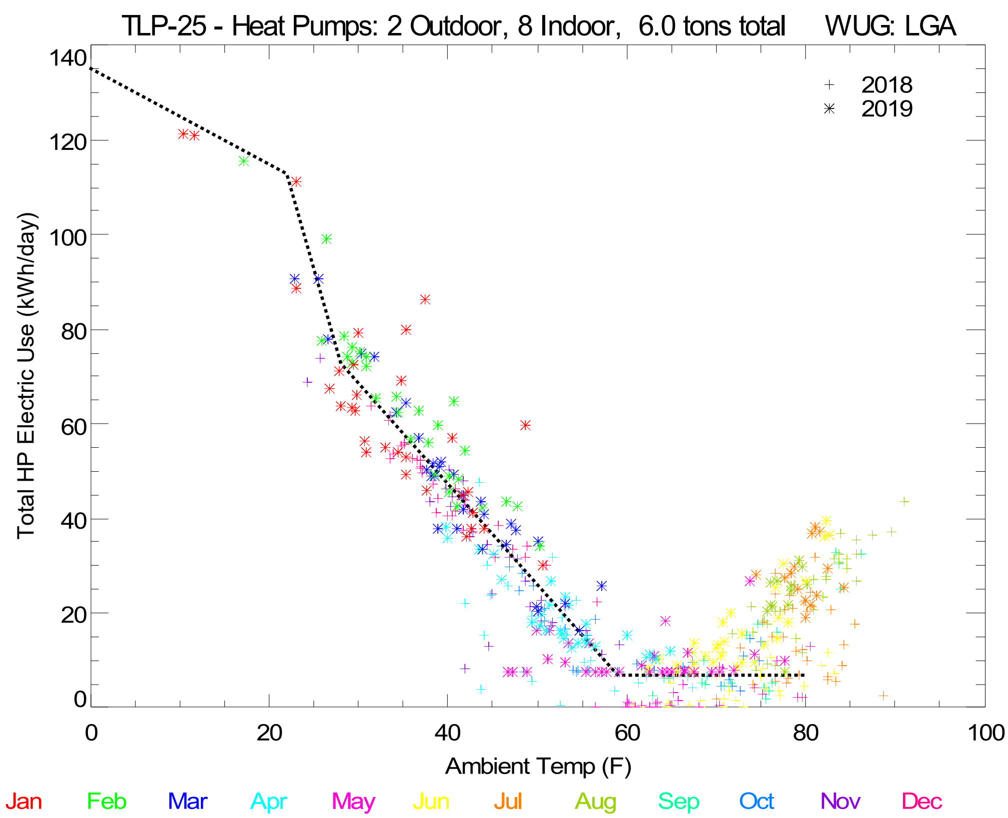


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data from 2018 (data before that year was a different owner and also included unoccupied periods). The dotted line is the best fit to the post-retrofit data which was just due to water heating.

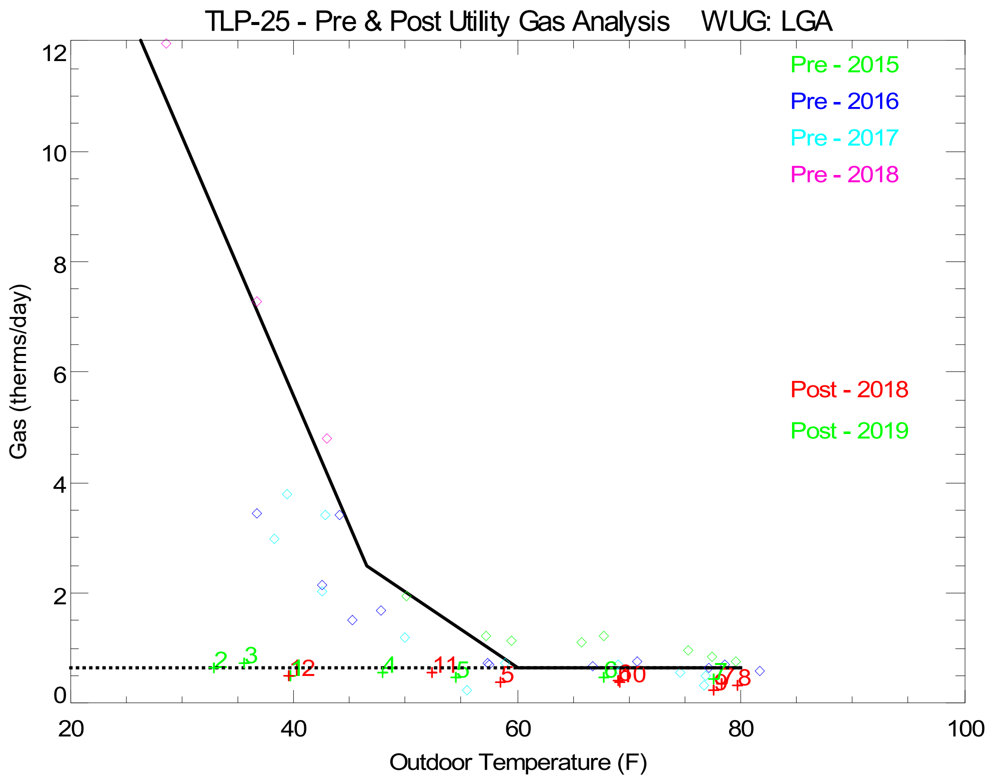


Figure 5. Trend of Gas Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre- and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above (focused on early Winter 2018) were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-25** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Gas** $ 1.403 per therm

Floor Are: **1870**

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	37.4	0.7	162.5	0.7	5.0	52.5	33.4	
-22.5	0	35.0	0.7	157.5	0.7	4.8	49.2	32.4	
-17.5	0	32.7	0.7	152.5	0.7	4.6	45.9	31.4	
-12.5	0	30.3	0.7	147.5	0.7	4.4	42.6	30.4	
-7.5	0	28.0	0.7	142.5	0.7	4.2	39.2	29.4	
-2.5	0	25.6	0.7	137.5	0.7	4.0	35.9	28.4	
2.5	0	23.3	0.7	132.5	0.7	3.7	32.6	27.4	
7.5	11	20.9	0.7	127.5	0.7	3.5	29.3	26.4	
12.5	22	18.5	0.7	122.5	0.7	3.2	26.0	25.4	
17.5	101	16.2	0.7	117.5	0.7	2.9	22.7	24.4	
22.5	167	13.8	0.7	109.7	0.7	2.6	19.4	22.8	
27.5	247	11.5	0.7	76.3	0.7	3.1	16.1	16.2	
32.5	475	9.1	0.7	63.4	0.7	2.9	12.8	13.6	
37.5	855	6.7	0.7	52.8	0.7	2.5	9.5	11.5	
42.5	708	4.4	0.7	42.1	0.7	1.9	6.2	9.3	
47.5	608	2.4	0.7	31.5	0.7	1.2	3.3	7.2	
52.5	880	1.7	0.7	20.8	0.7	1.1	2.4	5.1	
57.5	750	1.0	0.7	10.2	0.7	0.7	1.4	3.0	
62.5	814	0.7	0.7	7.0	0.7	0.0	0.9	2.3	
67.5	723	0.7	0.7	7.0	0.7	0.0	0.9	2.3	
72.5	751	0.7	0.7	7.0	0.7	0.0	0.9	2.3	

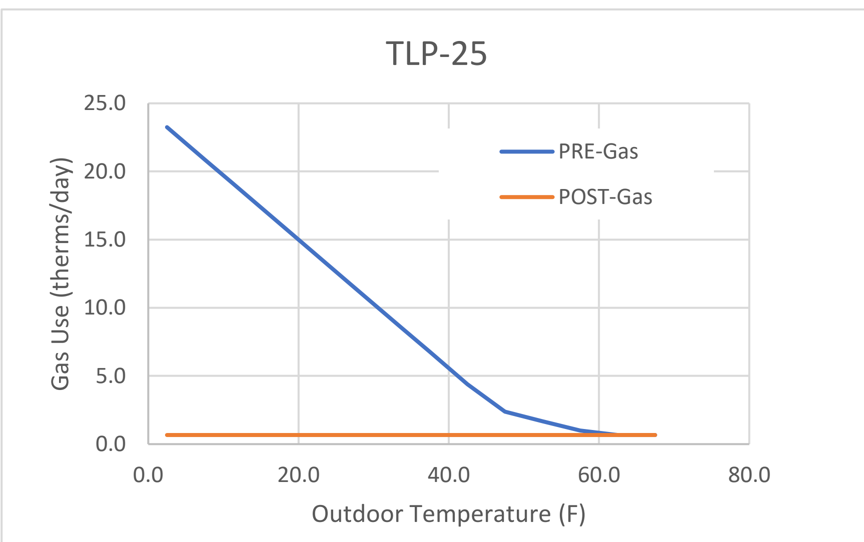


Figure 6. Trend of PRE- and POST-Retrofit Gas Use With Outdoor Temperature for Bin Analysis

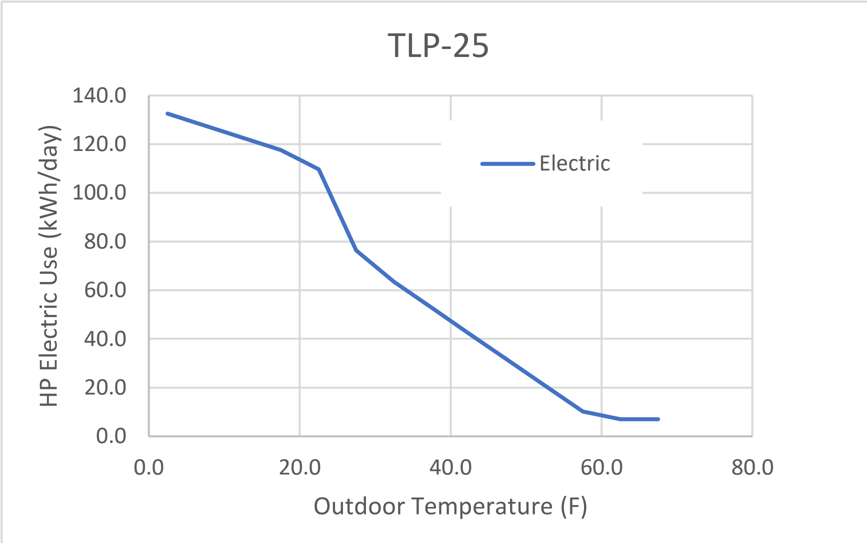


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 880 therms per year for all improvements. However, if we subtract the gas savings from the envelope improvements, the fuel savings attributable to the heat pumps is 731 therms per year. The heat pumps are estimated to use 7,065 kWh per year, excluding the heat pump fans (which ran continuously during the winter). From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.3.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Exclude HP Fan Power

Heating Only TLP-25	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Gas (therms/yr)	880	-	149	880	731
HP Electric (kWh/yr)		7,065		(7,065)	
Total Heating Costs	$ 1,235	$ 1,413	$ 210	$ (178)	$ (387)
Implied Seasonal COP				2.7	2.3

Summary Statistics	
0.47	Htg therms per sq ft per year
37.2	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
8,607	Measured HP Electric (kWh/yr)
122%	of typical year kWh

Note that if we do NOT exclude the fan power, the COP decreases to 1.8.

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

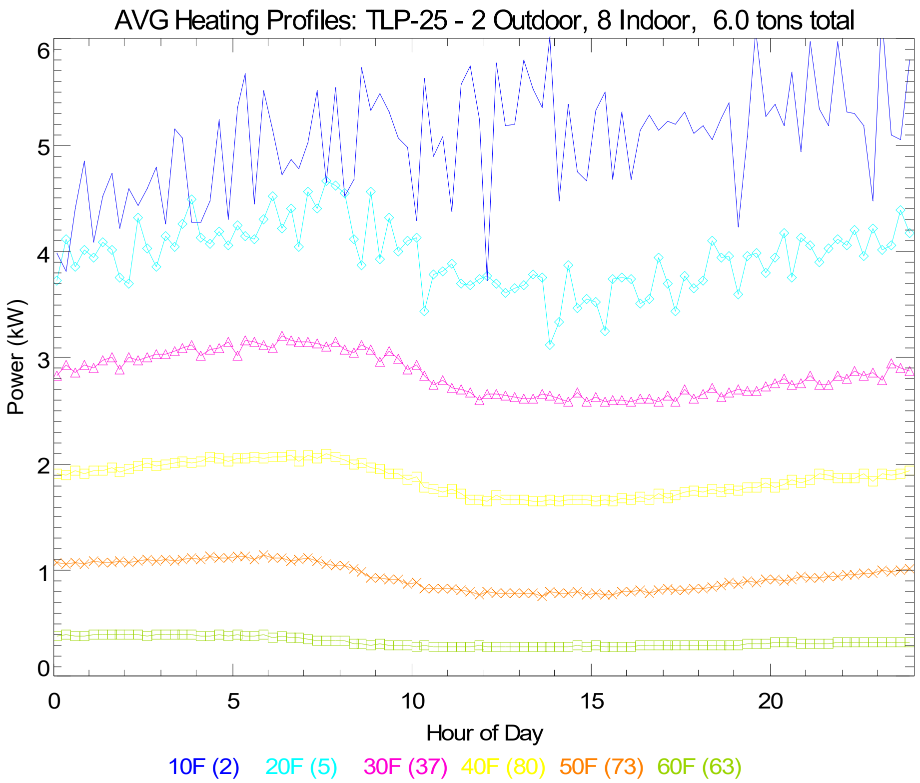


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

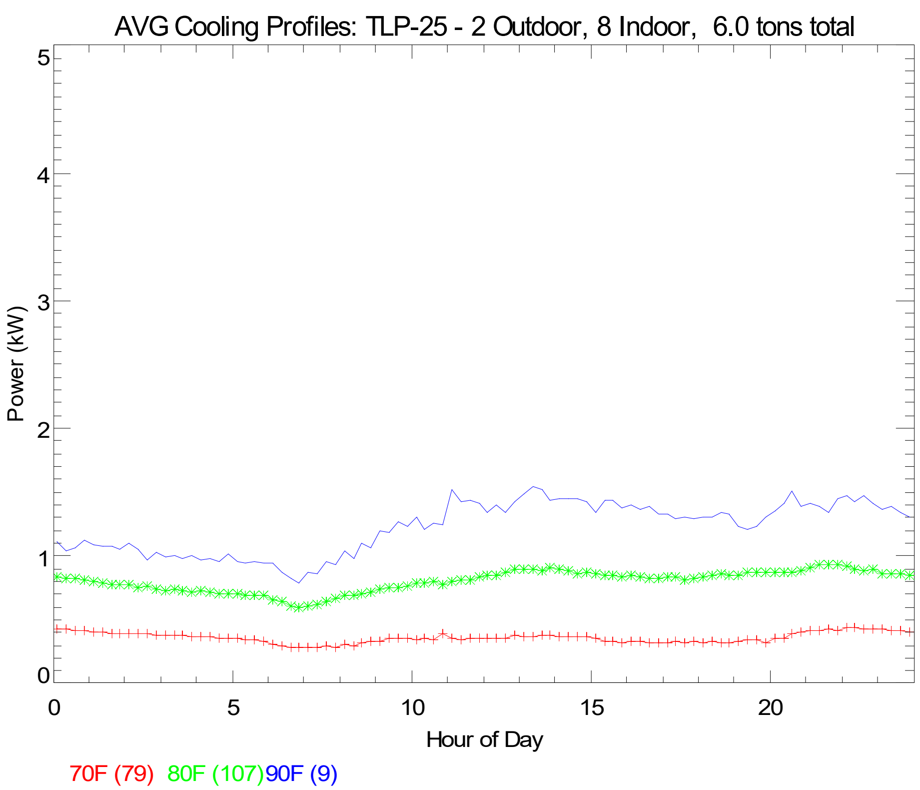


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

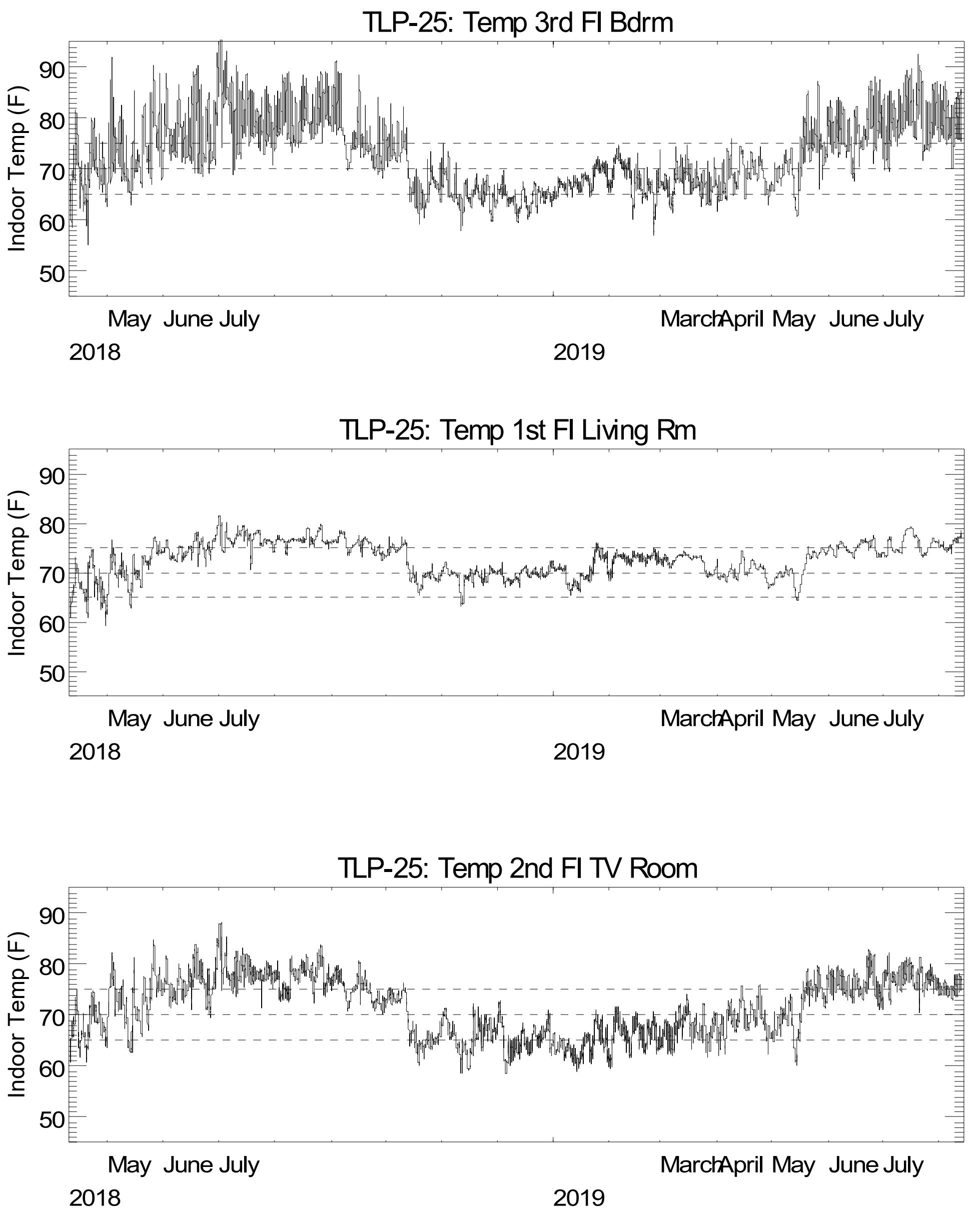


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 31 Savings Analysis

This 2,625 sq ft single-family home originally used a gas boiler with conventional baseboard radiation. Two electric heat pumps with a total capacity of 5 tons were added to the home in mid-2019. The gas boiler was upgraded to a high efficiency boiler to provide backup heating and to supplement the heat pumps on the coldest days. Monitoring equipment was installed on August 14, 2019 to collect data at 15-minute intervals. No weatherization improvements were made at this house.

Table 1 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps.

Table 1. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	Boiler (hrs)
Aug-19	57%	240.9	112.5	128.3	22.6
Sep-19	100%	67.6	25.8	41.8	34.1
Oct-19	100%	36.5	15.9	20.6	21.6
Nov-19	100%	842.0	568.3	273.7	61.2
Dec-19	100%	1,067.2	693.6	373.6	146.1
Jan-20	100%	998.8	675.3	323.5	163.3
Feb-20	104%	927.3	622.6	304.7	138.6
Mar-20	100%	735.6	494.1	241.4	84.5
Apr-20	100%	644.1	458.8	185.3	46.3
May-20	100%	193.9	153.8	40.2	36.5
Jun-20	100%	170.2	74.8	95.4	35.4
Jul-20	100%	584.8	313.6	271.2	37.8
Aug-20	79%	263.9	209.5	54.4	27.5
Annual	98%	6,531.9	4,306.1	2,225.8	832.9
Summer (Jun-Sep)		1,086.5	623.7	462.8	134.8
Winter (Oct-May)		5,445.4	3,682.4	1,763.0	698.1

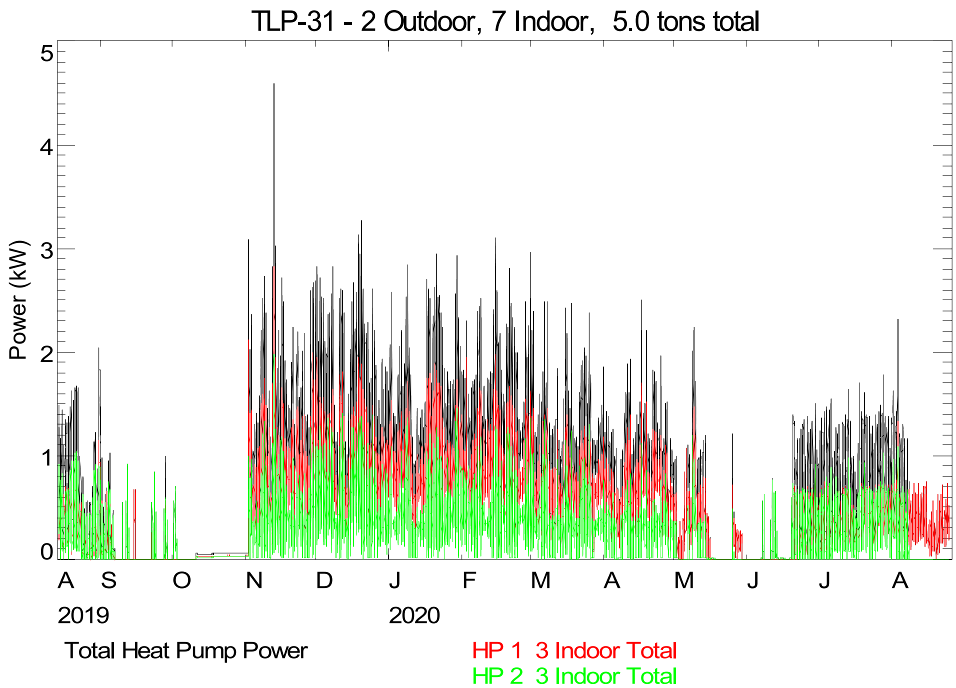


Figure 1. Plot of Power Use for All Heat Pumps at Site

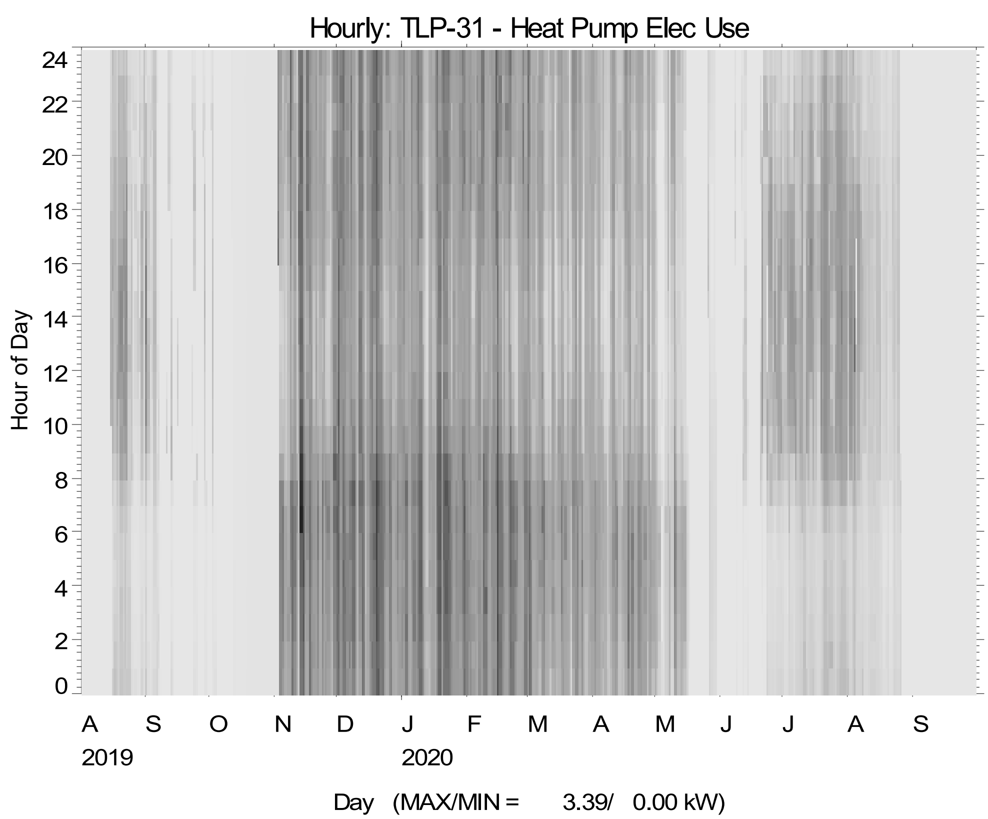


Figure 2. Shade Plot of Total Heat Pump Power

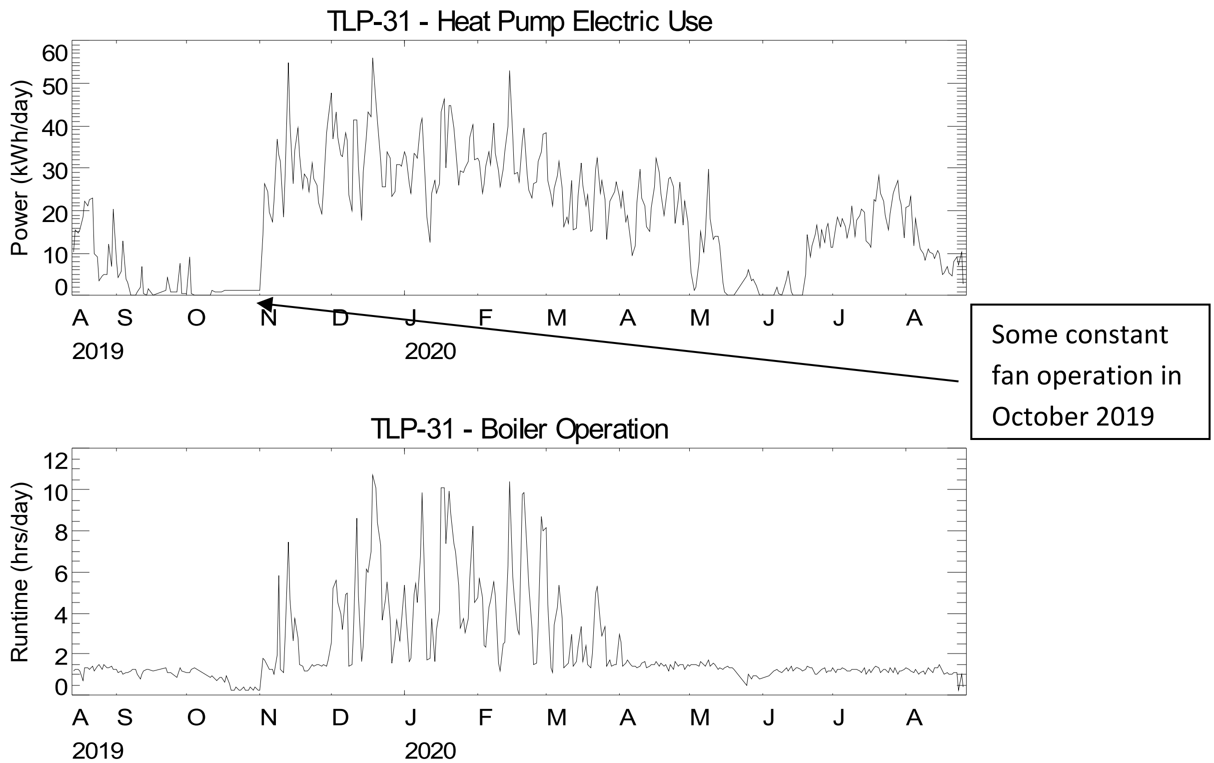


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year.

Figure 5 shows the correlation between daily boiler runtime and the daily average ambient temperature from JFK. The same colors and symbols were used to represent months and years as described above.

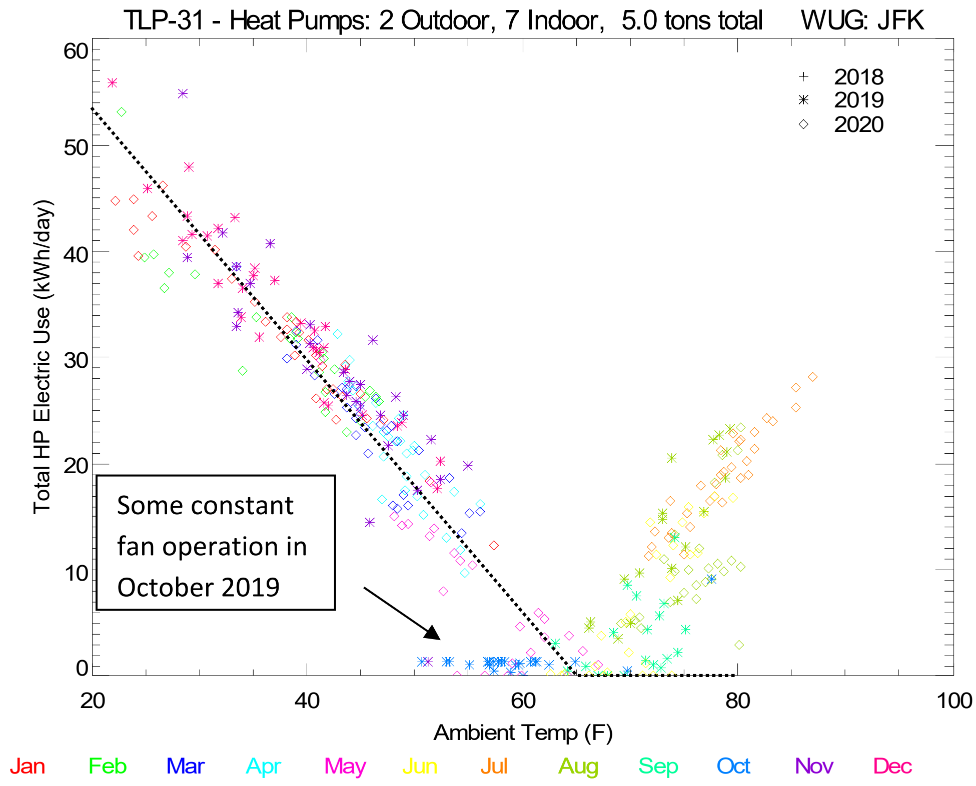


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

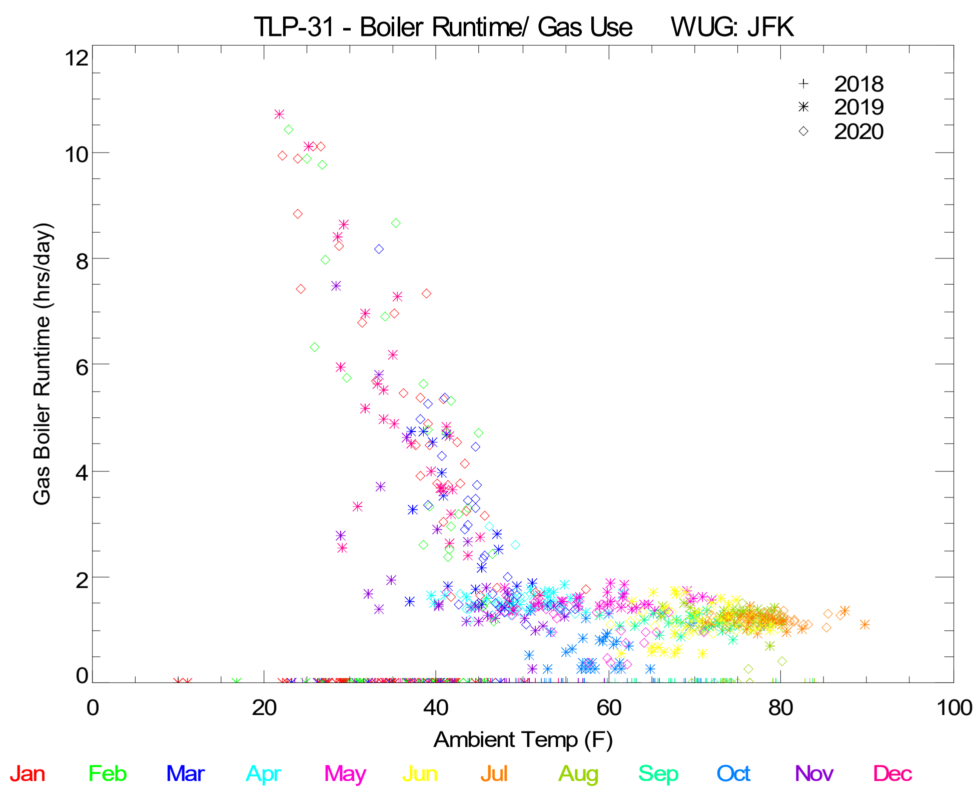


Figure 5. Daily Boiler Runtime versus Outdoor Temperature

Figure 6 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. The dotted line is the best fit to the post-retrofit data.

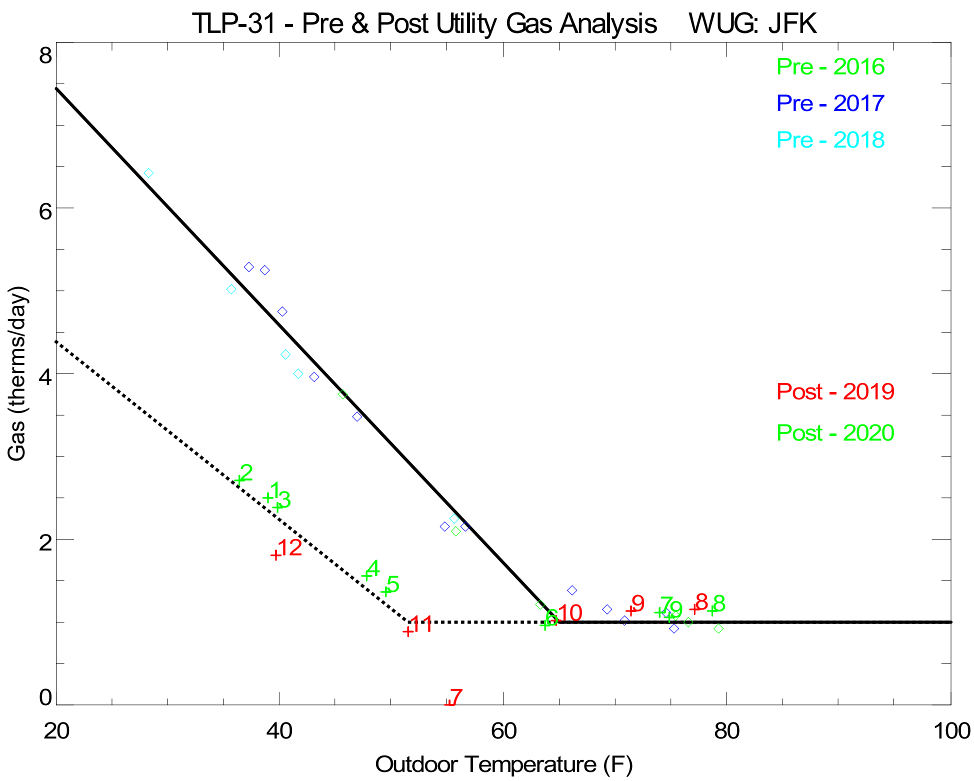


Figure 6. Trend of Gas Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre- and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 7 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 8 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 2. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE:	TLP-31	WEATHER:	New_York	$ 0.20	per kWh
FUEL:	Gas			$ 1.403	per therm

Floor Are: 2625

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	14.26	9.53	109.77	9.5	1.2	20.0	35.3	
-22.5	0	13.54	8.99	103.83	9.0	1.2	19.0	33.4	
-17.5	0	12.83	8.45	97.90	8.4	1.2	18.0	31.4	
-12.5	0	12.11	7.91	91.97	7.9	1.3	17.0	29.5	
-7.5	0	11.39	7.37	86.03	7.4	1.3	16.0	27.5	
-2.5	0	10.68	6.83	80.10	6.8	1.3	15.0	25.6	
2.5	0	9.96	6.29	74.17	6.3	1.4	14.0	23.7	
7.5	11	9.24	5.75	68.23	5.7	1.4	13.0	21.7	
12.5	22	8.53	5.21	62.30	5.2	1.5	12.0	19.8	
17.5	101	7.81	4.67	56.37	4.7	1.5	11.0	17.8	
22.5	167	7.09	4.13	50.43	4.1	1.6	10.0	15.9	
27.5	247	6.38	3.59	44.50	3.6	1.7	8.9	13.9	
32.5	475	5.66	3.05	38.57	3.1	1.9	7.9	12.0	
37.5	855	4.94	2.51	32.63	2.5	2.1	6.9	10.1	
42.5	708	4.23	1.97	26.70	2.0	2.3	5.9	8.1	
47.5	608	3.51	1.43	20.77	1.4	2.8	4.9	6.2	
52.5	880	2.79	1.00	14.83	1.0	3.4	3.9	4.4	
57.5	750	2.08	1.00	8.90	1.0	3.4	2.9	3.2	
62.5	814	1.36	1.00	2.97	1.0	3.4	1.9	2.0	
67.5	723	1.00	1.00	0.00	1.0	0.0	1.4	1.4	
72.5	751	1.00	1.00	0.00	1.0	0.0	1.4	1.4	

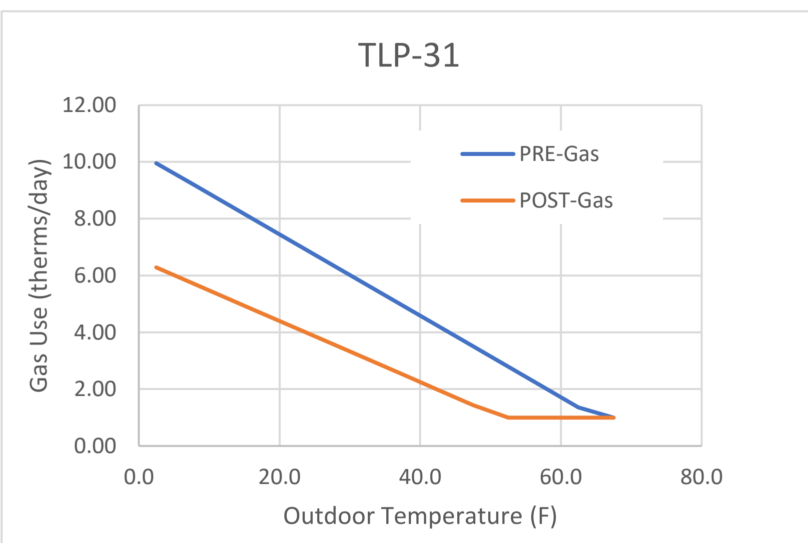


Figure 7. Trend of PRE- and POST-Retrofit Gas Use with Outdoor Temperature for Bin Analysis

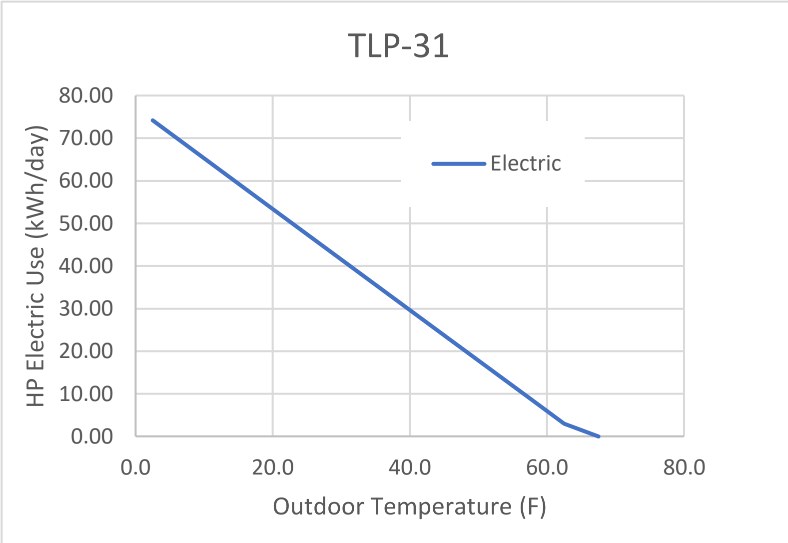


Figure 8. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 3 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 436 therms per year for the heat pumps. The heat pumps are estimated to use 5,297 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.3.

Table 3. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-31	**PRE Retrofit**	**POST Retrofit**	**Envelope Savings**	**ASHP & Env Savings**	**ASHP Savings**
Gas (therms/yr)	640	204	-	436	436
HP Electric (kWh/yr)		5,297		(5,297)	
Total Heating Costs	$ 898	$ 1,346	$ -	$ (448)	$ (448)
Implied Seasonal COP				2.3	2.3

Summary Statistics	
0.24	Htg therms per sq ft per year
19.3	Htg MBtu per sq ft per year
68%	Reduction in Htg Fuel Use
5,445	Measured HP Electric (kWh/yr)
103%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 9 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 10 shows the same calculation process associated with cooling operation.

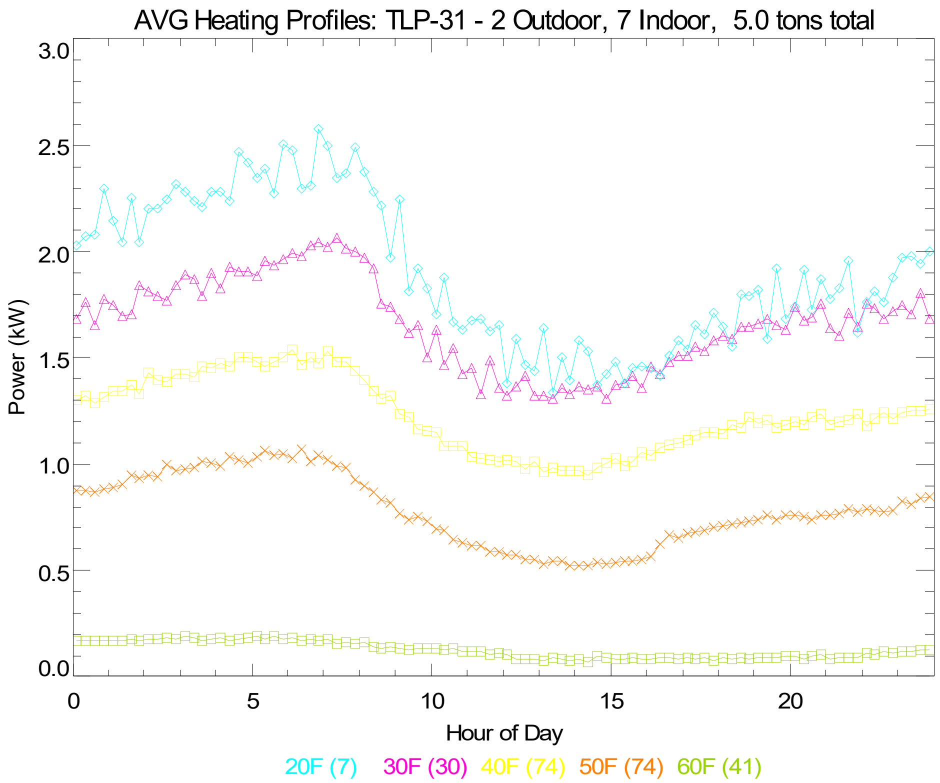


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

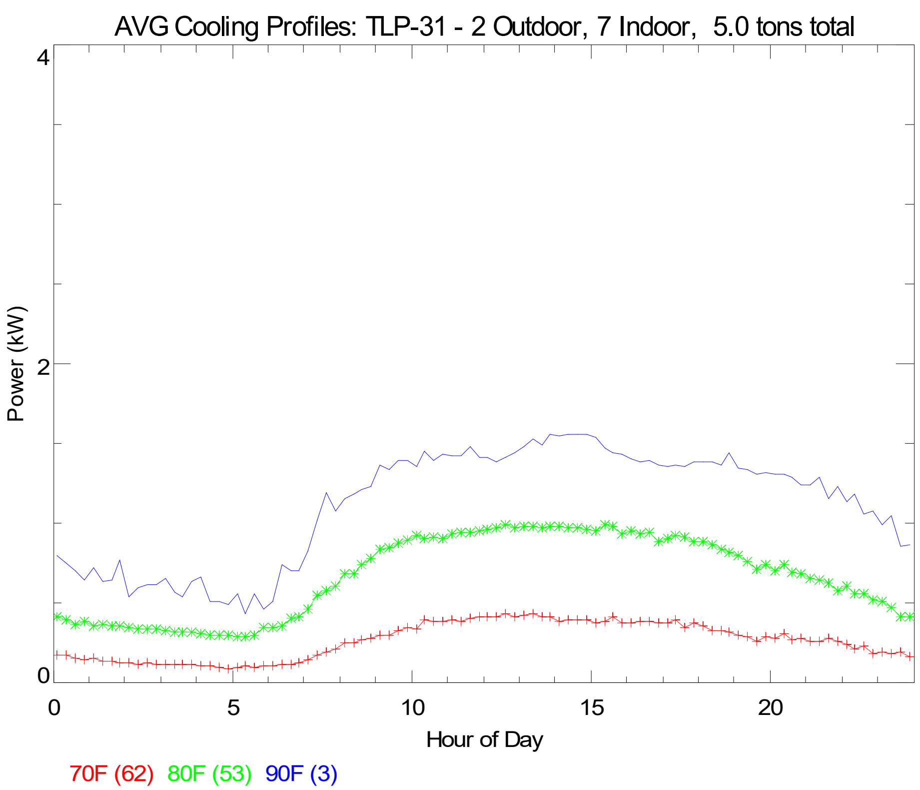
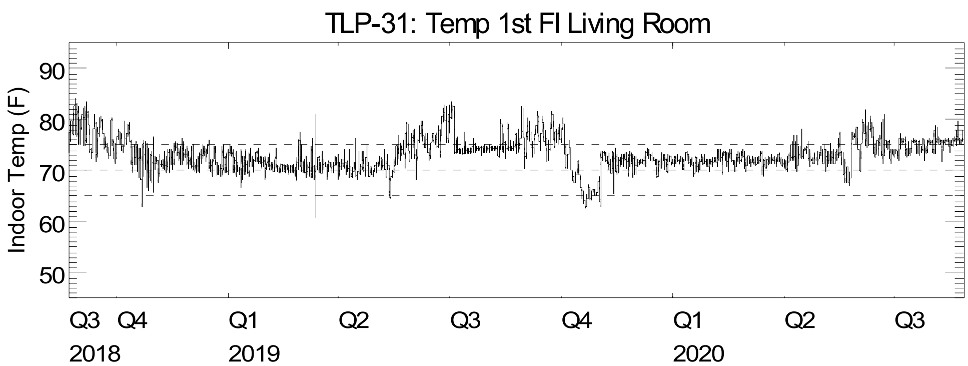
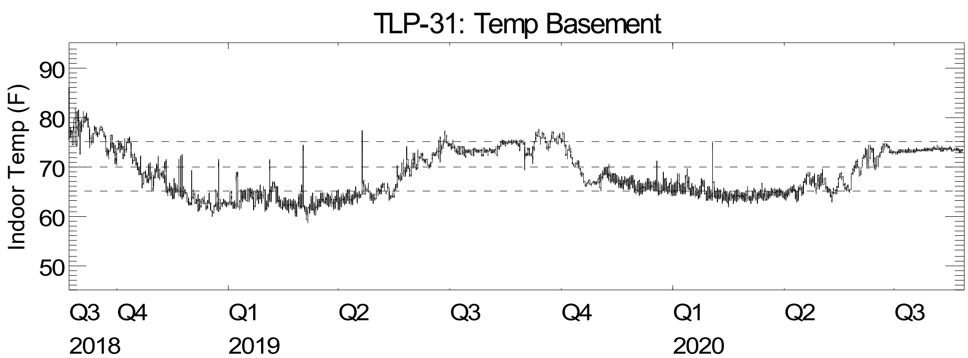


Figure 10. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 11.





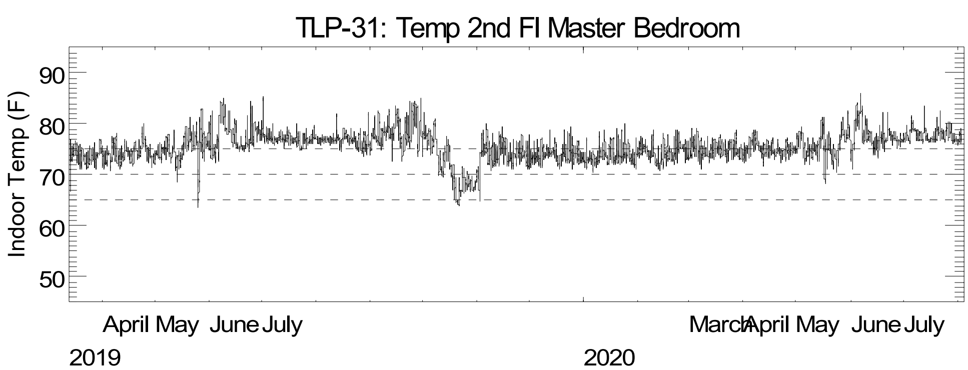


Figure 11. Plot of Space Temperatures at Various Indoor Locations

Site 32 Savings Analysis

This 1,350 sq ft single-family home originally used an oil boiler with conventional baseboard radiation. One electric heat pump with a total capacity of 3 tons were added to the home in mid-2018. The oil boiler was removed. DHW was switched from the oil boiler to an electric tankless unit. Monitoring equipment was installed on August 22, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, rim joist) implemented that were projected to save 244 gallons of oil per year. Table 1 summarizes the proposed envelope measures.

Table 1. Summary List of Proposed and Final Envelope Savings

Measure	Proposed Details	Final Details
Air Sealing	Reduce overall air leakage of heated area from 6,525 CFM50 to 2,320 CFM50 SAVINGS: 244 gallons	Same
Insulation	Insulate Roof rafters with fiberglass and foam board. SAVINGS: unknown	

Note: Air sealing impact determined by assuming 6.8 MBtu/yr Heating reduction per each CFM50 reduction.

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps as well as the runtime for the oil boiler.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)
Aug-18	30%	91.6	91.6
Sep-18	100%	176.6	176.6
Oct-18	100%	249.5	249.5
Nov-18	100%	503.5	503.5
Dec-18	100%	678.7	678.7
Jan-19	100%	961.0	961.0
Feb-19	100%	788.1	788.1
Mar-19	100%	715.9	715.9
Apr-19	100%	228.4	228.4
May-19	100%	130.8	130.8
Jun-19	100%	184.2	184.2
Jul-19	100%	324.9	324.9
Aug-19	100%	269.6	269.6
Sep-19	100%	164.2	164.2
Oct-19	100%	125.0	125.0
Nov-19	100%	499.0	499.0
Dec-19	57%	429.7	429.7
Annual	100%	5,211.2	5,211.2
Summer (Jun-Sep)		955.3	955.3
Winter		4,255.9	4,255.9

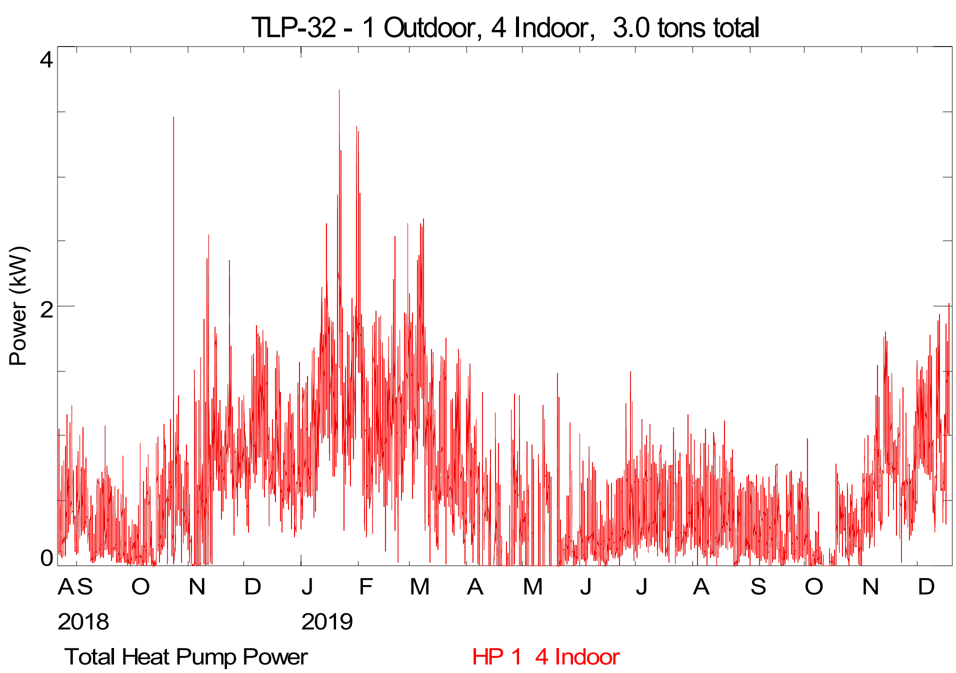


Figure 1. Plot of Power Use for All Heat Pumps at Site

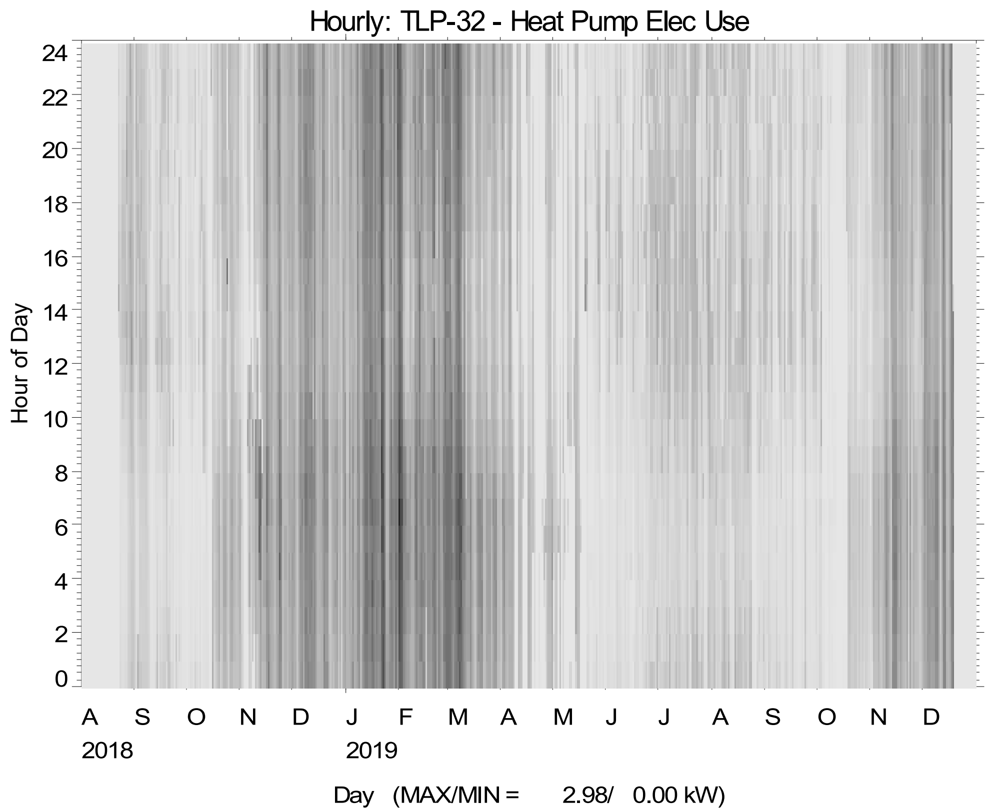


Figure 2. Shade Plot of Total Heat Pump Power

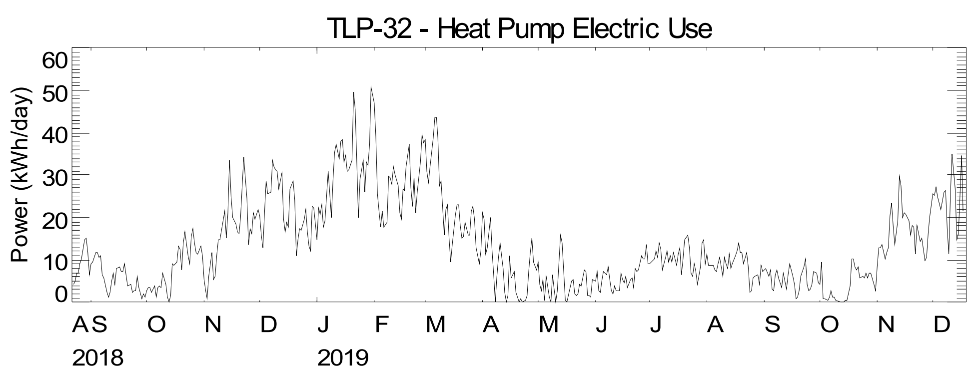


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year.

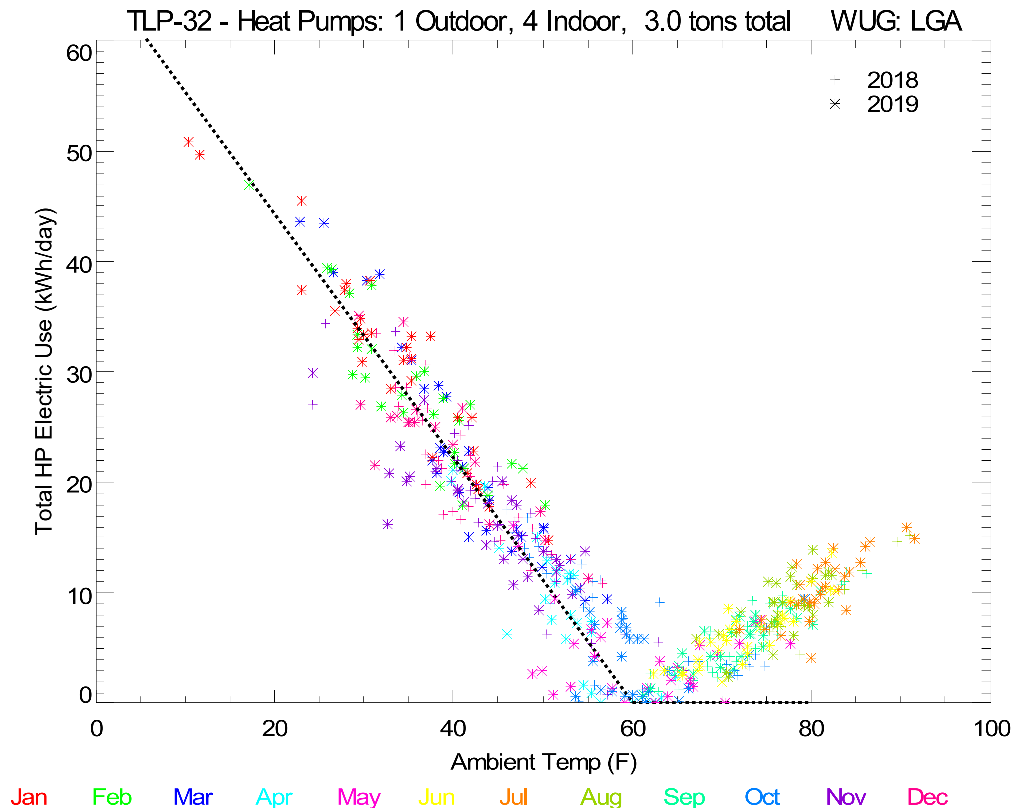


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. There was no post-retrofit oil consumption since the boiler was removed. DHW was converted to electric at this house, so in the analysis we assume the post-retrofit period had same baseline summer use as in the pre-retrofit period.

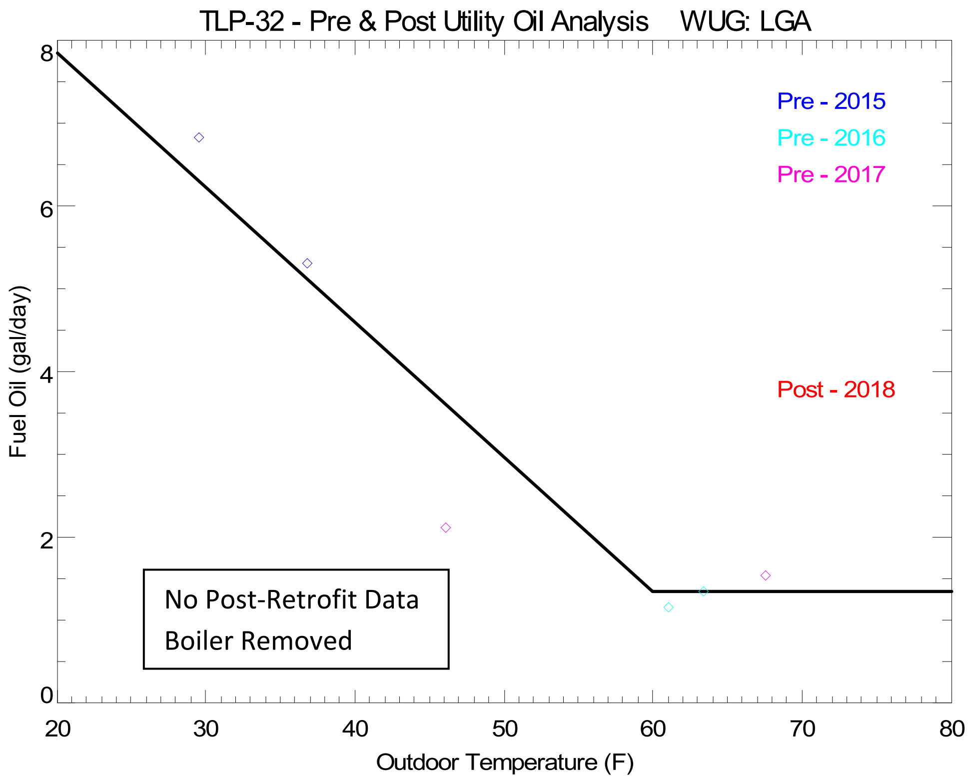


Figure 5. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

Annual Savings Analysis

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE:	TLP-32				WEATHER:	New_York		$ 0.20	per kWh
FUEL:	Oil							$ 2.447	per gal
Floor Are:	1350								

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	15.6	0.0	97.0	1.4	5.0	38.1	22.7	0.1
-22.5	0	14.8	0.0	91.4	1.4	5.0	36.1	21.6	0.1
-17.5	0	13.9	0.0	85.9	1.4	5.0	34.1	20.5	0.1
-12.5	0	13.1	0.0	80.4	1.4	5.0	32.1	19.4	0.1
-7.5	0	12.3	0.0	74.8	1.4	5.0	30.1	18.3	0.1
-2.5	0	11.5	0.0	69.3	1.4	5.0	28.2	17.2	0.1
2.5	0	10.7	0.0	63.7	1.4	5.0	26.2	16.0	0.1
7.5	11	9.9	0.0	58.2	1.4	5.0	24.2	14.9	0.1
12.5	22	9.1	0.0	52.6	1.4	5.0	22.2	13.8	0.1
17.5	101	8.3	0.0	47.1	1.4	5.0	20.2	12.7	0.2
22.5	167	7.4	0.0	41.6	1.4	5.0	18.2	11.6	0.2
27.5	247	6.6	0.0	36.0	1.4	5.0	16.2	10.5	0.2
32.5	475	5.8	0.0	30.5	1.4	5.0	14.2	9.4	0.2
37.5	855	5.0	0.0	24.9	1.4	5.0	12.3	8.3	0.3
42.5	708	4.2	0.0	19.4	1.4	5.0	10.3	7.2	0.3
47.5	608	3.4	0.0	13.9	1.4	5.0	8.3	6.1	0.4
52.5	880	2.6	0.0	8.3	1.4	5.0	6.3	5.0	0.5
57.5	750	1.8	0.0	2.8	1.4	5.0	4.3	3.9	0.8
62.5	814	1.4	0.0	0.0	1.4	0.0	3.3	3.3	1.0
67.5	723	1.4	0.0	0.0	1.4	0.0	3.3	3.3	1.0
72.5	751	1.4	0.0	0.0	1.4	0.0	3.3	3.3	1.0

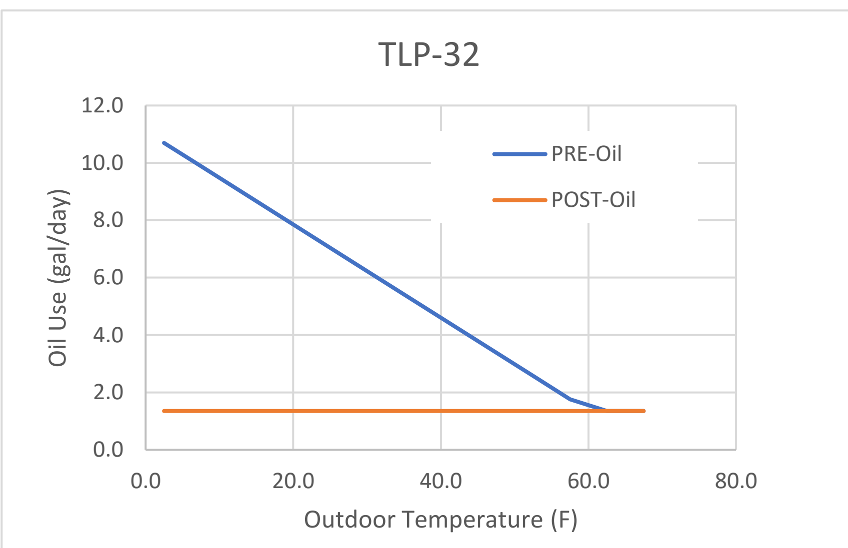


Figure 6. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

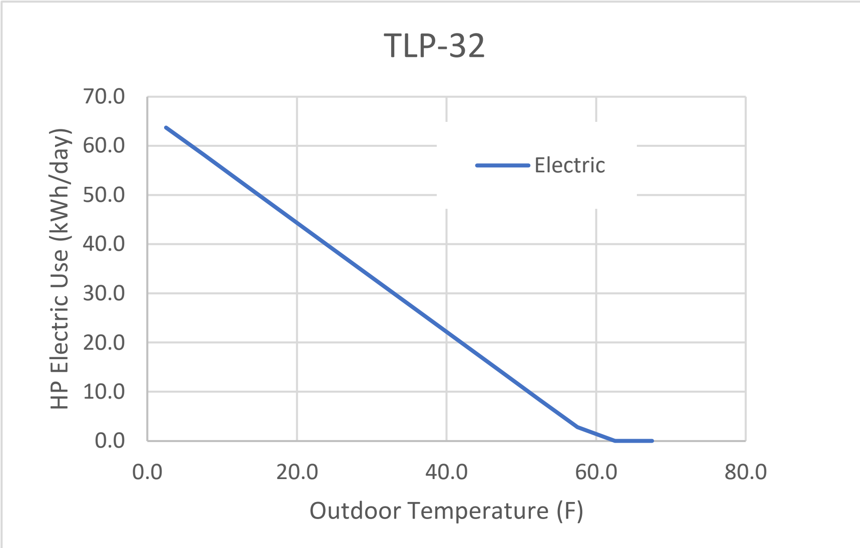


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 548 gallons per year for all improvements. However, if we subtract the oil savings from the envelope (i.e., air sealing) improvements, the fuel savings attributable to the heat pumps is 304 gallons per year. The heat pumps are estimated to use 3,739 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.8.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-32	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	548	-	244	548	304
HP Electric (kWh/yr)		3,739		(3,739)	
Total Heating Costs	$ 1,342	$ 748	$ 597	$ 594	$ (3)
Implied Seasonal COP				5.0	2.8

Summary Statistics	
0.41	Htg gal per sq ft per year
47.4	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
4,256	Measured HP Electric (kWh/yr)
114%	of typical year kWh

The implied COP may be high because we were unable to attribute energy savings to the attic insulation.

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

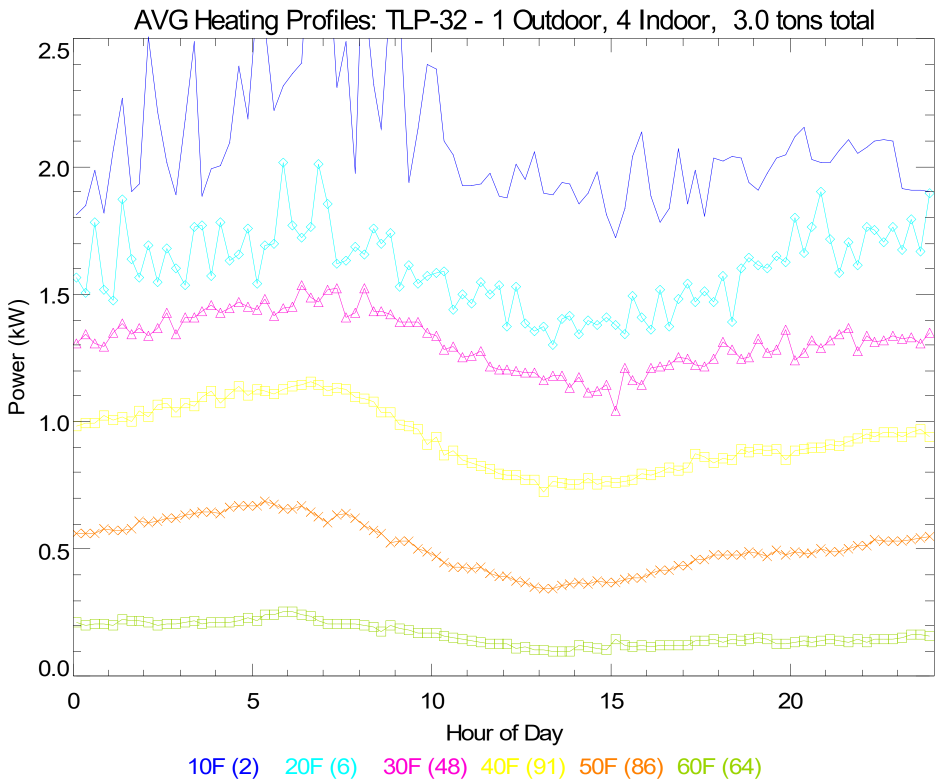


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

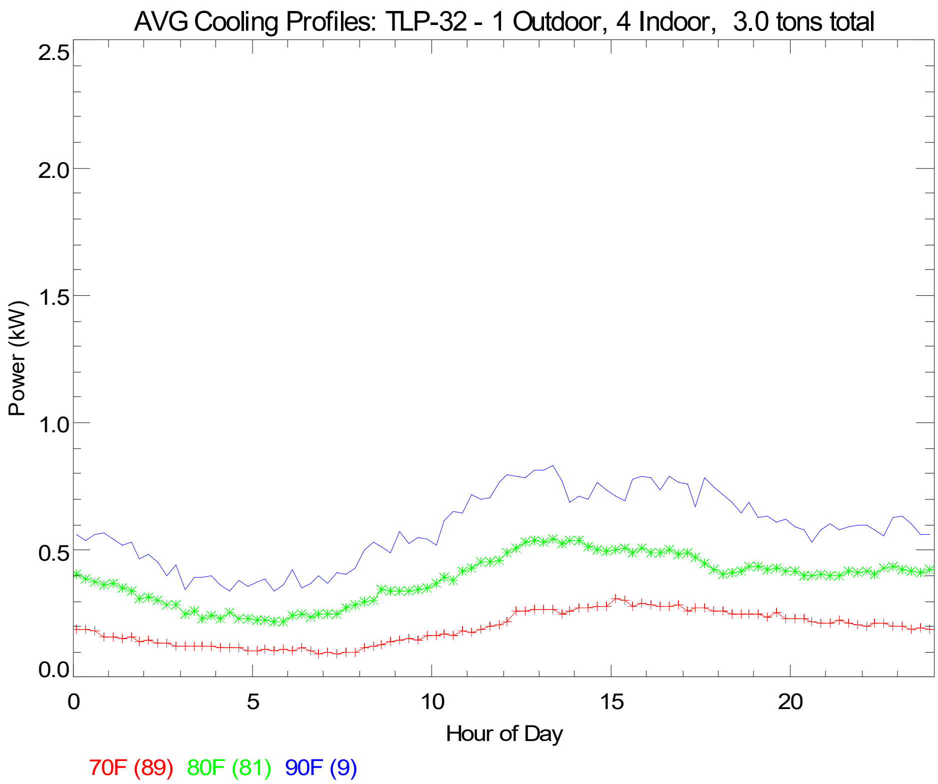


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

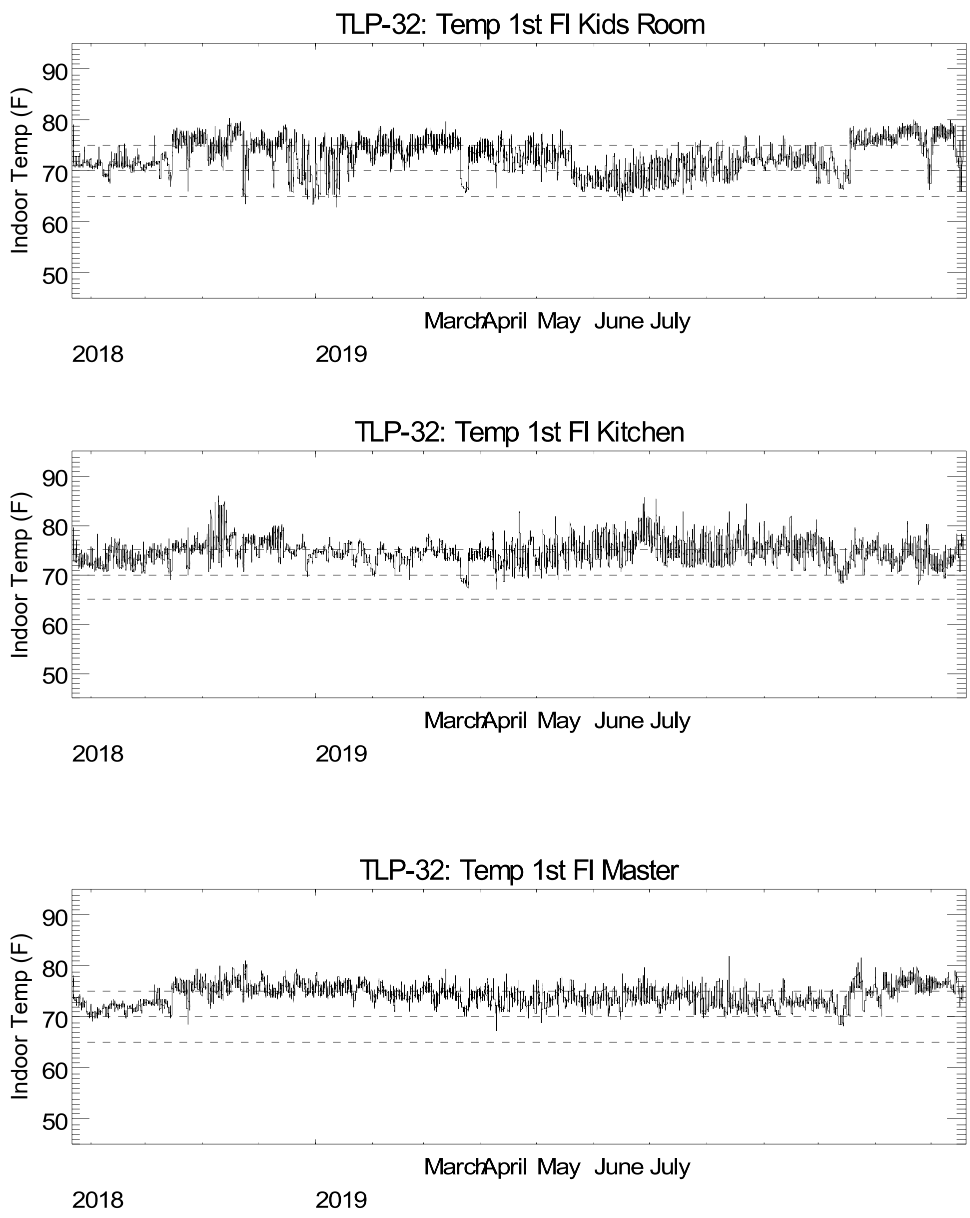


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 35 Savings Analysis

This 1,700 sq ft single-family home originally used an oil boiler with conventional baseboard radiation. One electric heat pump with 6 indoor heads and a total capacity of 4 tons was added to the home in mid-2019. The oil boiler remained in place to help meet the heating load on the coldest days and provide water heating. The monitoring equipment was installed on August 15, 2019 to collect data at 15-minute intervals. The house did not have any weatherization improvements implemented.

Table 1 summarizes the energy use of the heat pump across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Both Figure 1 and Figure 2 show that the heat pump was down for several weeks in November and December 2019 and then again in January and February 2020.

Figure 3 shows the daily energy use of the all the heat pumps as well as the runtime for the oil boiler. When the HP was off, oil use increased.

Table 1. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	Boiler Runtime (hrs)
Aug-19	100%	200.8	200.8	-
Sep-19	100%	92.4	92.4	0.1
Oct-19	100%	238.2	238.2	11.0
Nov-19	100%	173.7	173.7	23.3
Dec-19	100%	292.0	292.0	111.0
Jan-20	100%	46.0	46.0	179.4
Feb-20	104%	590.3	590.3	111.3
Mar-20	100%	971.8	971.8	49.7
Apr-20	100%	1,049.6	1,049.6	31.1
May-20	100%	615.0	615.0	14.6
Jun-20	100%	368.7	368.7	1.6
Jul-20	100%	699.8	699.8	-
Aug-20	76%	431.3	431.3	-
Annual	100%	5,338.3	5,338.3	533.1
Summer (Jun-Sep)		1,361.7	1,361.7	1.7
Winter (Oct-May)		3,976.6	3,976.6	531.4

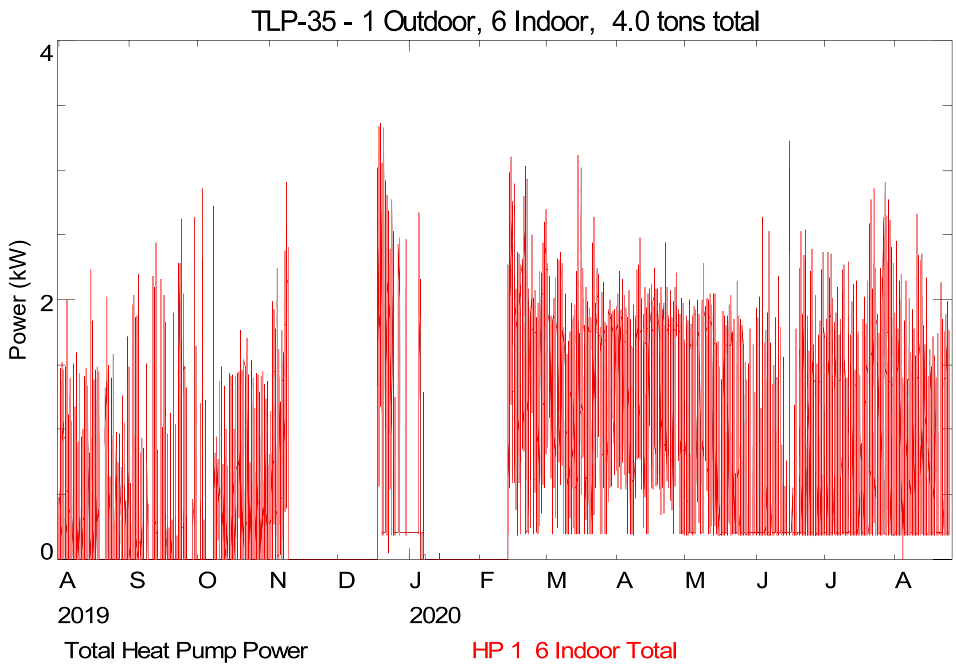


Figure 1. Plot of Power Use for All Heat Pumps at Site

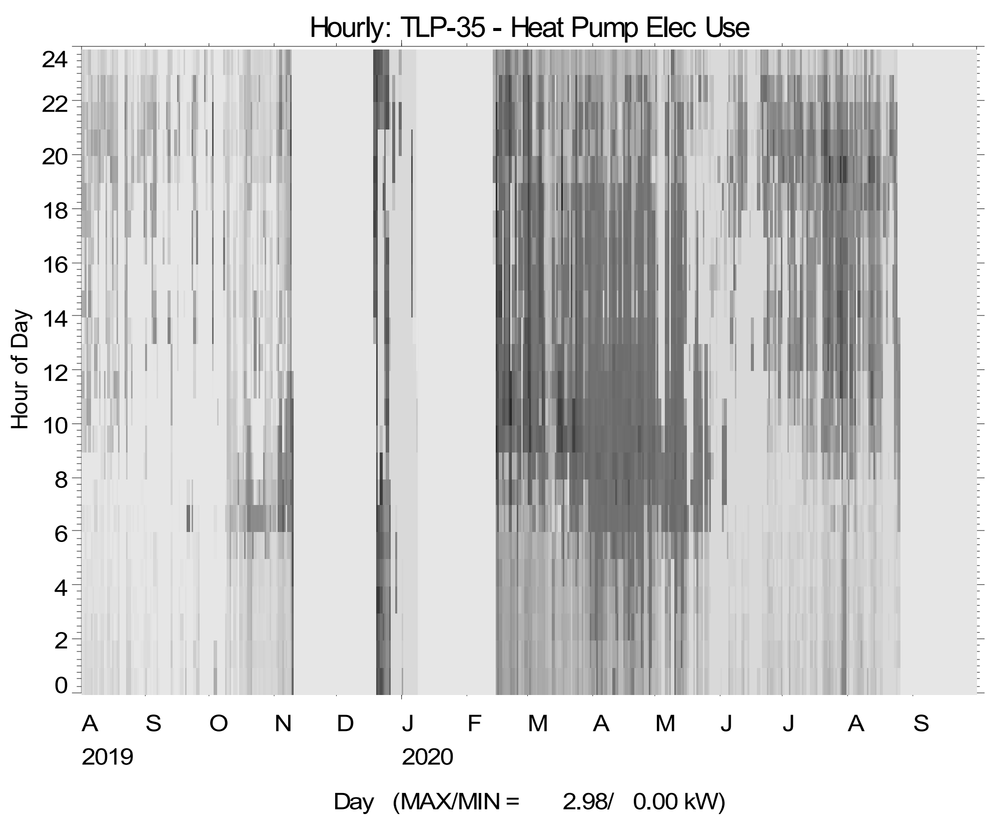


Figure 2. Shade Plot of Total Heat Pump Power

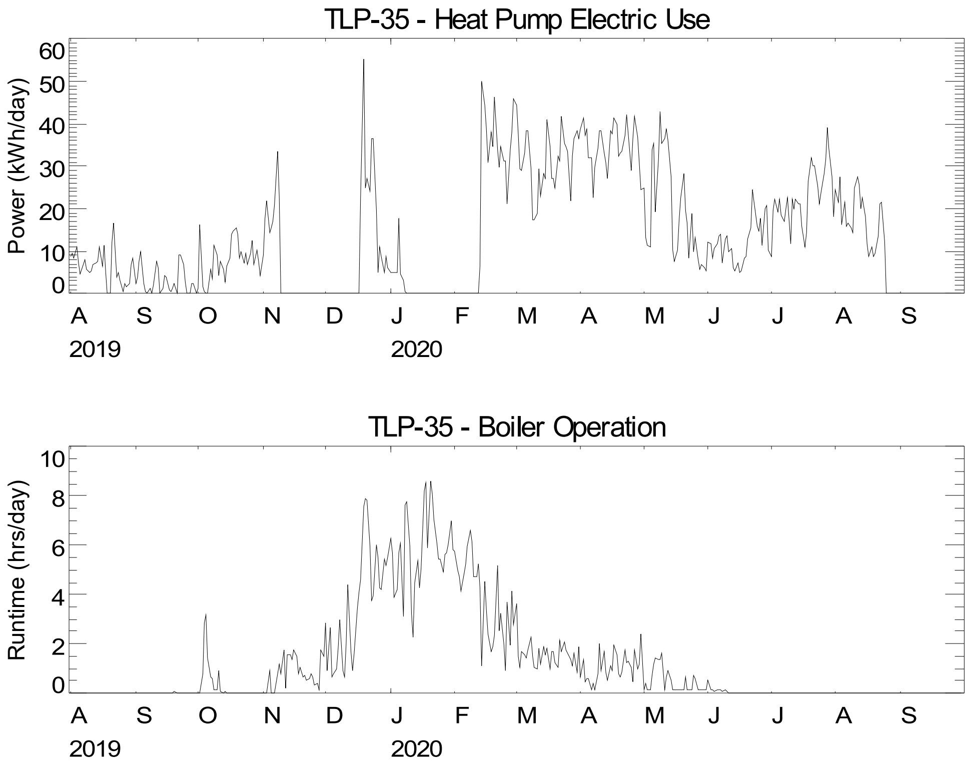


Figure 3. Plot of Daily Total HP Electric Use (and boiler runtime)

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year. The linear model on Figure 4 was biased towards the days when the heat pump was fully operating as expected. Figure 5 shows the trend of boiler runtime with outdoor temperature. The trends of higher use when the HP was off is apparent.

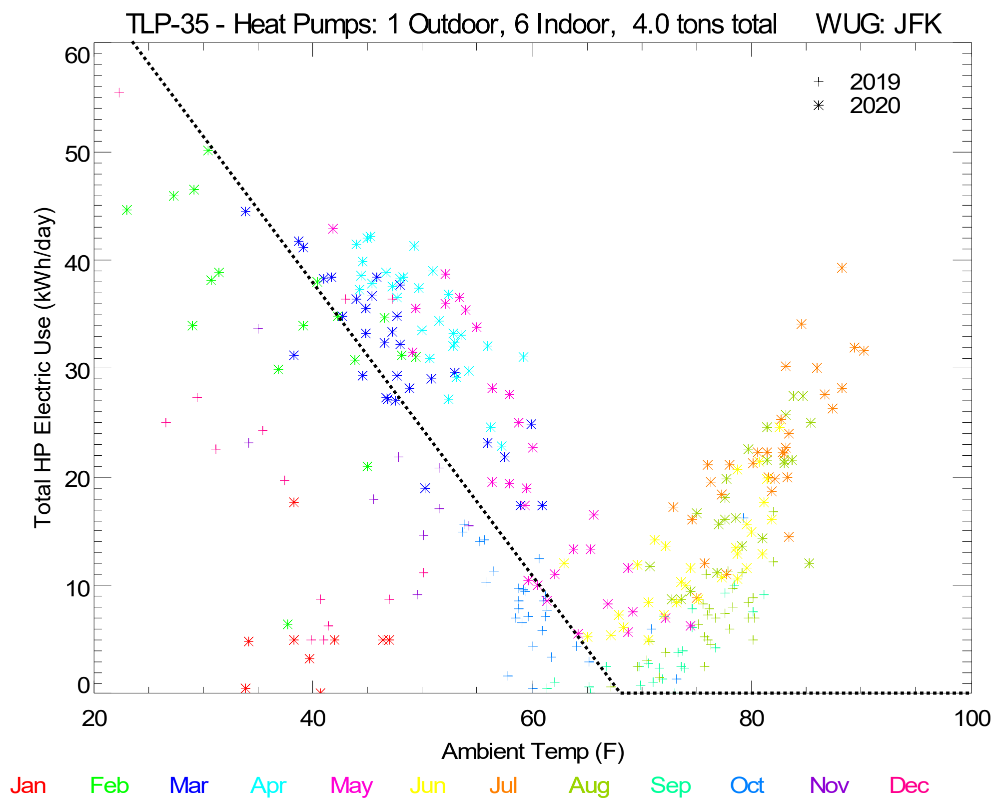


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

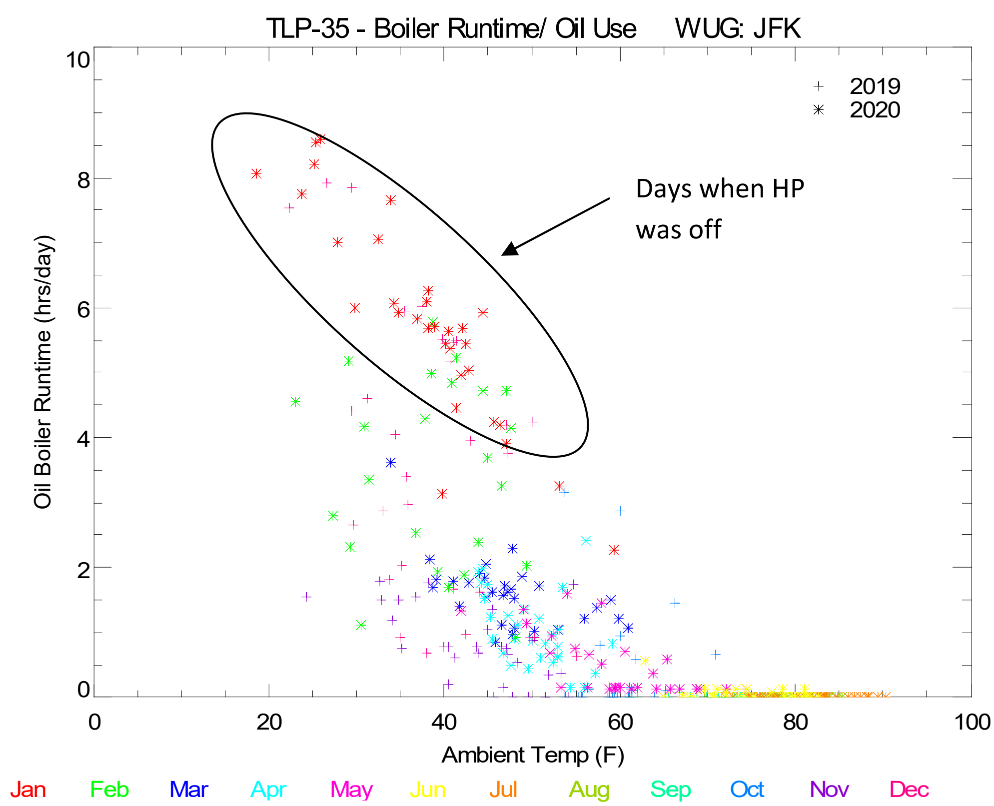


Figure 5. Daily Boiler Runtime versus Outdoor Temperature

Figure 6 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. Oil was used for DHW in the summer months, so baseload of 0.4 gallons per day was assumed. Oil use was reduced in the post-retrofit periods except for the readings in January and February 2020. The summertime DHW baseload determined from the pre-retrofit period was assumed to also apply to the post-retrofit period. The linear trend for the post-retrofit period was developed using the 3 readings from November and December 2019 and March 2020 when heat pump operation was normal.

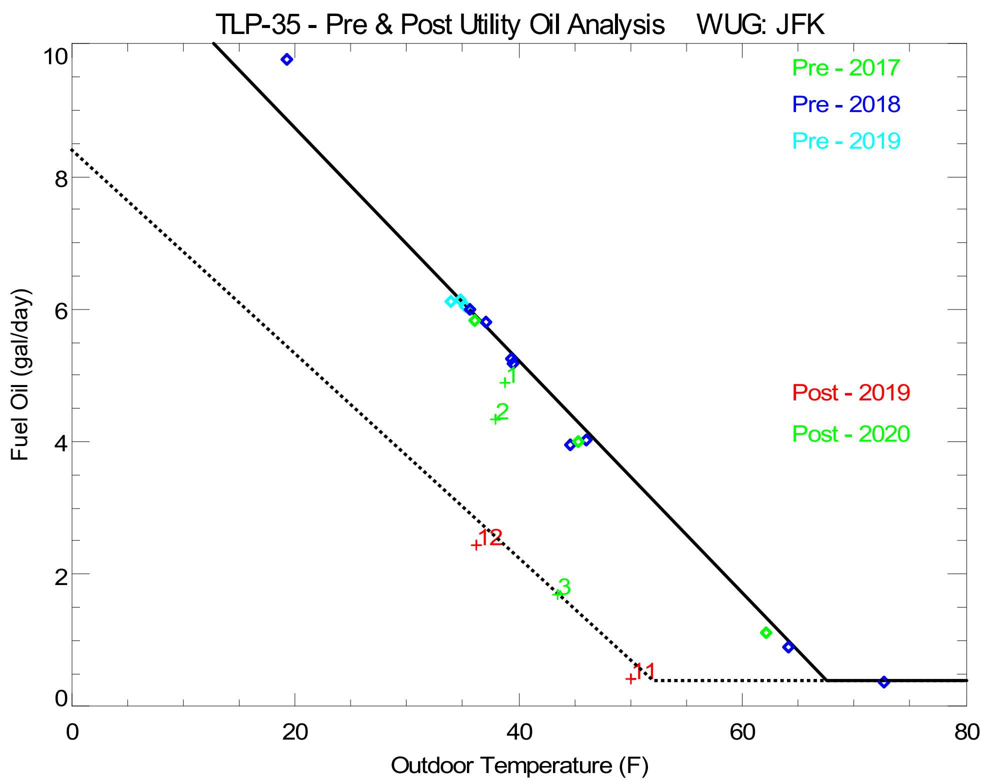


Figure 6. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 7 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 8 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 2. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE:	TLP-35	WEATHER:	New_York	$	0.20	per kWh
FUEL:	Oil			$	2.447	per gal

Floor Area 1700

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	17.1	12.6	129.3	12.6	1.2	41.8	56.8	
-22.5	0	16.2	11.9	122.6	11.9	1.2	39.6	53.5	
-17.5	0	15.3	11.1	115.8	11.1	1.2	37.5	50.3	
-12.5	0	14.4	10.3	109.0	10.3	1.3	35.3	47.1	
-7.5	0	13.6	9.6	102.2	9.6	1.3	33.2	43.8	
-2.5	0	12.7	8.8	95.5	8.8	1.4	31.0	40.6	
2.5	0	11.8	8.0	88.7	8.0	1.5	28.9	37.4	
7.5	11	10.9	7.2	81.9	7.2	1.5	26.7	34.1	
12.5	22	10.1	6.5	75.2	6.5	1.6	24.6	30.9	
17.5	101	9.2	5.7	68.4	5.7	1.7	22.5	27.6	
22.5	167	8.3	4.9	61.6	4.9	1.9	20.3	24.4	
27.5	247	7.4	4.2	54.8	4.2	2.0	18.2	21.2	
32.5	475	6.5	3.4	48.1	3.4	2.2	16.0	17.9	
37.5	855	5.7	2.6	41.3	2.6	2.5	13.9	14.7	
42.5	708	4.8	1.9	34.5	1.9	2.9	11.7	11.5	
47.5	608	3.9	1.1	27.8	1.1	3.5	9.6	8.2	
52.5	880	3.0	0.4	21.0	0.4	4.3	7.4	5.2	
57.5	750	2.2	0.4	14.2	0.4	4.2	5.3	3.8	
62.5	814	1.3	0.4	7.4	0.4	4.0	3.1	2.5	
67.5	723	0.4	0.4	0.7	0.4	0.0	1.0	1.1	
72.5	751	0.4	0.4	0.0	0.4	0.0	1.0	1.0	
77.5	870	0.4	0.4	0.0	0.4	0.0	1.0	1.0	

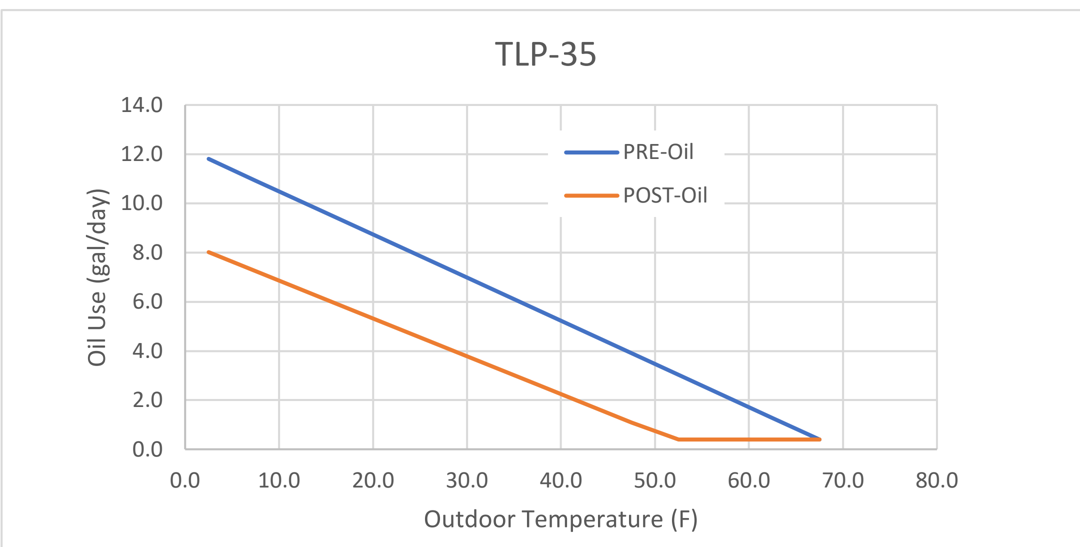


Figure 7. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

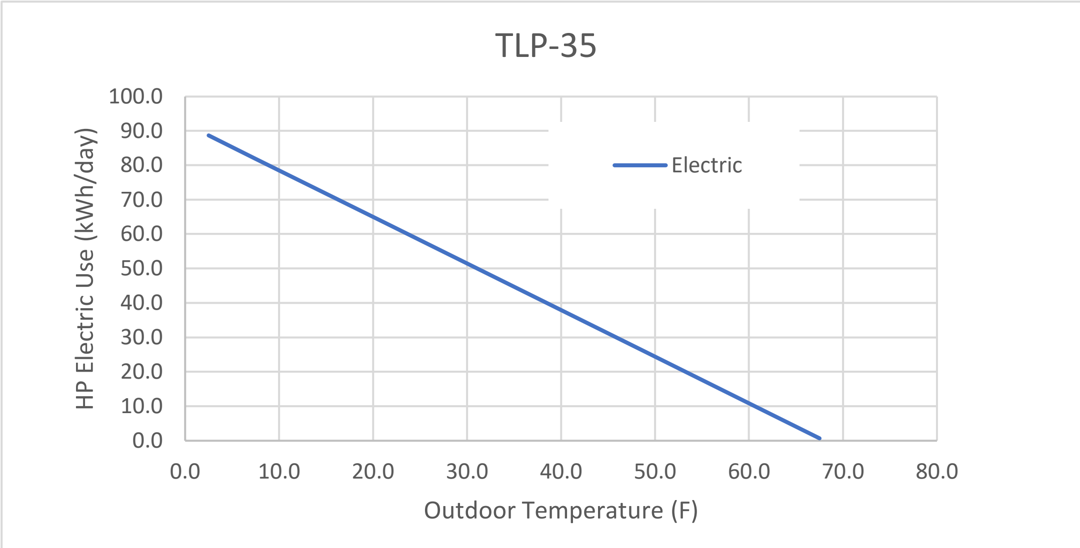


Figure 8. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 3 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 586 gallons per year for the HP. There were no envelope improvements. The heat pumps are estimated to use 7,019 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.9.

Table 3. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-35	**PRE Retrofit**	**POST Retrofit**	**Envelope Savings**	**ASHP & Env Savings**	**ASHP Savings**
Oil (gal/yr)	886	301		586	586
HP Electric (kWh/yr)		7,019		(7,019)	
Total Heating Costs	$ 2,169	$ 2,140	$ -	$ 29	$ 29
Implied Seasonal COP				2.9	2.9

Summary Statistics	
0.52	Htg gal per sq ft per year
60.9	Htg MBtu per sq ft per year
66%	Reduction in Htg Fuel Use
3,977	Measured HP Electric (kWh/yr)
57%	of typical year kWh

The estimated heat pump use is higher than the actual use from Table 1 since the bin-analysis assumes the HP operated normally throughout the year.

Average Heat Pump Demand Profiles

Figure 9 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 10 shows the same calculation process associated with cooling operation.

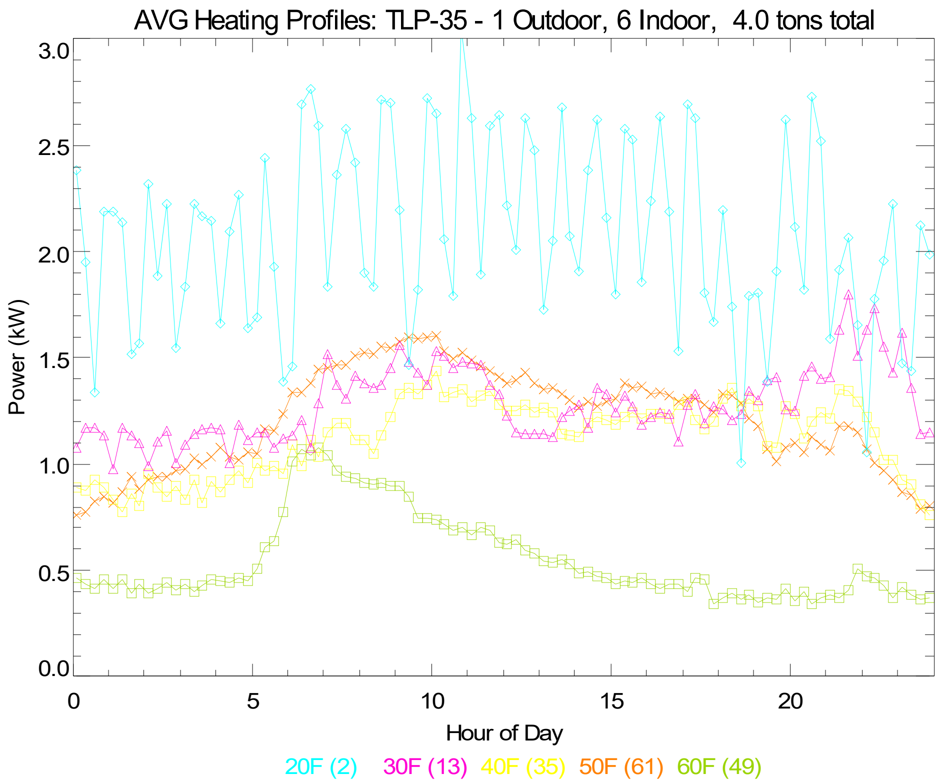


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

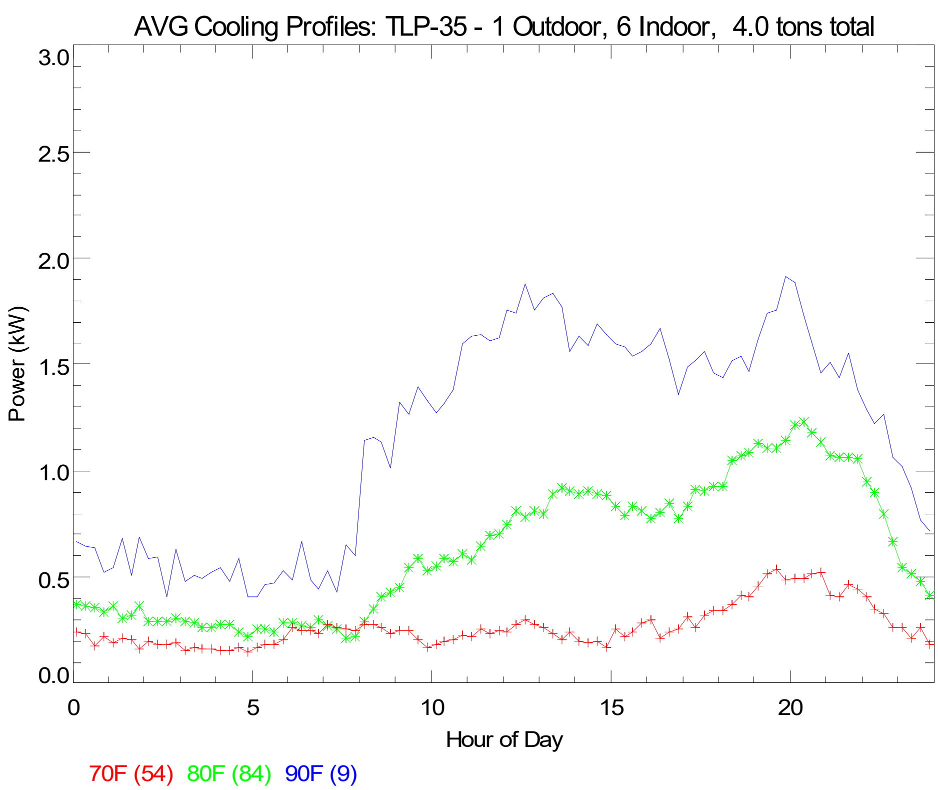


Figure 10. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 11.

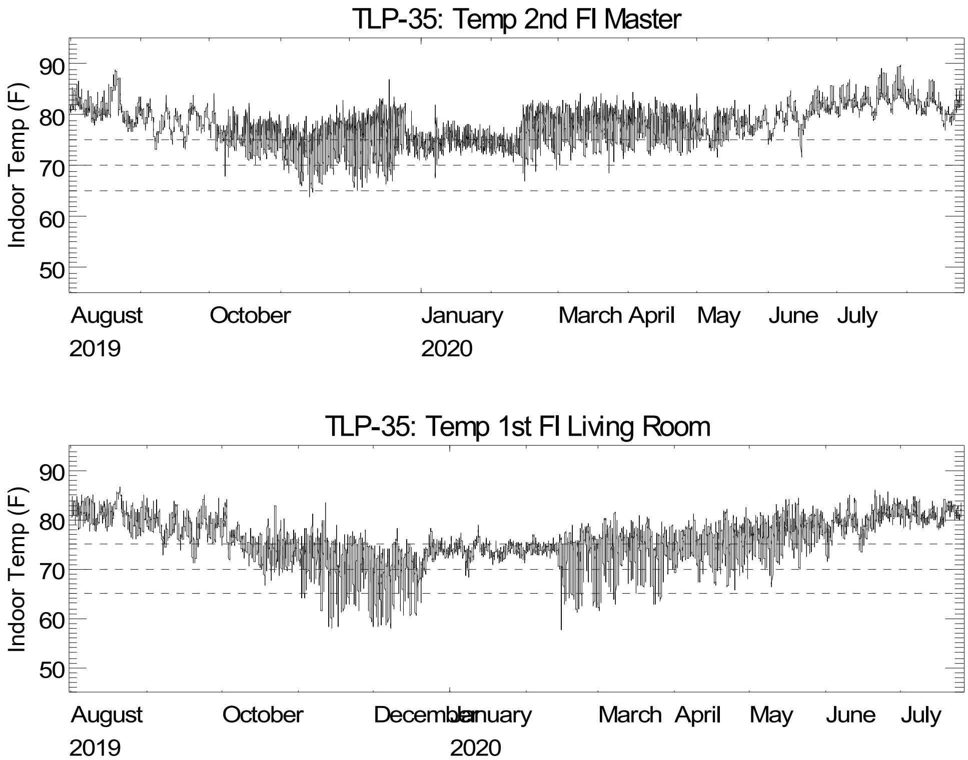


Figure 11. Plot of Space Temperatures at Various Indoor Locations

Site 39 Savings Analysis

This 1,387 sq ft single-family home originally used an oil boiler with conventional baseboard radiation. One electric heat pump with a total capacity of 3 tons were added to the home in early 2019. The oil boiler remained in place to help meet the heating load on the coldest days. Monitoring equipment was installed on March 13, 2019 to collect data at 15-minute intervals. The house did not have any weatherization improvements.

Table 1 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps as well as the runtime for the oil boiler. The heat pump did not operate in March to May 2020. The boiler met the load instead.

Table 1. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	Boiler Runtime (hrs)
Mar-19	60%	497.8	497.8	0.7
Apr-19	100%	360.7	360.7	-
May-19	100%	133.9	133.9	-
Jun-19	100%	190.9	190.9	-
Jul-19	100%	610.4	610.4	-
Aug-19	100%	459.1	459.1	-
Sep-19	100%	243.9	243.9	-
Oct-19	100%	81.1	81.1	-
Nov-19	100%	904.1	904.1	-
Dec-19	100%	1,379.8	1,379.8	0.3
Jan-20	100%	1,367.0	1,367.0	-
Feb-20	100%	955.1	955.1	20.2
Mar-20	100%	40.3	40.3	97.6
Apr-20	100%	25.2	25.2	81.8
May-20	107%	8.8	8.8	26.2
Jun-20	100%	194.9	194.9	-
Jul-20	100%	629.6	629.6	-
Aug-20	79%	298.2	298.2	-
Annual	100%	6,726.3	6,726.3	118.1
Summer (Jun-Sep)		1,504.3	1,504.3	-
Winter (Oct-May)		5,222.0	5,222.0	118.1

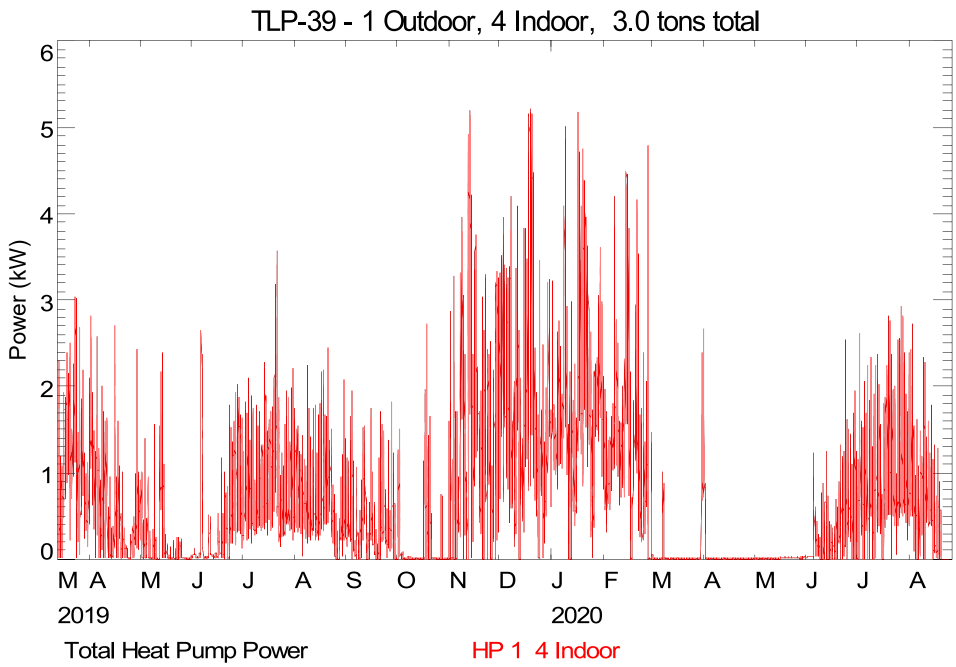


Figure 1. Plot of Power Use for All Heat Pumps at Site

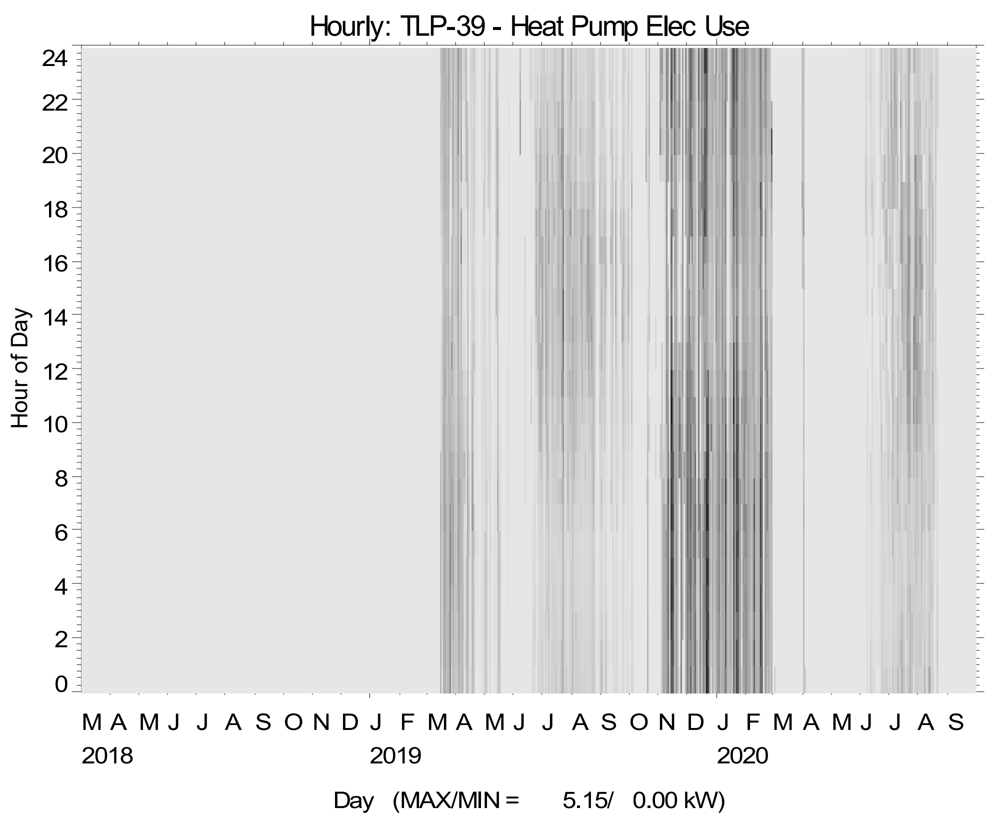


Figure 2. Shade Plot of Total Heat Pump Power

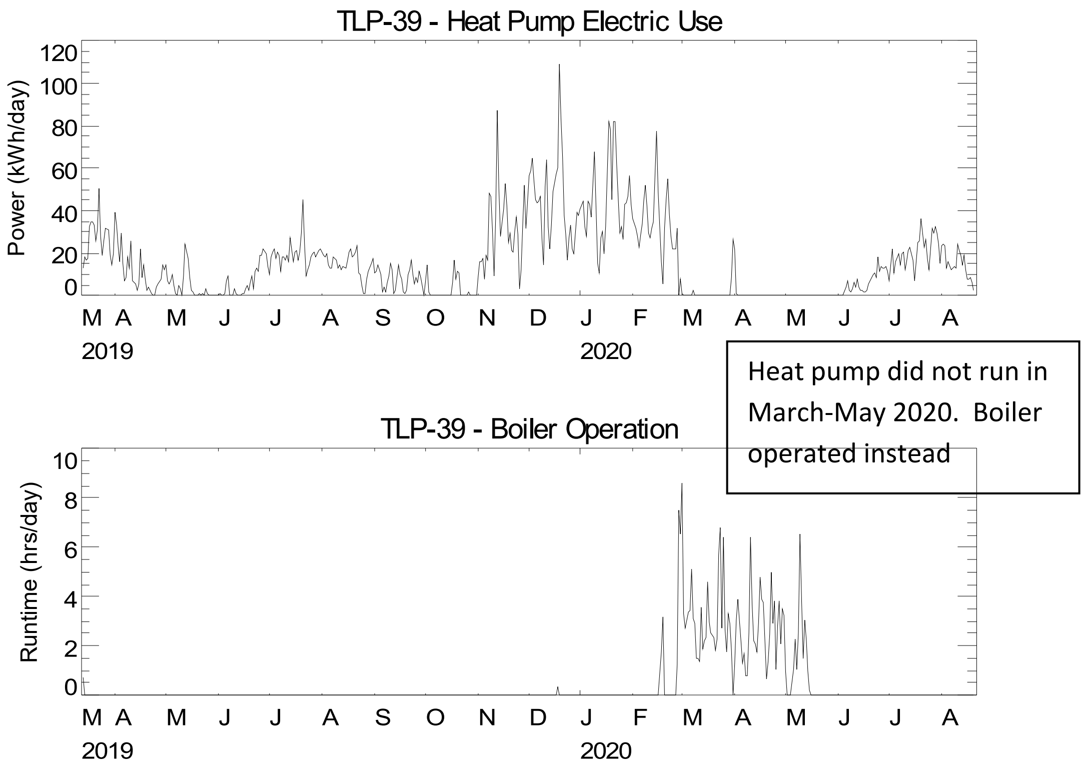


Figure 3. Plot of Daily Total HP Electric Use (and boiler runtime)

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year.

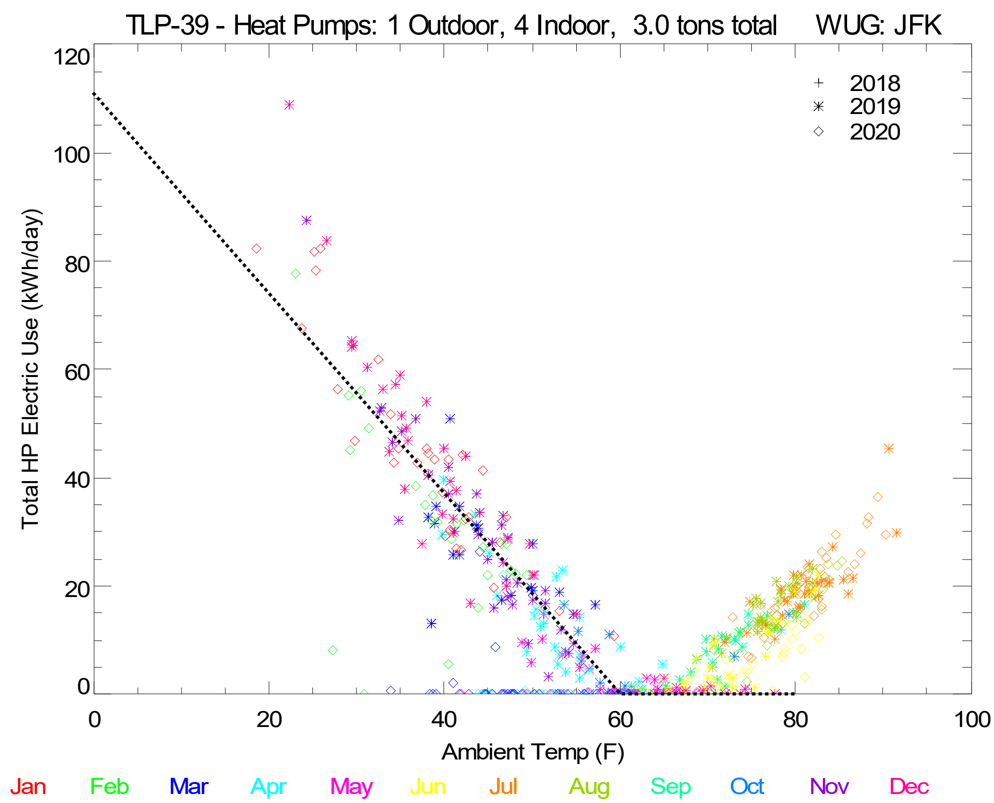


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

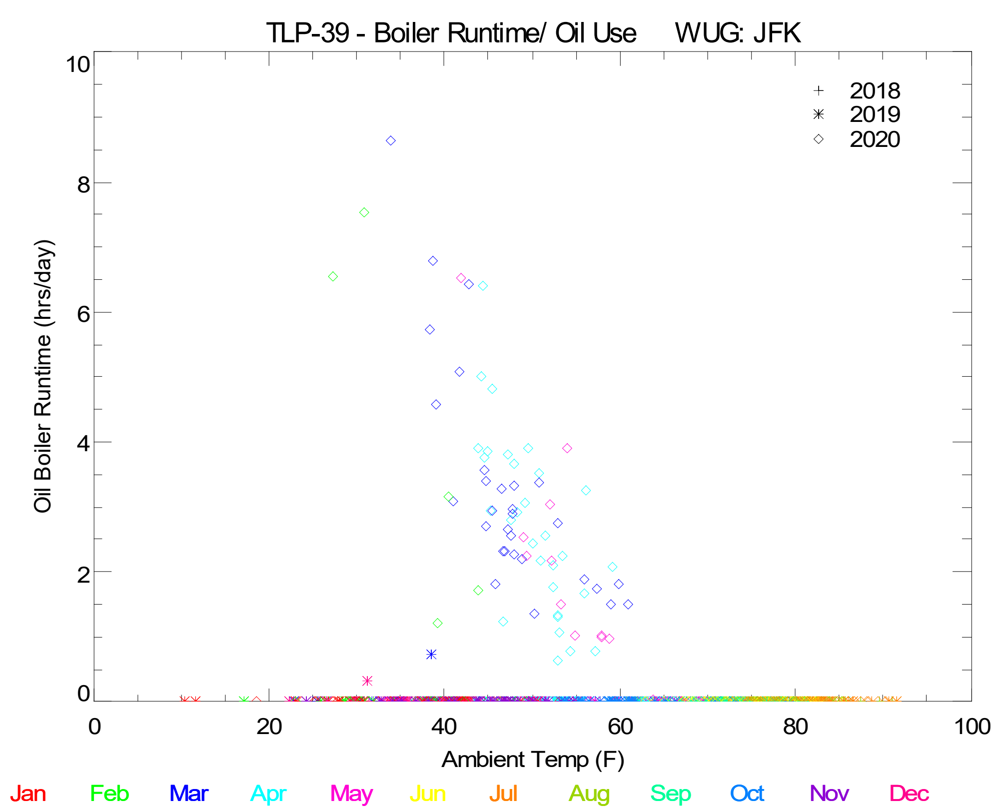


Figure 5 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years (only three readings were available from May 2016 to May 2017). Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. There was no post-retrofit oil consumption since the boiler was removed. There was no post-retrofit data available. In the analysis we assume the post retrofit period had same baseline summer use as in the pre-retrofit period.

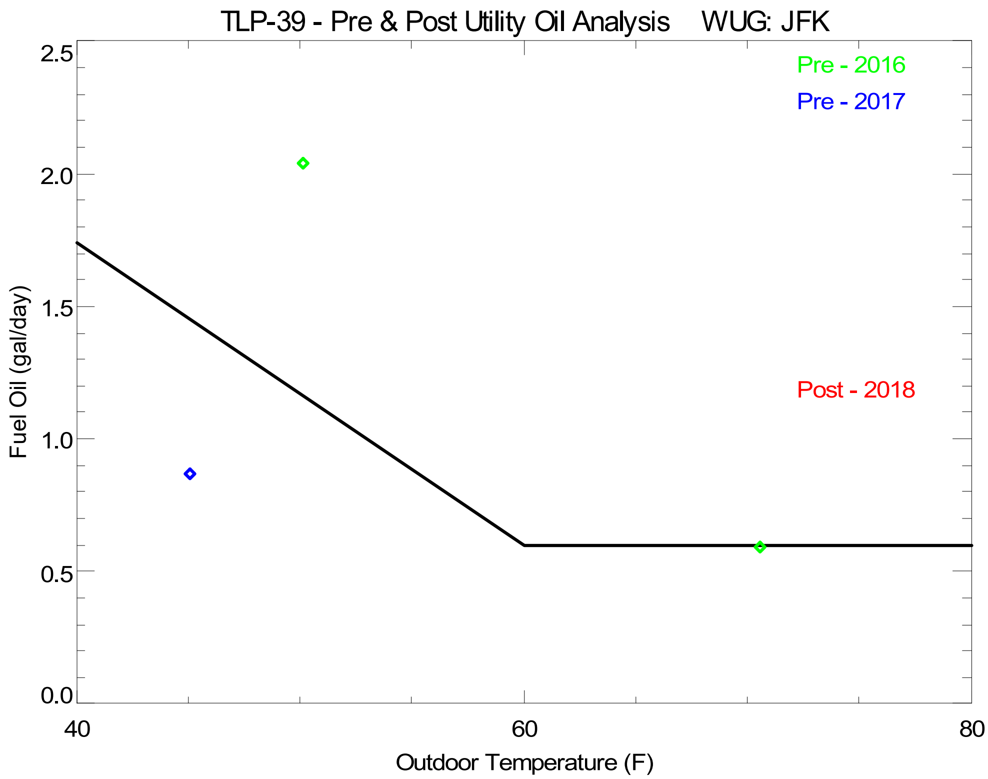


Figure 5. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

Annual Savings Analysis

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 2. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE:	TLP-39				WEATHER:	New_York		$ 0.20	per kWh
FUEL:	Oil							$ 2.447	per gal
Floor Area	1387								

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	5.6	0.0	161.9	0.6	1.1	13.7	33.8	0.1
-22.5	0	5.3	0.0	152.6	0.6	1.1	13.0	32.0	0.1
-17.5	0	5.0	0.0	143.4	0.6	1.1	12.3	30.1	0.1
-12.5	0	4.7	0.0	134.1	0.6	1.1	11.6	28.3	0.1
-7.5	0	4.4	0.0	124.9	0.6	1.1	10.9	26.4	0.1
-2.5	0	4.2	0.0	115.6	0.6	1.1	10.2	24.6	0.1
2.5	0	3.9	0.0	106.4	0.6	1.1	9.5	22.7	0.2
7.5	11	3.6	0.0	97.1	0.6	1.1	8.8	20.9	0.2
12.5	22	3.3	0.0	87.9	0.6	1.1	8.1	19.0	0.2
17.5	101	3.0	0.0	78.6	0.6	1.1	7.4	17.2	0.2
22.5	167	2.7	0.0	69.4	0.6	1.1	6.7	15.3	0.2
27.5	247	2.5	0.0	60.1	0.6	1.1	6.0	13.5	0.2
32.5	475	2.2	0.0	50.9	0.6	1.1	5.3	11.6	0.3
37.5	855	1.9	0.0	41.6	0.6	1.1	4.6	9.8	0.3
42.5	708	1.6	0.0	32.4	0.6	1.1	3.9	7.9	0.4
47.5	608	1.3	0.0	23.1	0.6	1.1	3.2	6.1	0.5
52.5	880	1.0	0.0	13.9	0.6	1.1	2.5	4.2	0.6
57.5	750	0.7	0.0	4.6	0.6	1.1	1.8	2.4	0.8
62.5	814	0.6	0.0	0.0	0.6	0.0	1.5	1.5	1.0
67.5	723	0.6	0.0	0.0	0.6	0.0	1.5	1.5	1.0
72.5	751	0.6	0.0	0.0	0.6	0.0	1.5	1.5	1.0

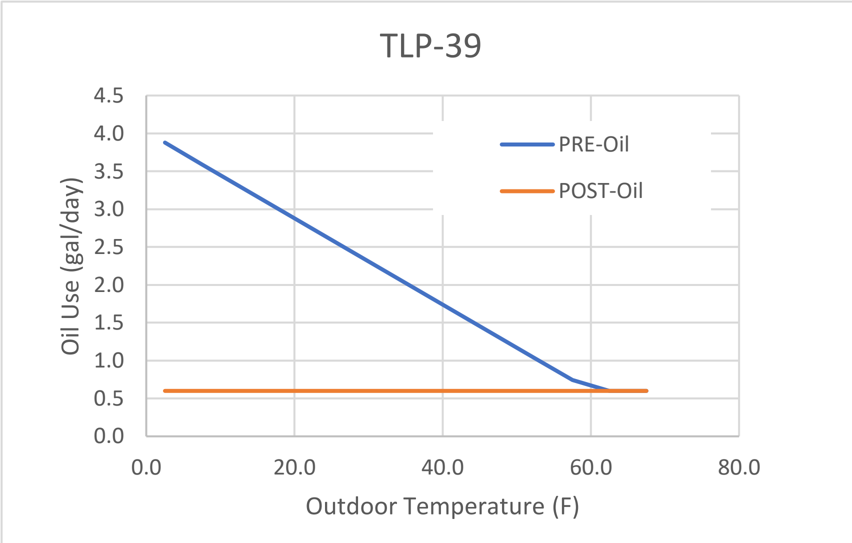


Figure 6. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

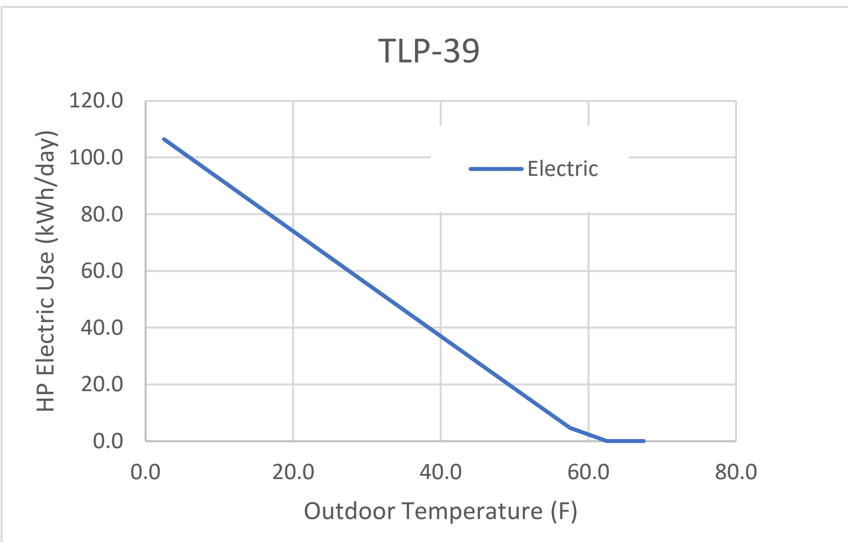


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 3 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings are estimated to be 192 gallons per year for the heat pump. The heat pumps are estimated to use 6,241 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 1.1.

Table 3. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-39	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	192	-	-	192	192
HP Electric (kWh/yr)		6,241		(6,241)	
Total Heating Costs	$ 471	$ 1,248	$ -	$ (778)	$ (778)
Implied Seasonal COP				1.1	1.1

Summary Statistics	
0.14	Htg gal per sq ft per year
16.2	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
5,222	Measured HP Electric (kWh/yr)
84%	of typical year kWh

The poor heating COP may be explained by limited pre-retrofit data.

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

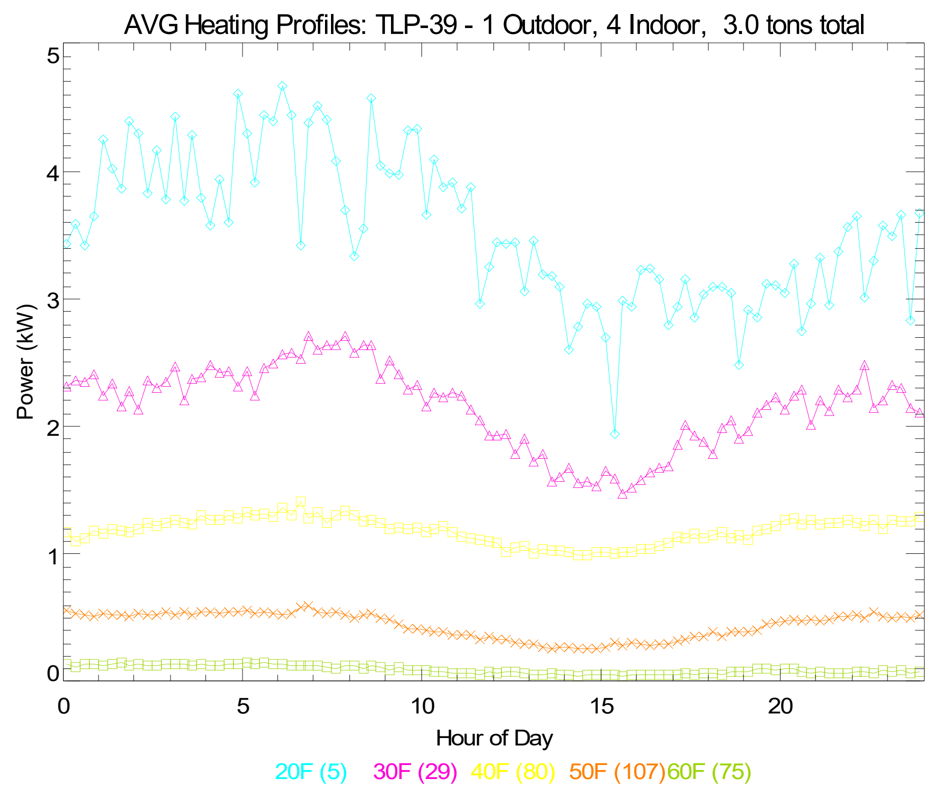


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

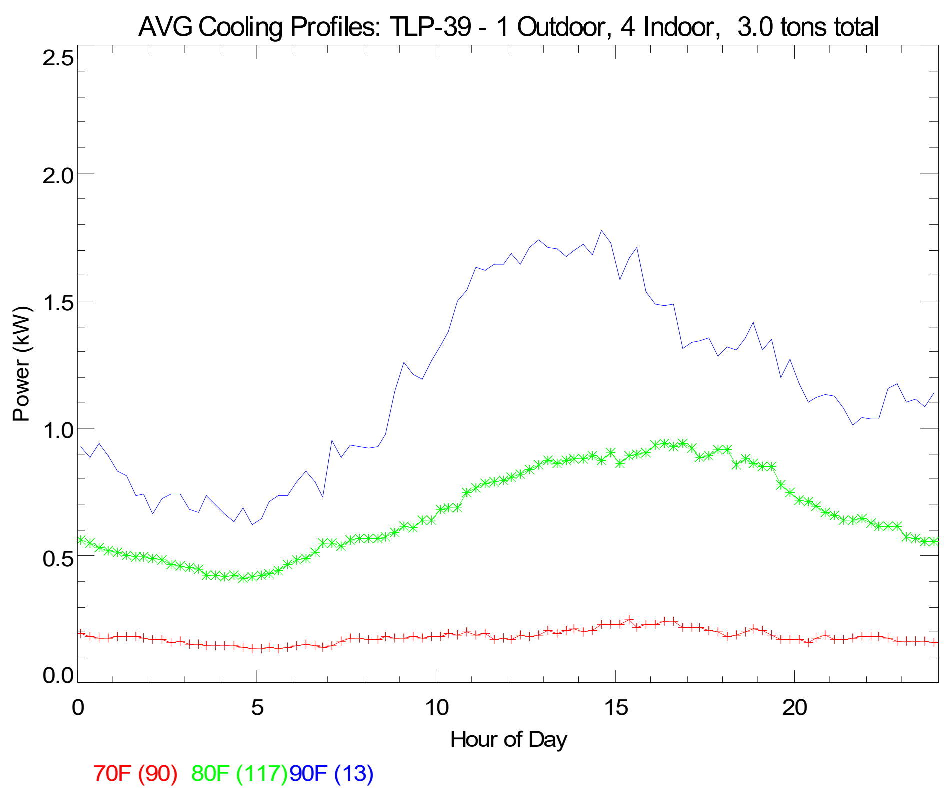


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

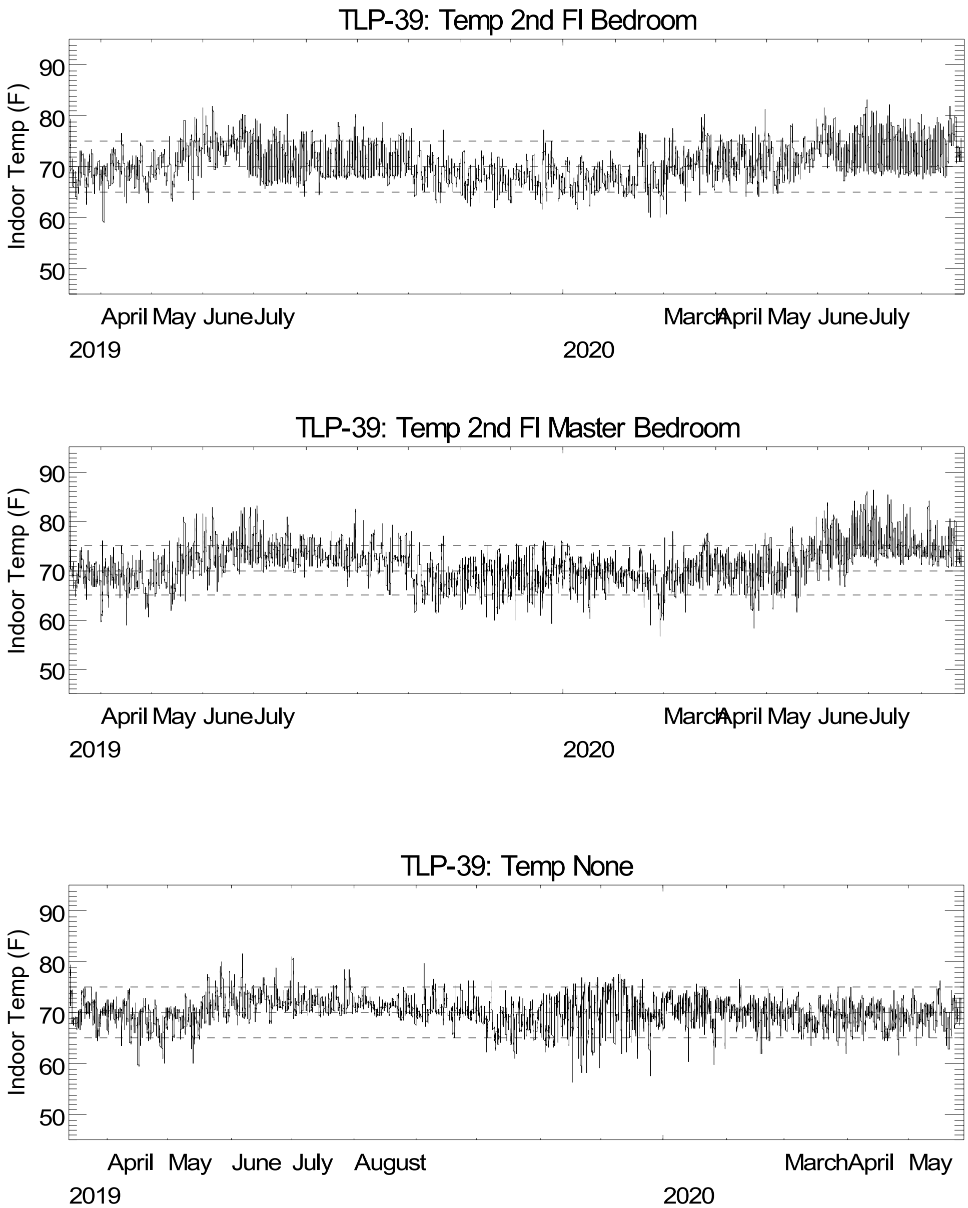


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 40 Savings Analysis

This 750 sq ft single-family home originally used a gas boiler with conventional baseboard radiation. One electric heat pump with a total capacity of 2 tons were added to the home in late 2018. The gas boiler was removed. Monitoring equipment was installed on December 3, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (air sealing, insulation) implemented that were projected to save 287 therms per year. Table 1 summarizes the proposed envelope measures, which were fully implemented.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	**Proposed Details**	**Final Details**
Air Sealing	Reduce infiltration rate from 3,750 CFM50 to 2,000 CFM50 SAVINGS: 150 therms	Completed
Insulation	Insulate roof cavity and crawlspace	Completed
ALL SAVINGS:	287 therms (67% of annual use)	

Note: savings estimated by change in Manual J Design Load due to weatherization

Table 2 summarizes the energy use of the heat pump across the period. Figure 1 shows the trend of power use for the heat pump.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the heat pump.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)
Dec-18	92%	760.6	760.6
Jan-19	100%	962.8	962.8
Feb-19	100%	782.1	782.1
Mar-19	100%	559.4	559.4
Apr-19	100%	113.3	113.3
May-19	100%	115.5	115.5
Jun-19	100%	193.6	193.6
Jul-19	100%	446.4	446.4
Aug-19	100%	298.7	298.7
Sep-19	100%	209.4	209.4
Oct-19	100%	47.8	47.8
Nov-19	100%	223.3	223.3
Dec-19	100%	375.1	375.1
Jan-20	100%	575.5	575.5
Feb-20	100%	512.9	512.9
Mar-20	100%	313.7	313.7
Apr-20	100%	244.0	244.0
May-20	100%	133.6	133.6
Jun-20	100%	348.9	348.9
Jul-20	100%	554.2	554.2
Aug-20	76%	374.6	374.6
Annual	100%	4,327.4	4,327.4
Summer (Jun-Sep)		1148.1	1148.1
Winter (Oct-May)		3,179.3	3,179.3

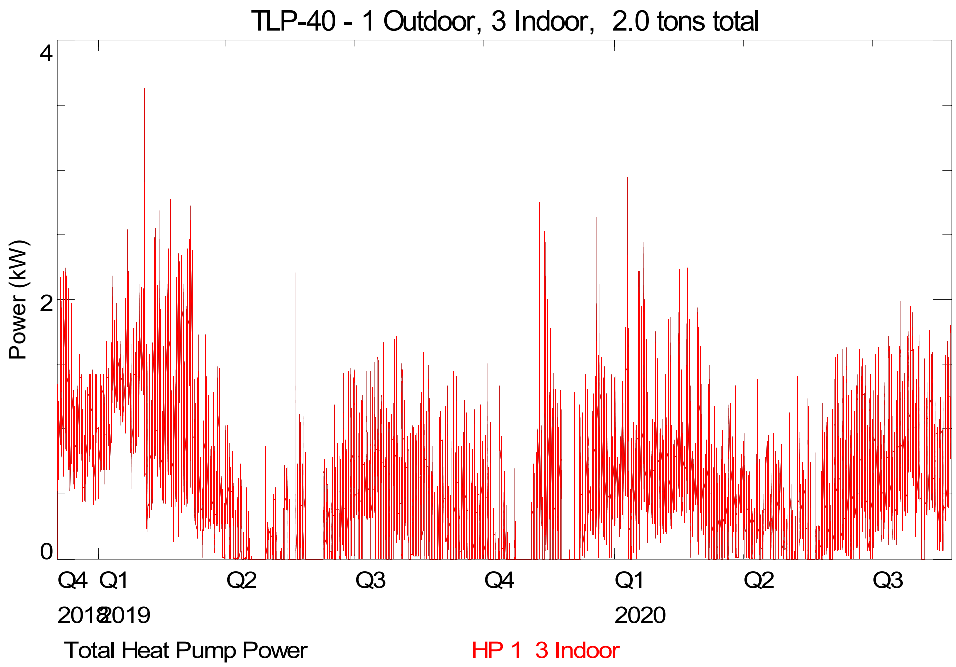


Figure 1. Plot of Power Use for All Heat Pumps at Site

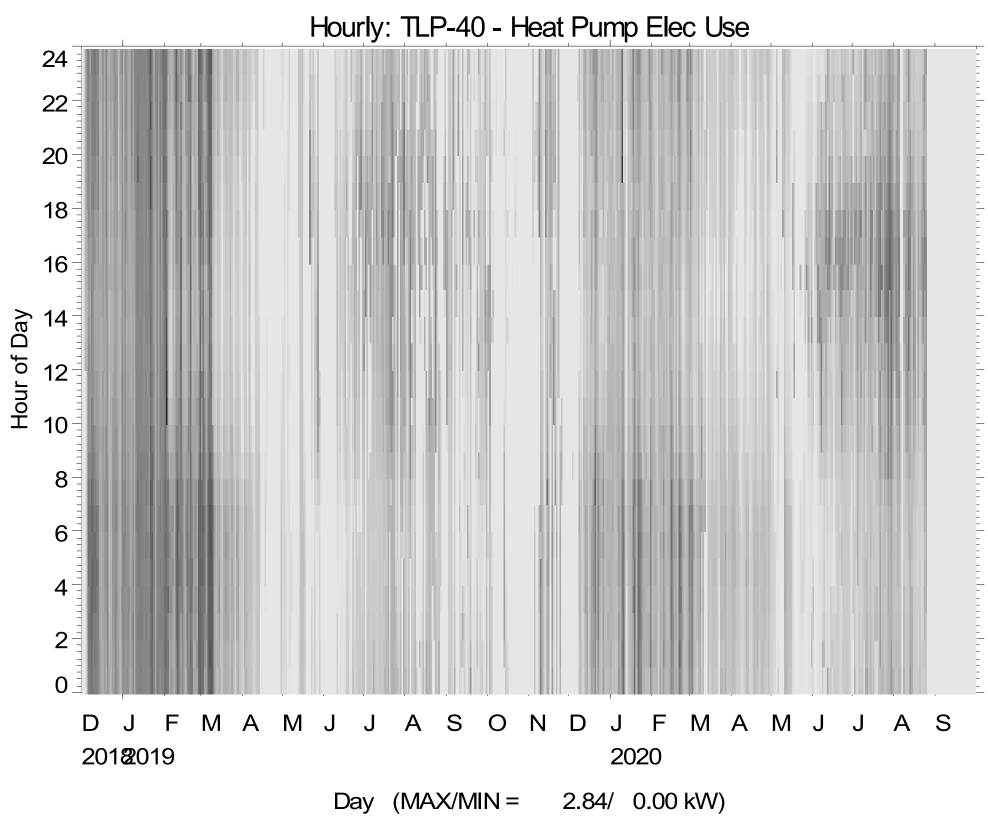


Figure 2. Shade Plot of Total Heat Pump Power

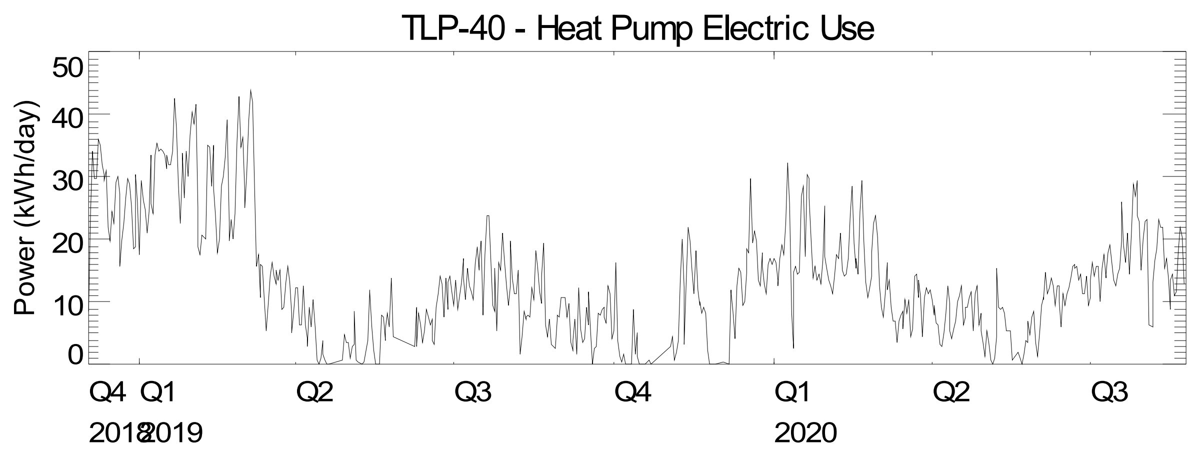


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year. The dotted line is the best fit to the initial data (December 2018 through early February 2019) when the HP met most of the load. During later periods it appears that some other heating source met some of the load (since the boiler was removed).

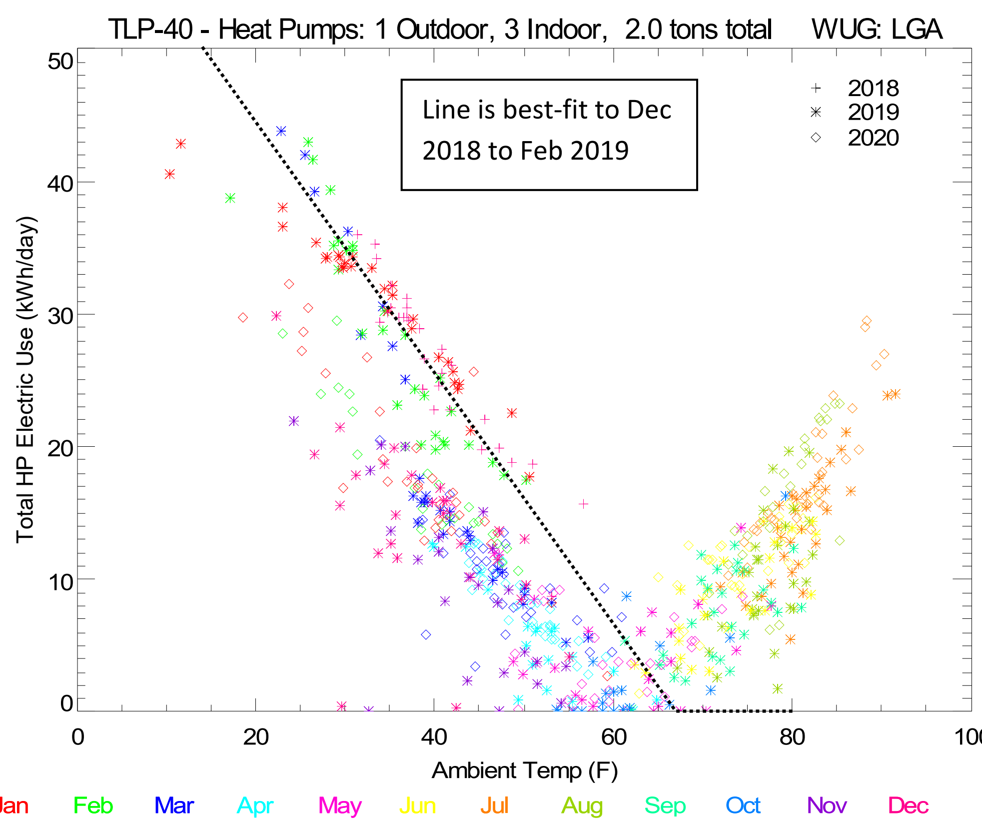


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. The boiler was removed so there are no post-retrofit data.

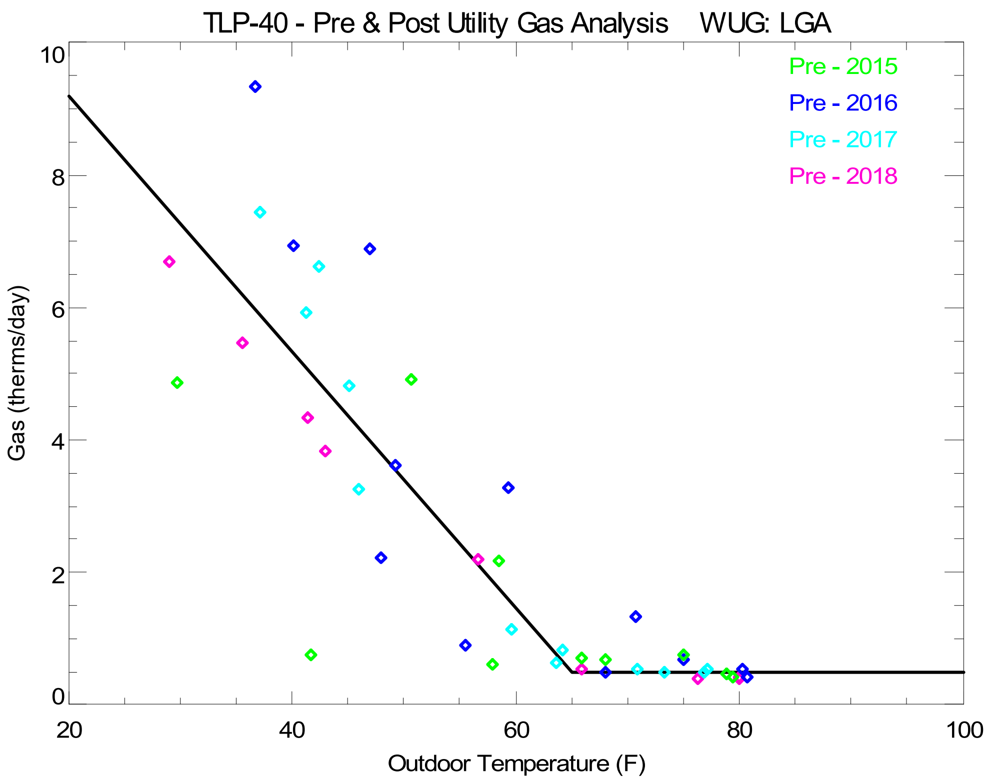


Figure 5. Trend of Gas Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre- and Post-Retrofit Periods

Annual Savings Analysis

The trends described in the plots above (focused on early Winter 2018) were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 7 shows the linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-40** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Gas** $ 1.403 per therm

Floor Area **750** Boiler Removed

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	18.4	0.0	89.5	0.5	4.6	25.8	18.6	0.0
-22.5	0	17.4	0.0	84.8	0.5	4.6	24.4	17.7	0.0
-17.5	0	16.5	0.0	80.0	0.5	4.6	23.1	16.7	0.0
-12.5	0	15.5	0.0	75.3	0.5	4.6	21.7	15.8	0.0
-7.5	0	14.5	0.0	70.5	0.5	4.6	20.4	14.8	0.0
-2.5	0	13.6	0.0	65.8	0.5	4.6	19.0	13.9	0.0
2.5	0	12.6	0.0	61.1	0.5	4.6	17.7	12.9	0.0
7.5	11	11.6	0.0	56.3	0.5	4.6	16.3	12.0	0.0
12.5	22	10.7	0.0	51.6	0.5	4.6	14.9	11.0	0.0
17.5	101	9.7	0.0	46.9	0.5	4.5	13.6	10.1	0.1
22.5	167	8.7	0.0	42.1	0.5	4.5	12.2	9.1	0.1
27.5	247	7.8	0.0	37.4	0.5	4.5	10.9	8.2	0.1
32.5	475	6.8	0.0	32.7	0.5	4.5	9.5	7.2	0.1
37.5	855	5.8	0.0	27.9	0.5	4.4	8.2	6.3	0.1
42.5	708	4.9	0.0	23.2	0.5	4.3	6.8	5.3	0.1
47.5	608	3.9	0.0	18.5	0.5	4.2	5.4	4.4	0.1
52.5	880	2.9	0.0	13.7	0.5	4.1	4.1	3.4	0.2
57.5	750	2.0	0.0	9.0	0.5	3.7	2.7	2.5	0.3
62.5	814	1.0	0.0	4.3	0.5	2.6	1.4	1.6	0.5
67.5	723	0.5	0.0	0.0	0.5	0.0	0.7	0.7	1.0
72.5	751	0.5	0.0	0.0	0.5	0.0	0.7	0.7	1.0

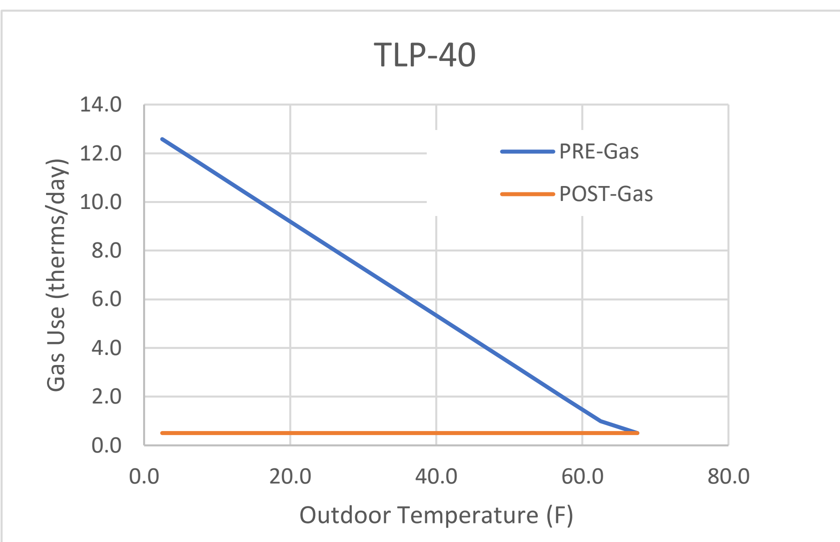


Figure 6. Trend of PRE- and POST-Retrofit Gas Use with Outdoor Temperature for Bin Analysis

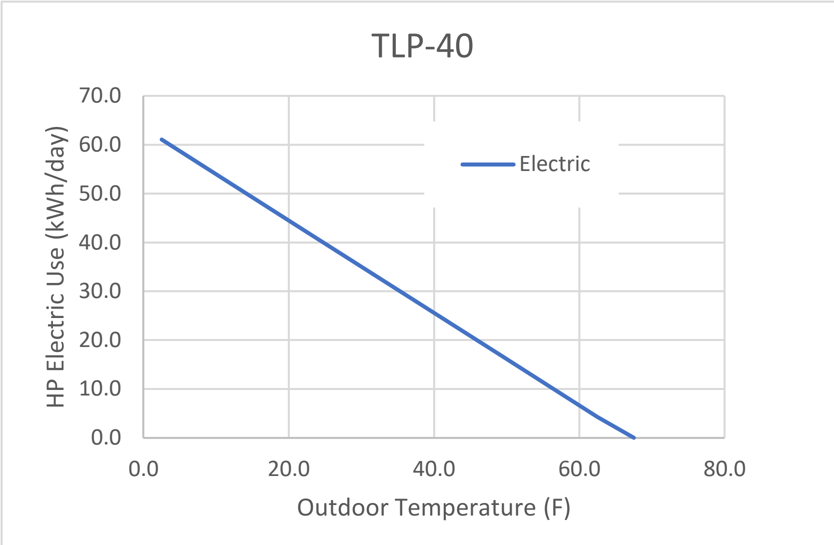


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 863 therms per year for all improvements. However, if we subtract the gas savings from the envelope improvements, the fuel savings attributable to the heat pumps is 576 therms per year. The heat pumps are estimated to use 4,672 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 2.9.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-40	**PRE Retrofit**	**POST Retrofit**	**Envelope Savings**	**ASHP & Env Savings**	**ASHP Savings**
Gas (therms/yr)	863	-	287	863	576
HP Electric (kWh/yr)		4,672		(4,672)	
Total Heating Costs	$ 1,211	$ 934	$ 403	$ 277	$ (126)
Implied Seasonal COP				4.3	2.9

Summary Statistics	
1.15	Htg therms per sq ft per year
90.9	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
3,179	Measured HP Electric (kWh/yr)
68%	of typical year kWh

Implied COP seems high, perhaps due to uncertainty around the energy impact of the envelop improvements based off the change in Manual J loads.

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

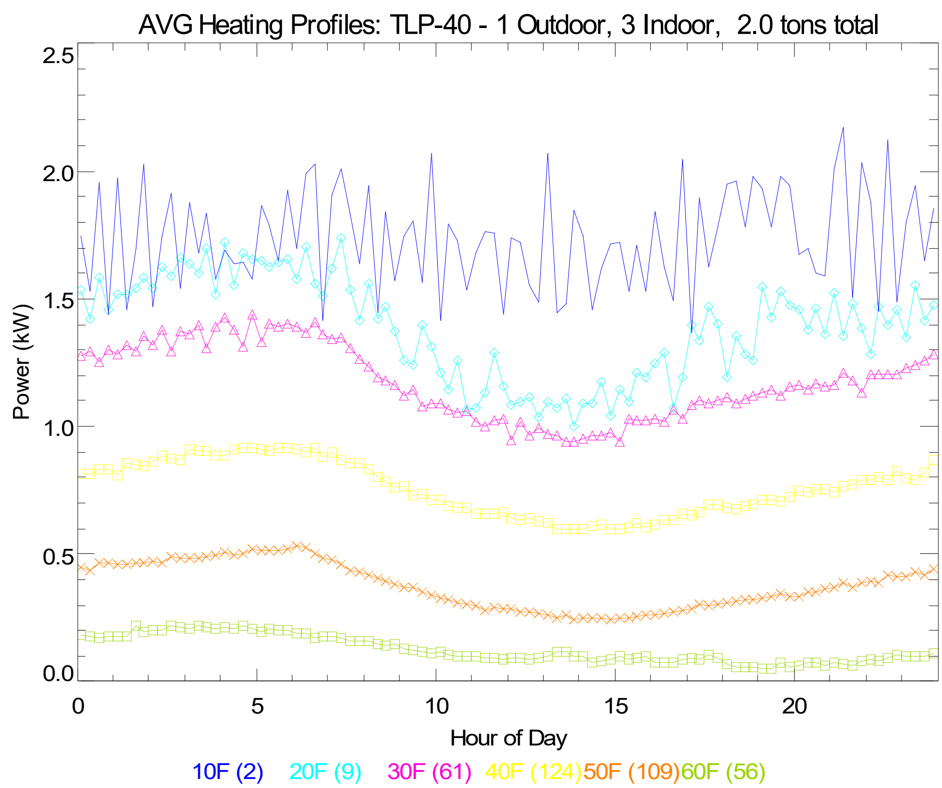


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

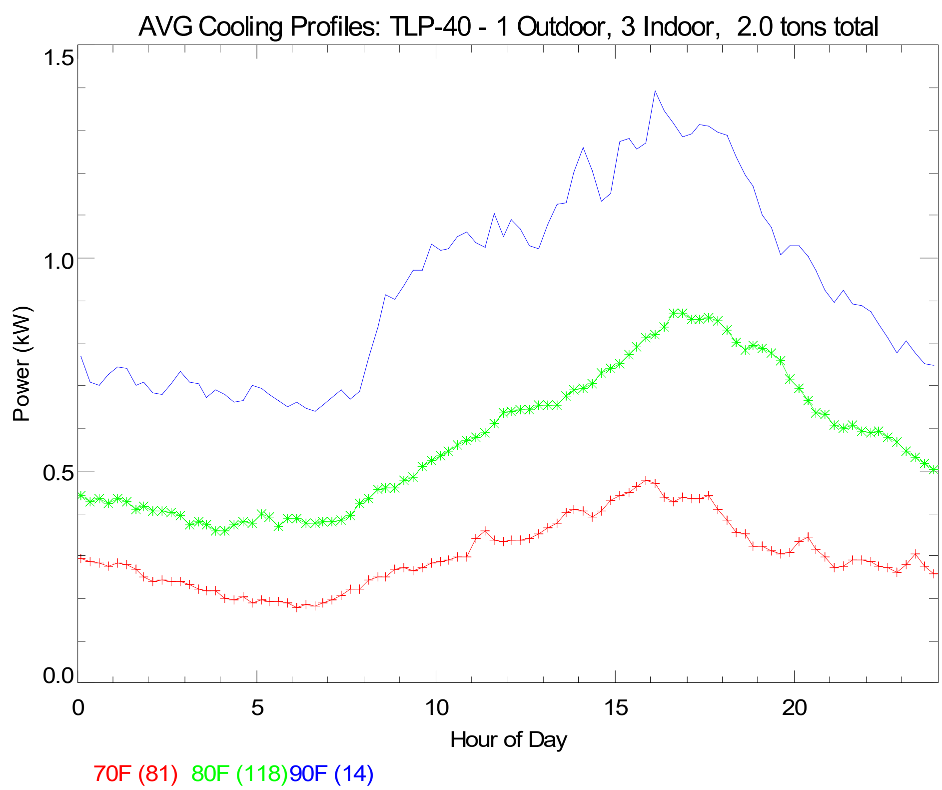
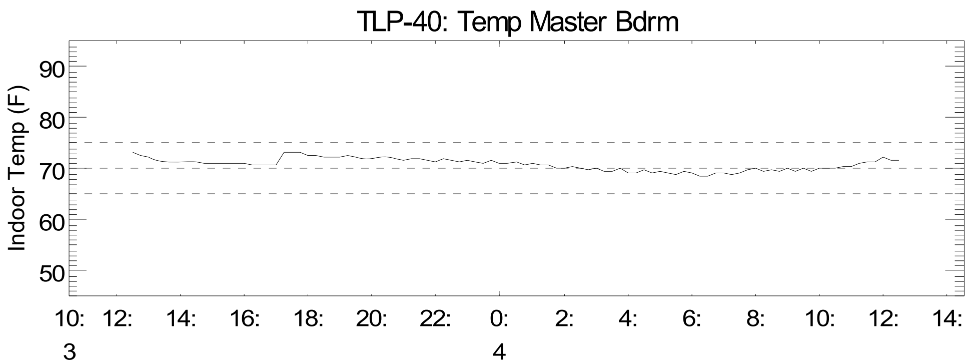


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10. The indoor temperatures in the living room dipped in early 2019, perhaps because the heat pumps could not meet the load.



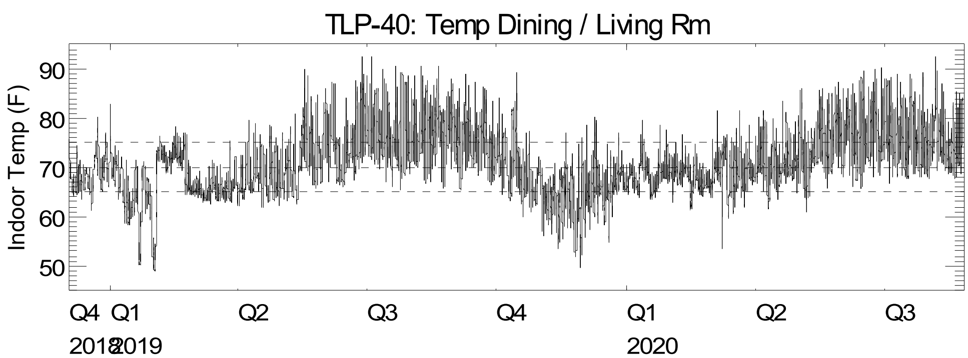


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 41 Savings Analysis

This 3,000 sq ft single-family home originally used a gas boiler with conventional baseboard radiation. One ducted electric heat pump with a total capacity of 4 tons were added to the home in late 2018. The gas boiler remained in place to help heat the house on the coldest days. Monitoring equipment was installed on December 20, 2018 to collect data at 15-minute intervals. The house had no weatherization improvements.

Table 1 summarizes the energy use of the heat pump across the period. Figure 1 shows the trend of power use for the heat pump.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown a
s white.

Figure 3 shows the daily energy use of the heat pump and the gas boiler. The gas boiler clearly meets a most of all of the heating load in the colder months. The heat pump is primarily used in the swing seasons.

Table 1. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	Boiler Runtime (hrs)
Dec-18	37%	123.1	123.1	90.6
Jan-19	100%	31.8	31.8	441.9
Feb-19	100%	62.8	62.8	409.5
Mar-19	100%	484.7	484.7	152.5
Apr-19	100%	187.3	187.3	40.1
May-19	100%	92.8	92.8	16.2
Jun-19	100%	64.7	64.7	-
Jul-19	100%	312.2	312.2	-
Aug-19	100%	174.8	174.8	0.7
Sep-19	100%	59.3	59.3	-
Oct-19	100%	132.2	132.2	5.8
Nov-19	100%	239.2	239.2	249.1
Dec-19	100%	97.4	97.4	423.5
Jan-20	100%	38.4	38.4	455.7
Feb-20	100%	57.2	57.2	373.5
Mar-20	100%	331.9	331.9	78.7
Apr-20	100%	146.2	146.2	143.2
May-20	100%	52.7	52.7	56.0
Jun-20	100%	207.6	207.6	-
Jul-20	100%	393.2	393.2	-
Aug-20	79%	143.2	143.2	-
Annual	100%	1,939.2	1,939.2	1,739.3
Summer (Jun-Sep)		611.0	611.0	0.7
Winter (Oct-May)		1,328.2	1,328.2	1,738.6

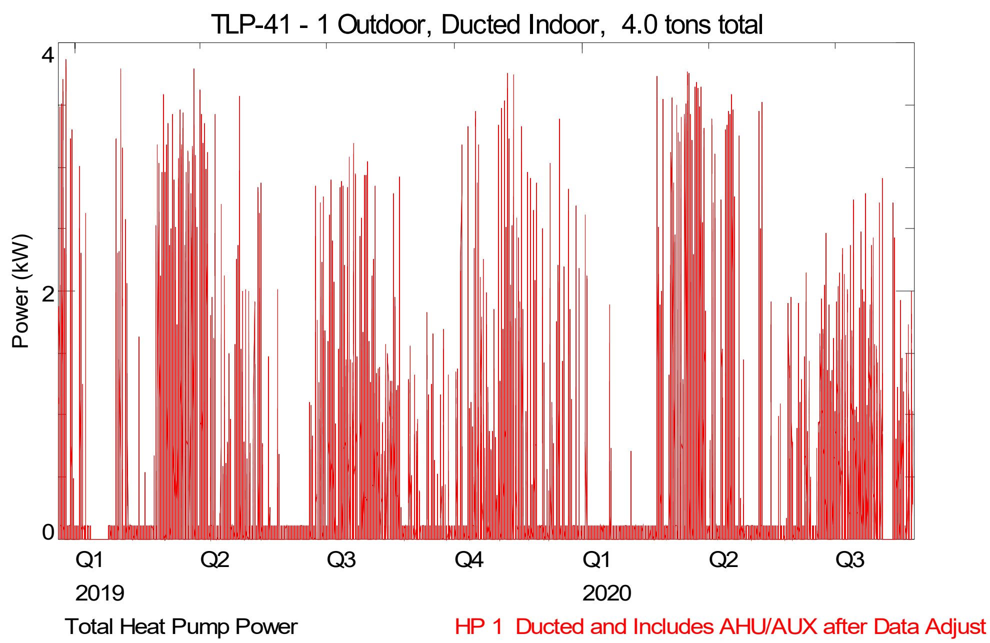


Figure 1. Plot of Power Use for All Heat Pumps at Site

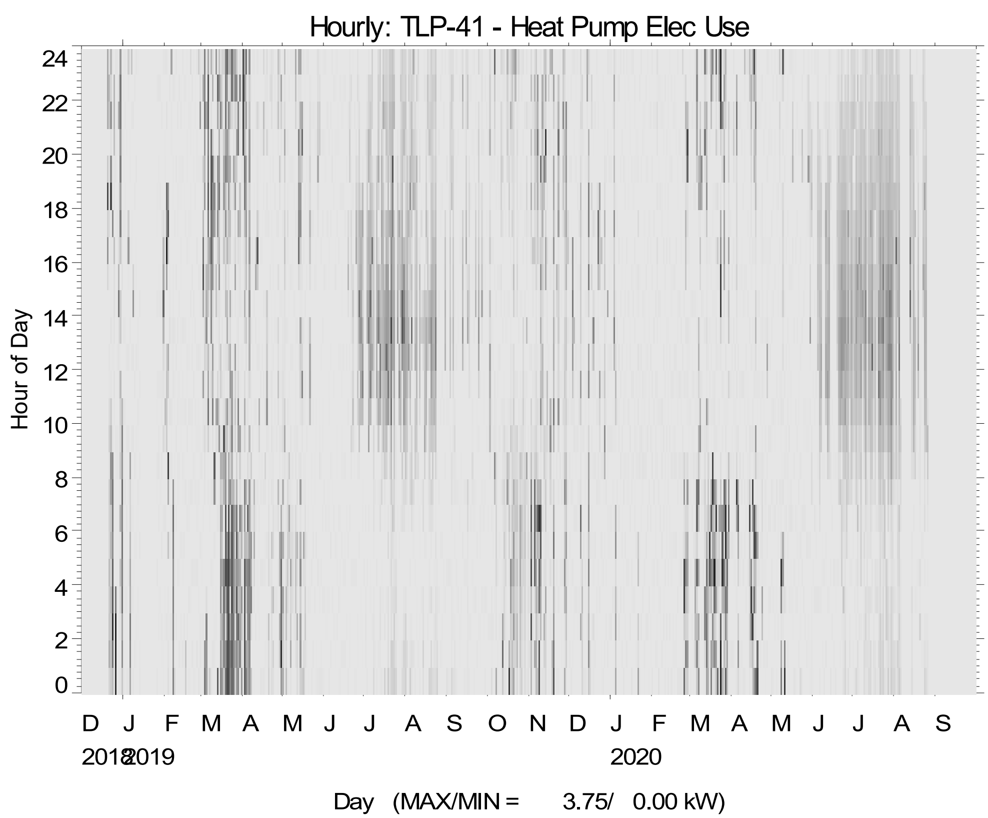


Figure 2. Shade Plot of Total Heat Pump Power

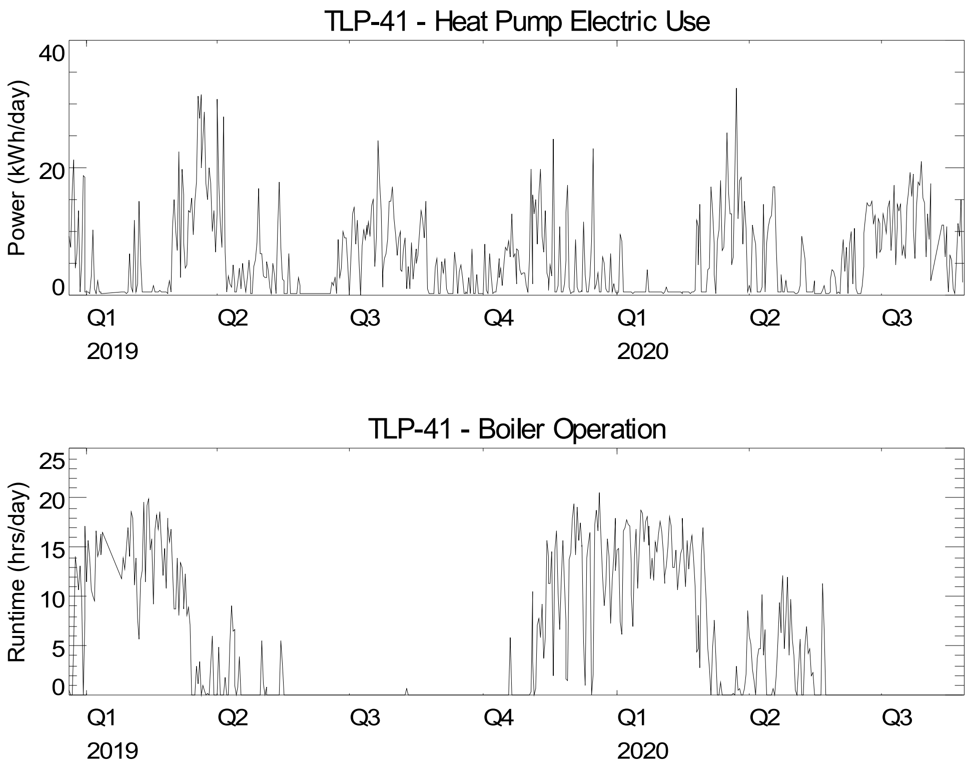


Figure 3. Plot of Daily Total HP Electric Use (and Boiler runtime)

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from Islip airport. The data for each month are shown with different colors. Different symbol types are used for each year. There is not a consistent linear trend with outdoor temperature, implying that the homeowners varied the thermostat so as to disable the heat pumps for prolonged colder periods in the winter.

Figure 5 confirms that the days with less heat pump operation correspond to more daily boiler operation.

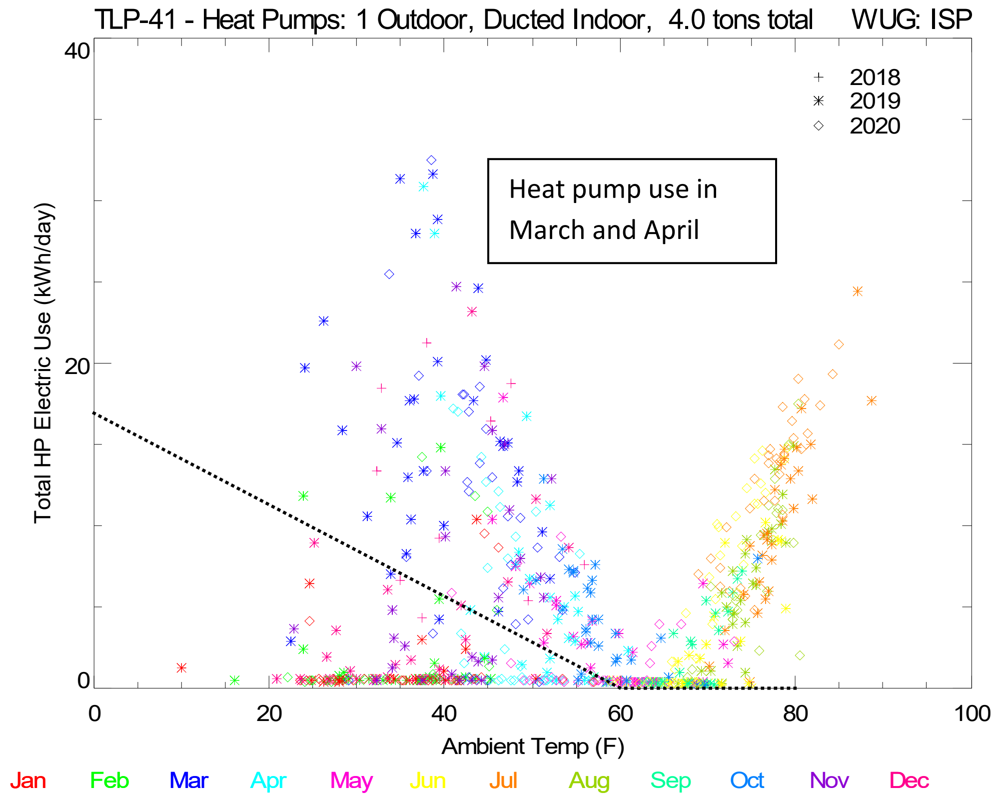


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

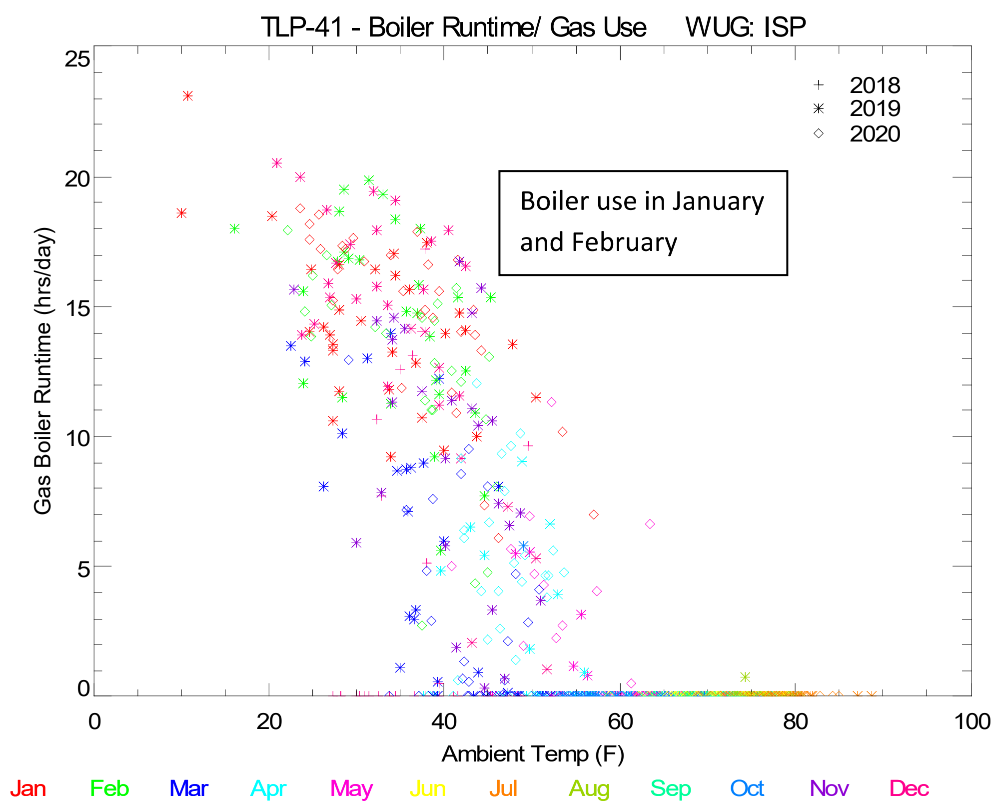


Figure 5. Daily Boiler Runtime versus Outdoor Temperature

Figure 6 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. Pre-retrofit data are shown as diamonds. Post-retrofit readings have month numbers associated with each data point. The solid black line shows the linear best fit line to the pre-retrofit data. The dotted line shows the best fit to the post retrofit data. The post-retrofit trend is actually higher than the pre-retrofit trend.

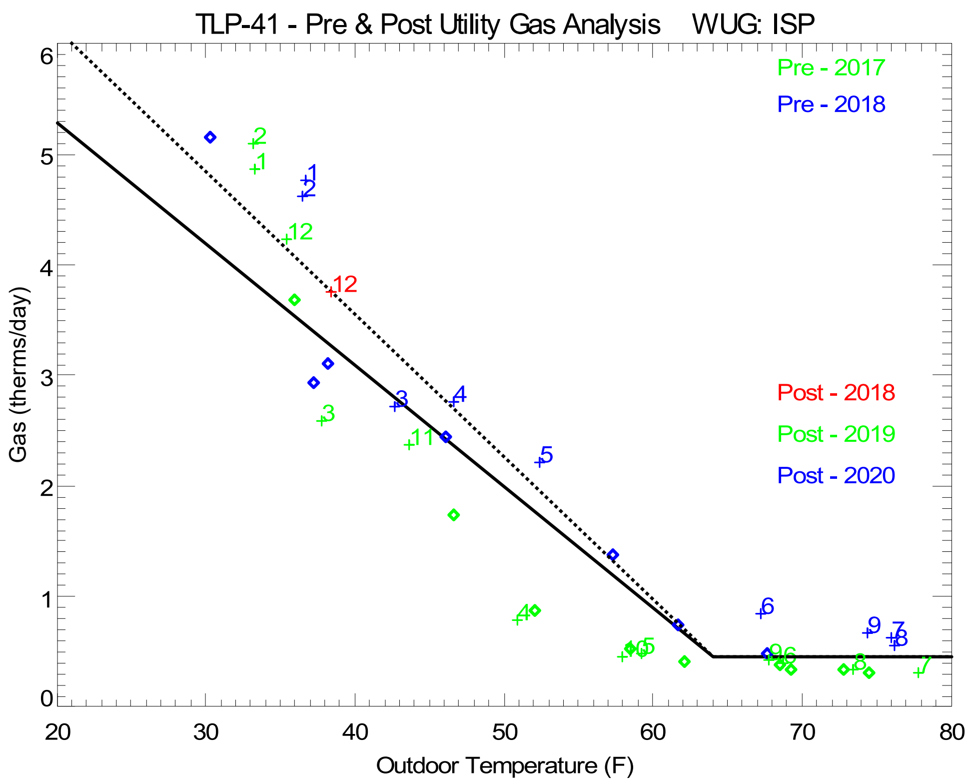


Figure 6. Trend of Gas Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre- and Post-Retrofit Periods

Annual Savings Analysis

The trends described in the plots above (focused on early Winter 2018) were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 7 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 8 shows the linear trend for POST-retrofit electric use of the heat pumps.

Table 2. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-41** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Gas** $ 1.403 per therm

Floor Area **3000**

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	10.5	12.3	24.8	12.3	0.0	14.7	22.2	0.0
-22.5	0	9.9	11.6	23.4	11.6	0.0	14.0	21.0	0.0
-17.5	0	9.4	11.0	22.0	11.0	0.0	13.2	19.8	0.0
-12.5	0	8.8	10.3	20.5	10.3	0.0	12.4	18.6	0.1
-7.5	0	8.3	9.7	19.1	9.7	0.0	11.6	17.4	0.1
-2.5	0	7.7	9.0	17.7	9.0	0.0	10.9	16.2	0.1
2.5	0	7.2	8.4	16.3	8.4	0.0	10.1	15.0	0.1
7.5	11	6.7	7.7	14.9	7.7	0.0	9.3	13.8	0.1
12.5	22	6.1	7.1	13.5	7.1	0.0	8.6	12.7	0.1
17.5	101	5.6	6.5	12.0	6.5	0.0	7.8	11.5	0.1
22.5	167	5.0	5.8	10.6	5.8	0.0	7.0	10.3	0.1
27.5	247	4.5	5.2	9.2	5.2	0.0	6.3	9.1	0.1
32.5	475	3.9	4.5	7.8	4.5	0.0	5.5	7.9	0.1
37.5	855	3.4	3.9	6.4	3.9	0.0	4.7	6.7	0.1
42.5	708	2.8	3.2	5.0	3.2	0.0	3.9	5.5	0.2
47.5	608	2.3	2.6	3.5	2.6	0.0	3.2	4.3	0.2
52.5	880	1.7	1.9	2.1	1.9	0.0	2.4	3.1	0.3
57.5	750	1.2	1.3	0.7	1.3	0.0	1.6	2.0	0.4
62.5	814	0.6	0.6	0.0	0.6	0.0	0.9	0.9	0.7
67.5	723	0.5	0.5	0.0	0.5	0.0	0.6	0.6	1.0
72.5	751	0.5	0.5	0.0	0.5	0.0	0.6	0.6	1.0

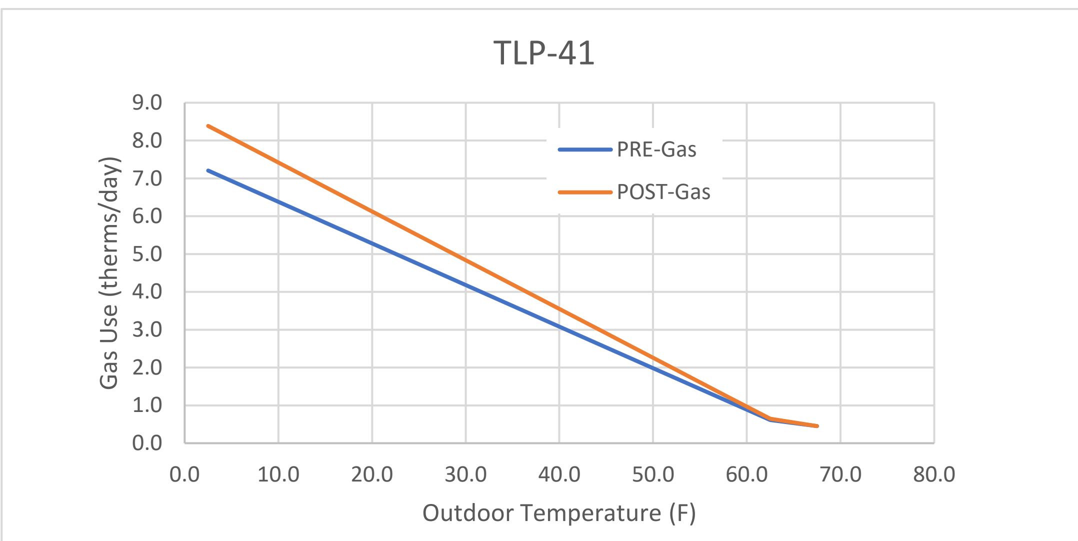


Figure 7. Trend of PRE- and POST-Retrofit Gas Use with Outdoor Temperature for Bin Analysis

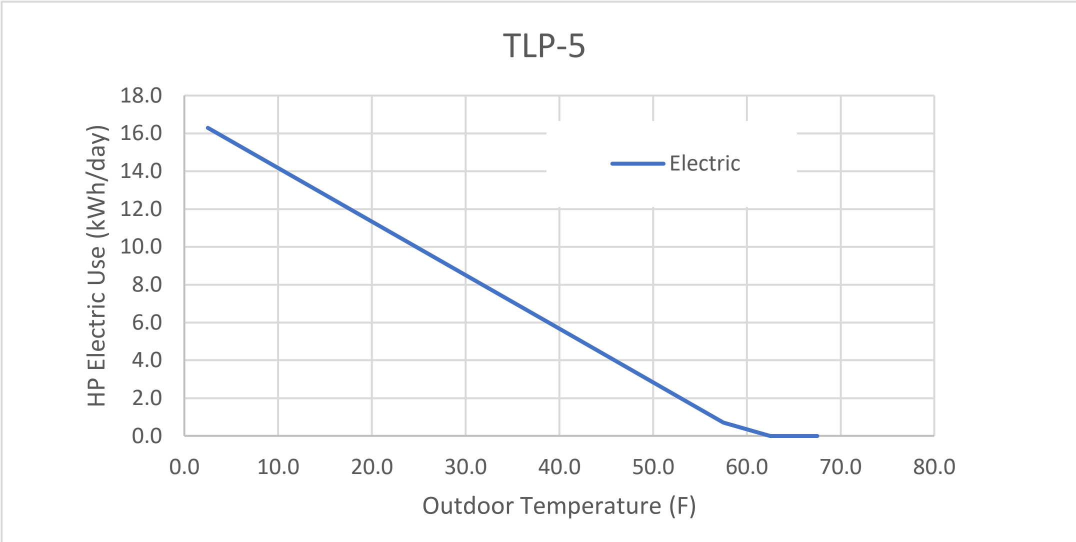


Figure 8. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 3 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be -83 therms per year for the heat pump. There were no savings and implied COP could not be determined.

Table 3. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-41	**PRE Retrofit**	**POST Retrofit**	**Envelope Savings**	**ASHP & Env Savings**	**ASHP Savings**
Gas (therms/yr)	464	546	-	(82)	(82)
HP Electric (kWh/yr)		956		(956)	
Total Heating Costs	$ 651	$ 957	$ -	$ (306)	$ (306)
Implied Seasonal COP				0.0	0.0

Summary Statistics	
0.15	Htg therms per sq ft per year
12.2	Htg MBtu per sq ft per year
-18%	Reduction in Htg Fuel Use
2,286	Measured HP Electric (kWh/yr)
239%	of typical year kWh

Implied COP seems too high.

<u>Average Heat Pump Demand Profiles</u>

Figure 9 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 10 shows the same calculation process associated with cooling operation.

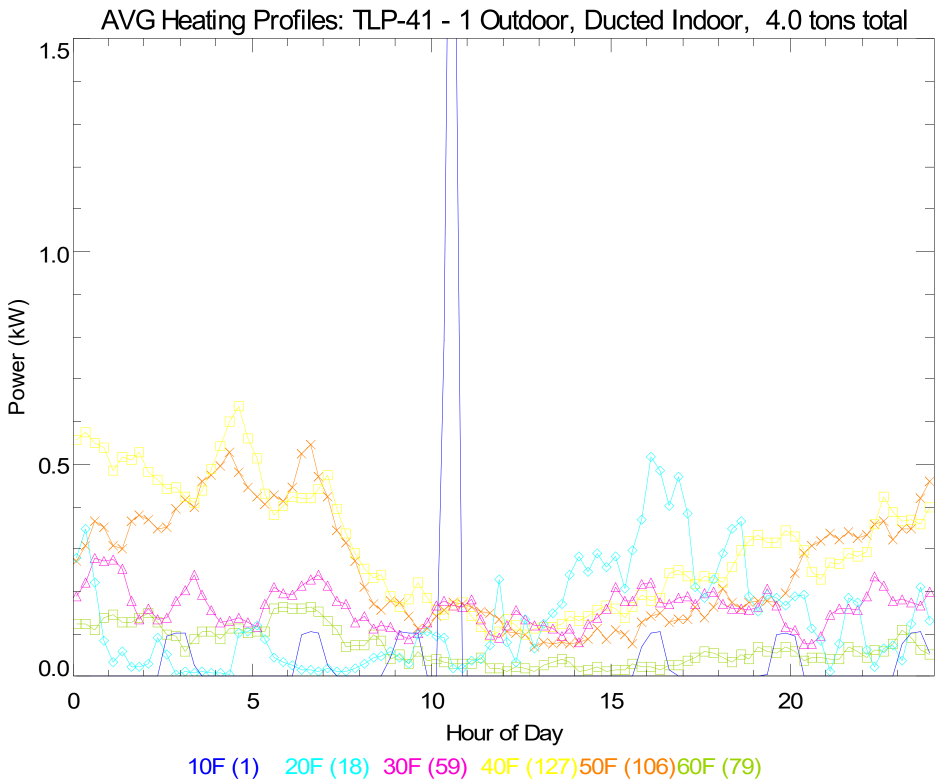


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

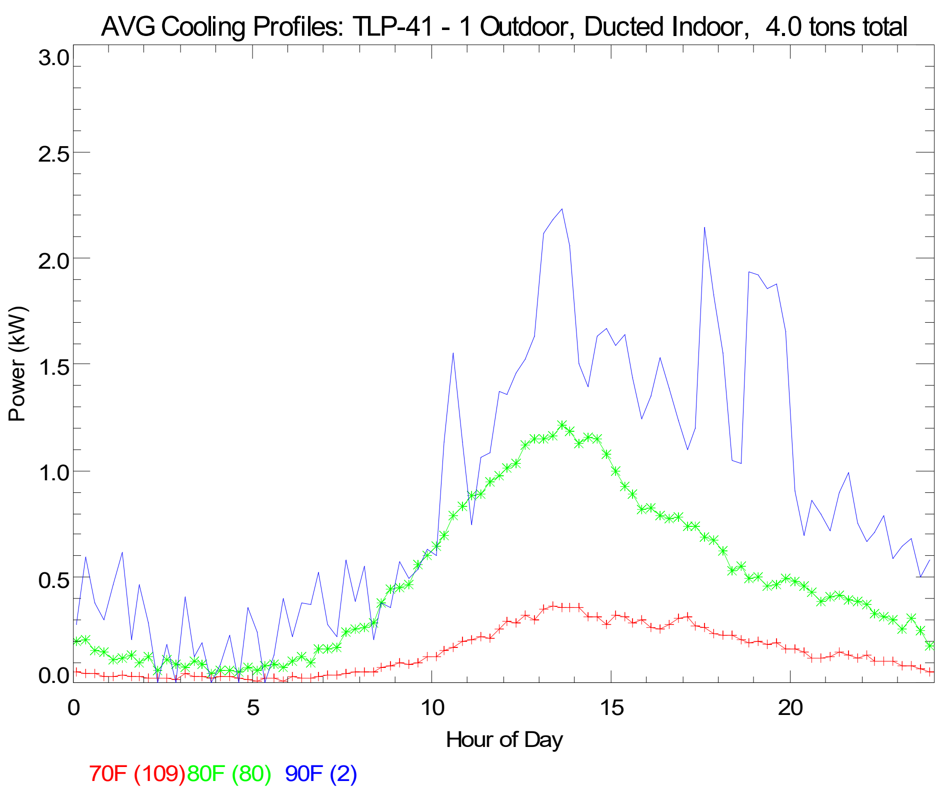


Figure 10. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 11

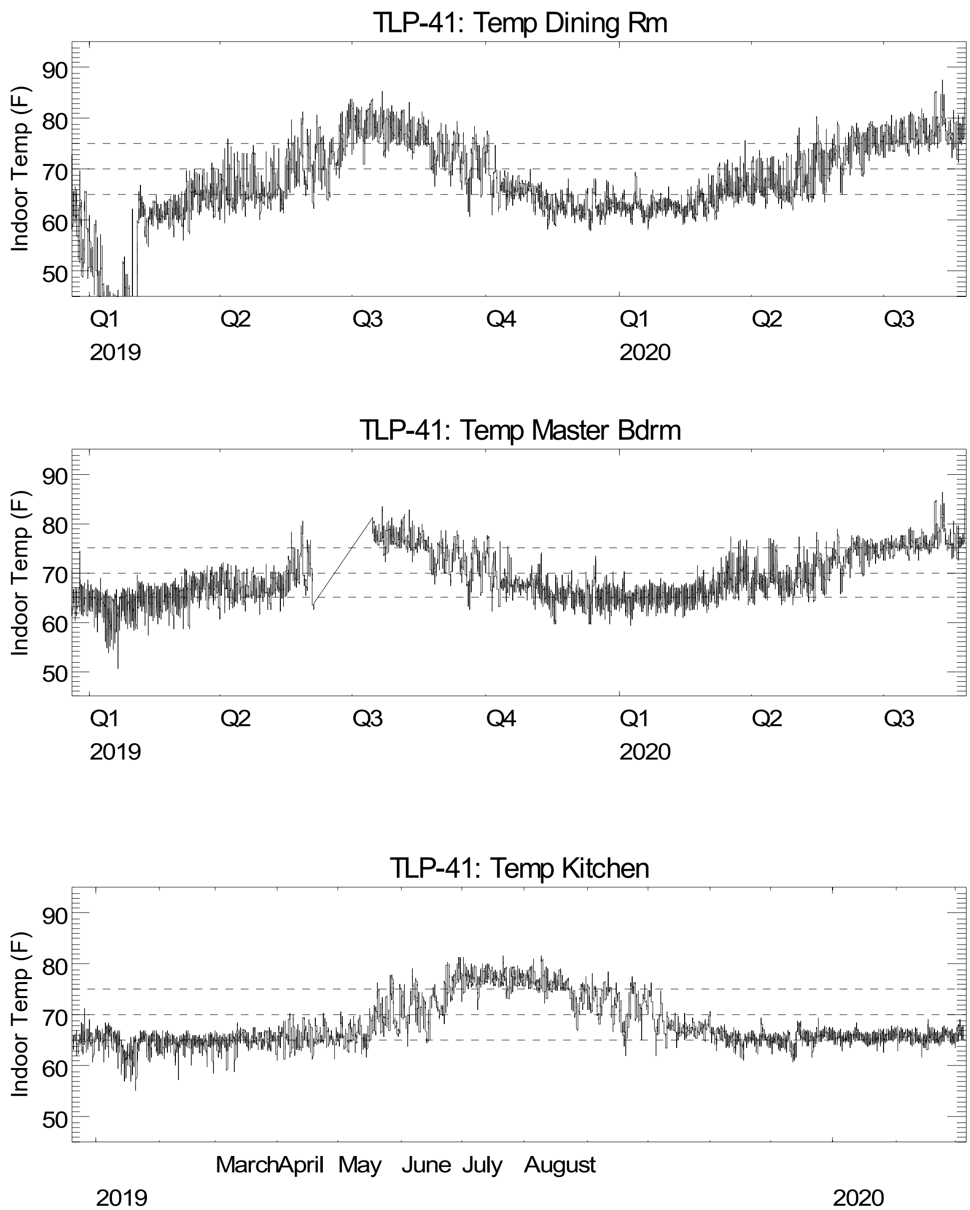


Figure 11. Plot of Space Temperatures at Various Indoor Locations

Site 44 Savings Analysis

This 1920 sq ft single-family home originally used a gas boiler with conventional baseboard radiation. Two electric heat pumps with a total capacity of 4 tons were added to the home in summer 2018. The gas boiler was removed. Monitoring equipment was installed on August 15, 2018 to collect data at 15-minute intervals. The house also had weatherization improvements (rim joist, insulation) implemented that were projected to save 20%, according to the change in Manual J loads, or 234 therms per year. Table 1 summarizes the proposed envelope measures, which were fully implemented.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	Proposed Details	Final Details
	Rim joist	Completed
	insulation	Completed
ALL SAVINGS:	234 therms (20% of annual gas use)	

Note: savings estimated by change in Manual J Design Load due to weatherization

Table 2 summarizes the energy use of the heat pump across the period. Figure 1 shows the trend of power use for the heat pump.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the heat pump.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)
Aug-18	53%	160.8	102.3	58.5
Sep-18	100%	112.3	63.5	48.8
Oct-18	100%	235.4	145.5	89.8
Nov-18	100%	625.3	350.0	275.3
Dec-18	100%	832.1	425.2	406.9
Jan-19	100%	1,219.6	672.3	547.3
Feb-19	100%	968.3	506.9	461.3
Mar-19	100%	757.5	387.2	370.3
Apr-19	100%	215.8	111.7	104.0
May-19	100%	64.1	38.1	26.1
Jun-19	100%	72.1	48.4	23.6
Jul-19	100%	299.7	192.5	107.2
Aug-19	100%	162.1	99.3	62.8
Sep-19	100%	66.2	33.8	32.4
Oct-19	100%	84.8	55.8	29.1
Nov-19	100%	623.1	370.7	252.4
Dec-19	50%	482.0	267.8	214.2
Annual	100%	5,564.3	3,040.6	2,523.4
Summer (Jun-Sep)		646.2	403.7	242.4
Winter (Oct-May)		4,918.1	2,636.9	2,281.0

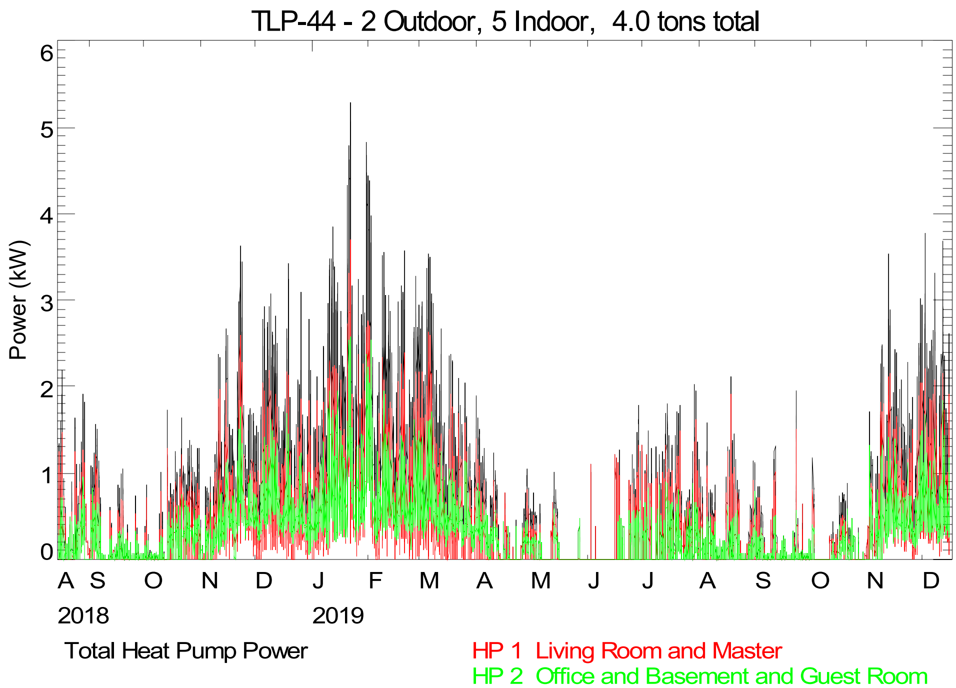


Figure 1. Plot of Power Use for All Heat Pumps at Site

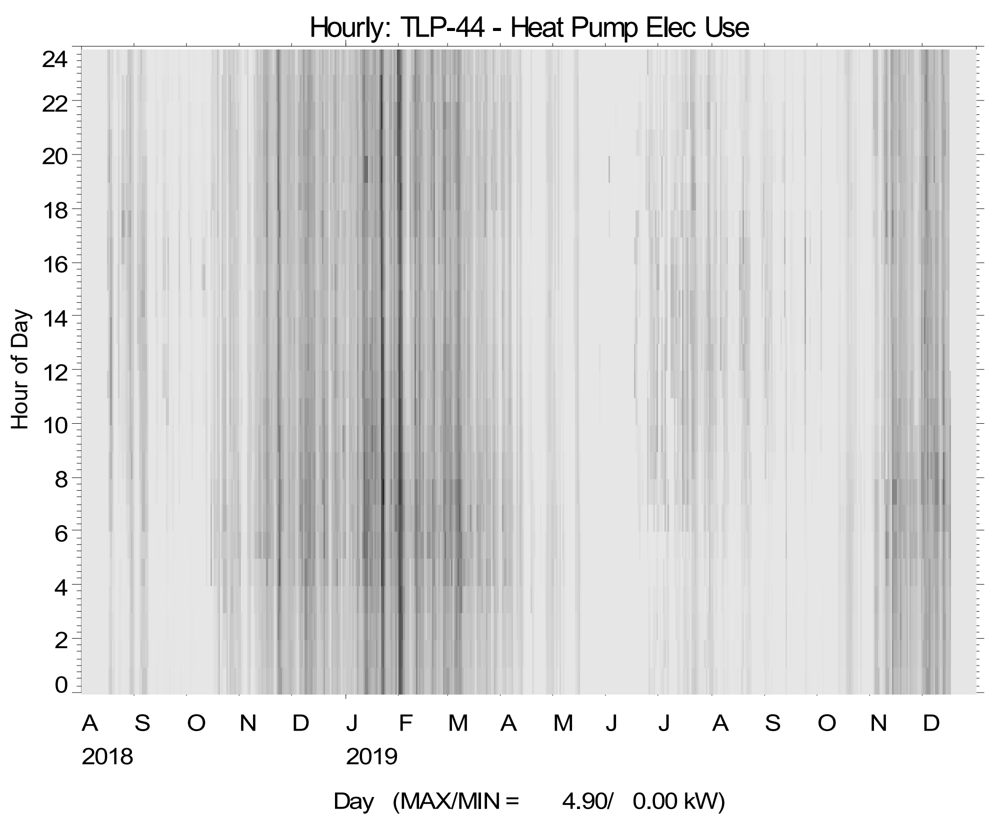


Figure 2. Shade Plot of Total Heat Pump Power

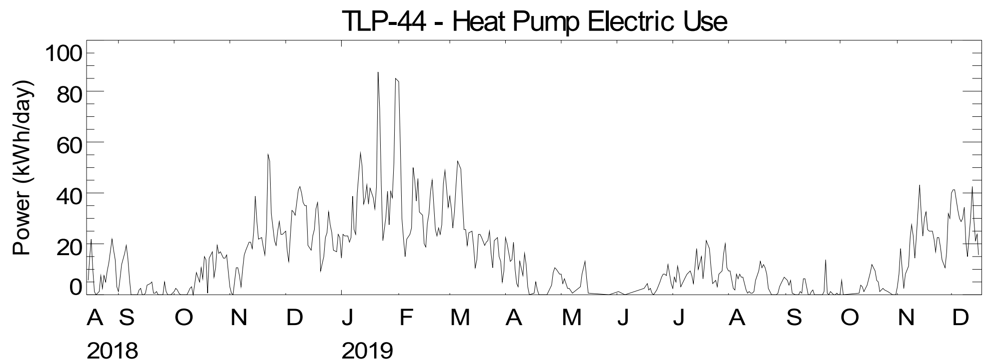


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year. The dotted line is the best fit the data.

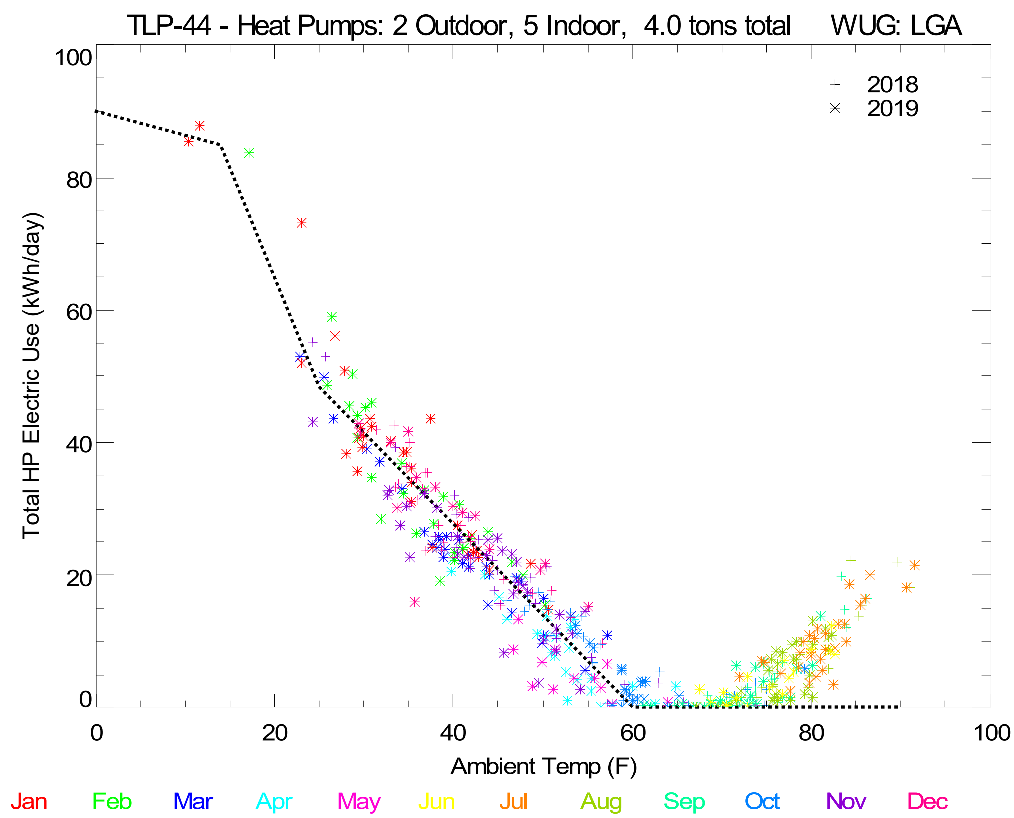


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre- and post-retrofit trends of gas use with ambient temperature based on utility bills. Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data. The boiler was removed so the post-retrofit data corresponds to other non-space heating end used in the home.

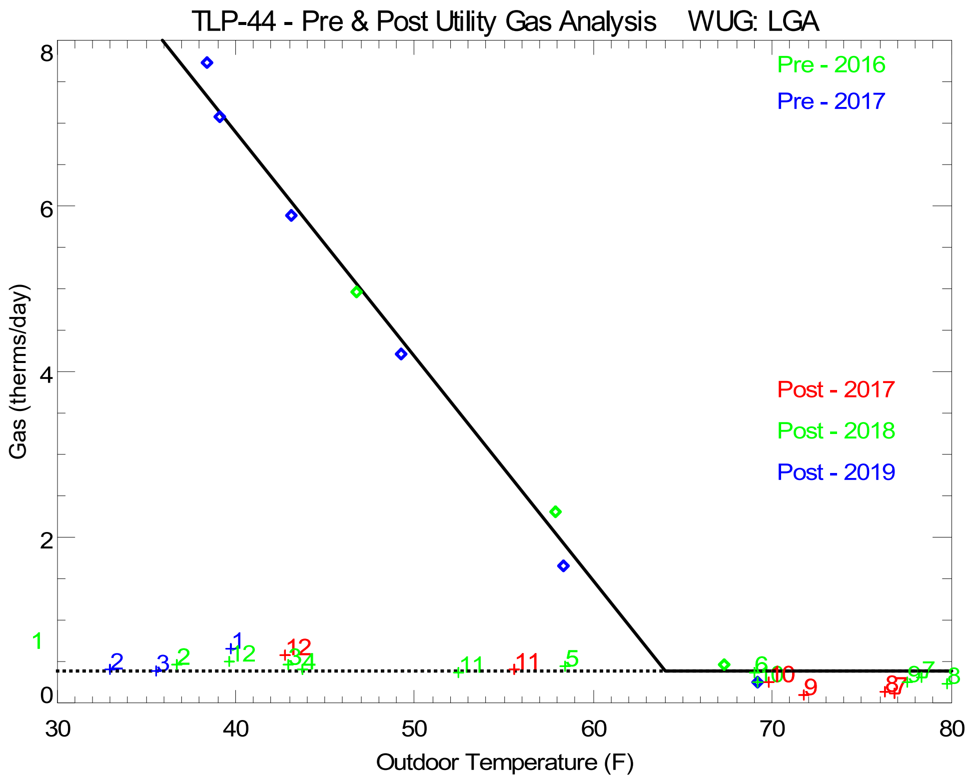


Figure 5. Trend of Gas Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre- and Post-Retrofit Periods

<u>Annual Savings Analysis</u>

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 7 shows the linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE:	**TLP-44**	WEATHER:	**New_York**	$ 0.20 per kWh
FUEL:	**Gas**			$ 1.403 per therm

Floor Area **1920**

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	25.2	0.4	99.8	0.4	5.7	35.3	20.5	
-22.5	0	23.8	0.4	98.0	0.4	5.5	33.4	20.2	
-17.5	0	22.5	0.4	96.3	0.4	5.3	31.5	19.8	
-12.5	0	21.1	0.4	94.5	0.4	5.1	29.6	19.5	
-7.5	0	19.7	0.4	92.7	0.4	4.8	27.7	19.1	
-2.5	0	18.4	0.4	90.9	0.4	4.6	25.8	18.7	
2.5	0	17.0	0.4	89.1	0.4	4.3	23.9	18.4	
7.5	11	15.7	0.4	87.3	0.4	4.1	22.0	18.0	
12.5	22	14.3	0.4	85.5	0.4	3.8	20.1	17.7	
17.5	101	13.0	0.4	73.4	0.4	4.0	18.2	15.2	
22.5	167	11.6	0.4	56.8	0.4	4.6	16.3	11.9	
27.5	247	10.3	0.4	45.0	0.4	5.1	14.4	9.6	
32.5	475	8.9	0.4	38.1	0.4	5.2	12.5	8.2	
37.5	855	7.6	0.4	31.2	0.4	5.3	10.6	6.8	
42.5	708	6.2	0.4	24.3	0.4	5.6	8.7	5.4	
47.5	608	4.9	0.4	17.3	0.4	6.0	6.8	4.0	
52.5	880	3.5	0.4	10.4	0.4	6.9	4.9	2.6	
57.5	750	2.2	0.4	3.5	0.4	11.8	3.0	1.3	
62.5	814	0.8	0.4	0.0	0.4	99.0	1.1	0.6	
67.5	723	0.4	0.4	0.0	0.4	0.0	0.6	0.6	
72.5	751	0.4	0.4	0.0	0.4	0.0	0.6	0.6	

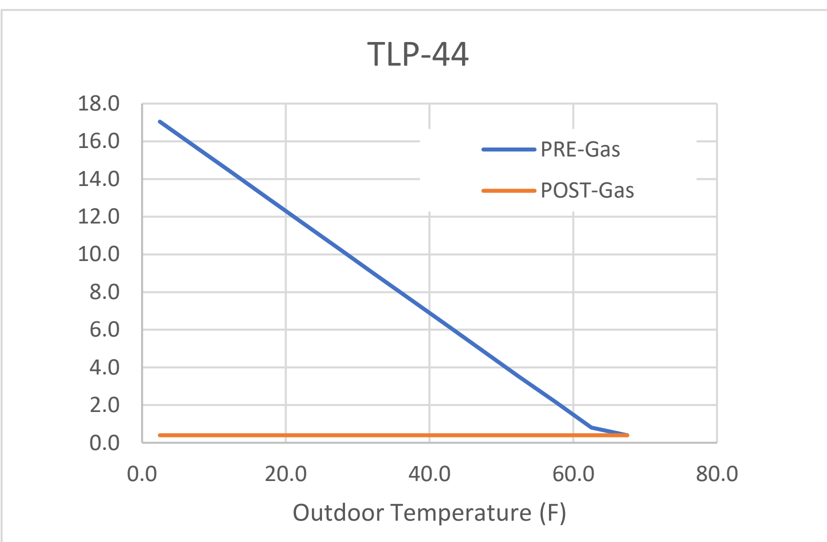


Figure 6. Trend of PRE- and POST-Retrofit Gas Use with Outdoor Temperature for Bin Analysis

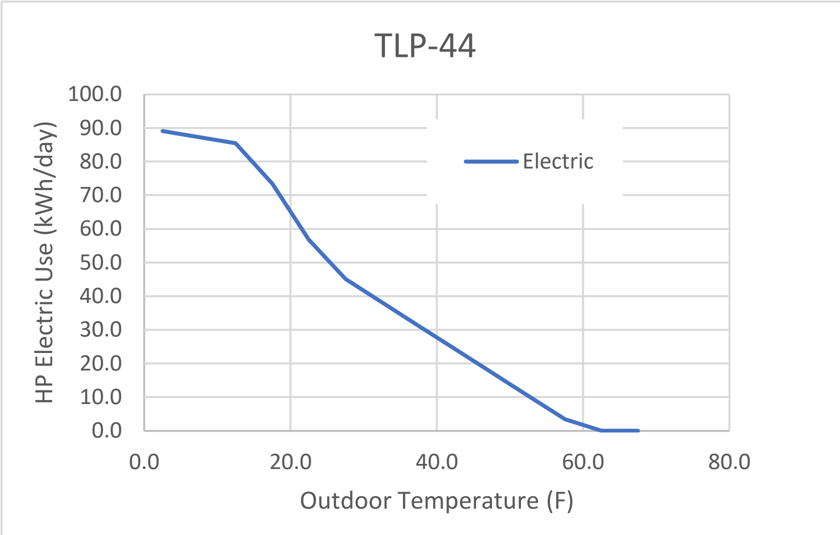


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total gas savings are estimated to be 1,144 therms per year for all improvements. However, if we subtract the gas savings from the envelope improvements, the fuel savings attributable to the heat pumps is 910 therms per year. The heat pumps are estimated to use 4,794 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 4.4.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-44	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Gas (therms/yr)	1,144	-	234	1,144	910
HP Electric (kWh/yr)		4,794		(4,794)	
Total Heating Costs	$ 1,606	$ 959	$ 329	$ 647	$ 318
Implied Seasonal COP				5.5	4.4

Summary Statistics	
0.60	Htg therms per sq ft per year
47.1	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
4,918	Measured HP Electric (kWh/yr)
103%	of typical year kWh

The implied COP seems VERY high. It is possible that some electric heat is used by a new radiant heater in the bathroom and by a wall heater in the laundry area. Another possibility is that the envelope improvements were more extensive than was implied by the 20% change in Manual J loads. Frontier staff reported that extensive work was completed as part of this gut rehab.

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

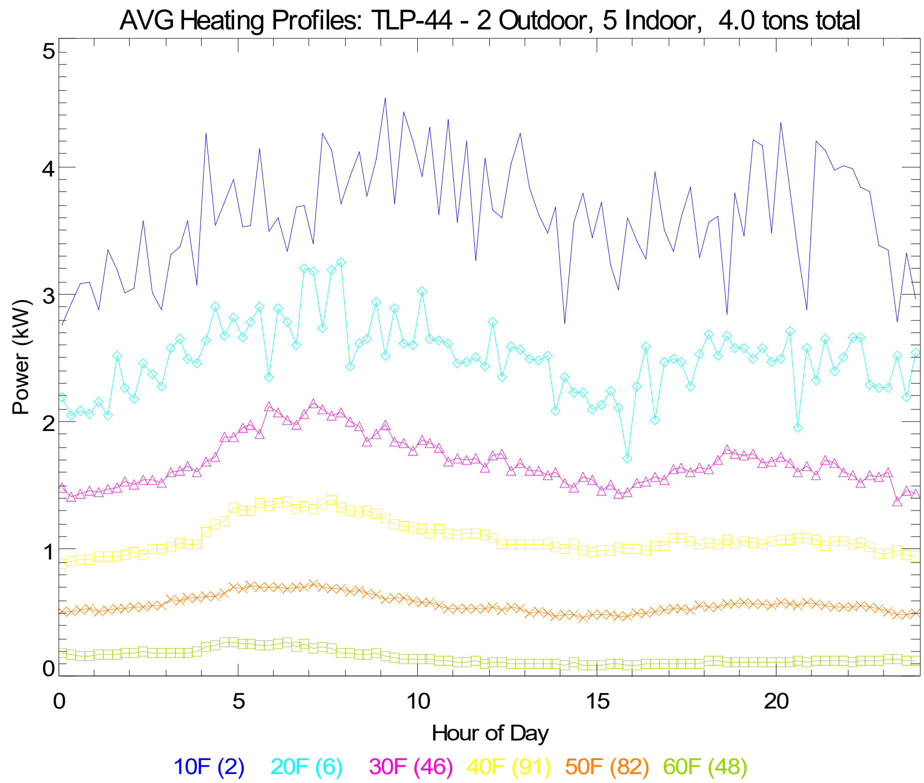


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

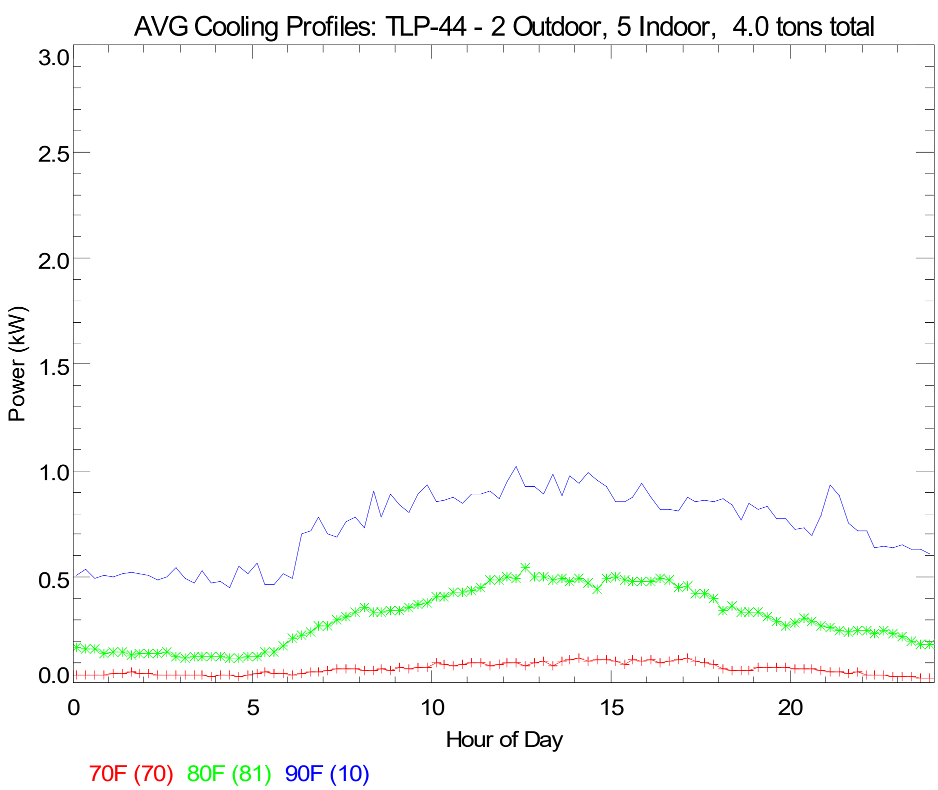
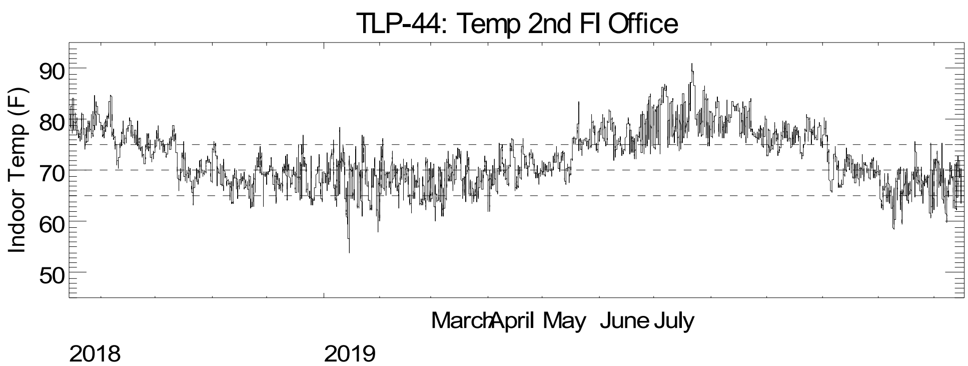
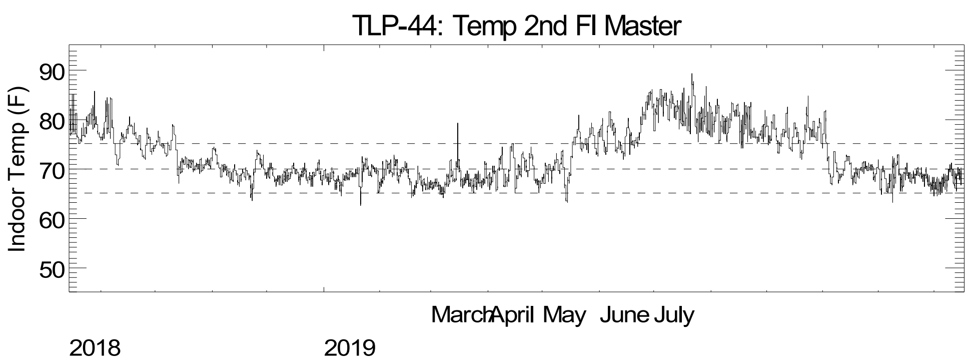


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.





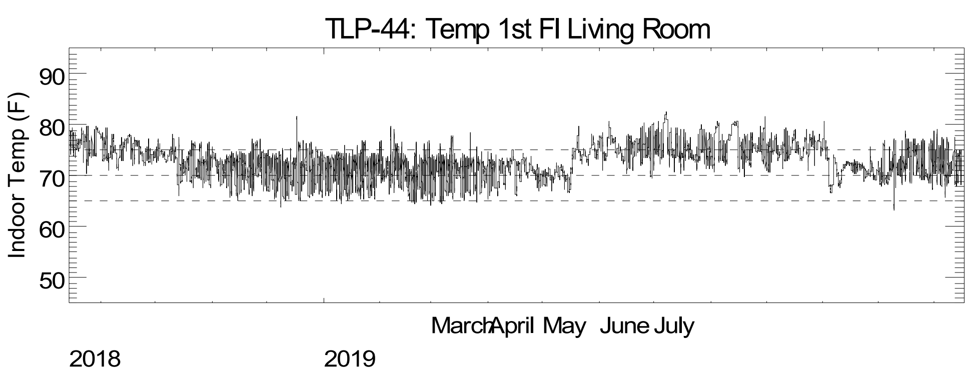


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 45 Savings Analysis

This 3,600 sq ft multi-family brownstone home originally used an oil boiler with conventional baseboard radiation. Five electric heat pumps with a total capacity of 8.5 tons were added to the home: the first four in Spring 2015 and the last one in Early 2018. The boiler was removed. Monitoring equipment was installed on August 15, 2018 to collect data at 15-minute intervals.

The house was expanded (from 3,099 to 3,600 sq ft) also had weatherization improvements (wall insulation, windows, and attic insulation) implemented that were projected to save 26%, according to the change in Manual J load, or 149 therms per year. Table 1 summarizes the proposed envelope measures, which were fully implemented.

Table 1. Summary List of Proposed and Final Envelope Measures

Measure	Proposed Details	Final Details
insulation	Walls and attic	Completed
Windows		Completed
ALL SAVINGS:	149 therms (26% of annual gas use)	

Note: savings estimated by change in Manual J Design Load due to weatherization.

Table 2 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps.

Table 2. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)	HP3 (kWh)	HP4 (kWh)	HP5 (kWh)
Mar-19	54%	435.9	77.3	107.4	15.8	154.4	81.0
Apr-19	100%	552.0	124.6	116.4	-	150.9	160.1
May-19	100%	447.6	73.7	61.5	1.0	207.9	103.5
Jun-19	100%	376.1	71.0	47.5	16.9	186.2	54.4
Jul-19	100%	856.3	275.8	120.7	65.1	340.1	54.6
Aug-19	100%	592.2	157.5	88.3	33.4	257.5	55.4
Sep-19	100%	308.3	61.3	57.2	0.8	137.8	51.2
Oct-19	100%	395.1	130.0	88.8	0.2	75.6	100.5
Nov-19	100%	1,152.6	354.9	282.8	37.9	358.8	118.2
Dec-19	100%	1,520.3	408.3	333.4	81.0	449.0	248.6
Jan-20	100%	1,412.0	416.9	336.0	51.5	405.2	202.2
Feb-20	100%	1,290.4	405.5	289.7	31.7	356.4	207.1
Mar-20	100%	979.6	242.2	233.6	-	263.4	240.5
Apr-20	100%	727.3	239.3	181.5	0.4	204.5	101.6
May-20	100%	427.4	75.1	98.0	-	200.7	53.6
Jun-20	100%	517.6	123.9	70.7	-	271.8	51.1
Jul-20	100%	783.3	227.3	118.0	-	385.6	52.4
Aug-20	85%	563.5	154.7	105.5	-	259.0	44.3
Annual	100%	9,882.5	2,721.7	2,055.9	319.5	3,188.8	1,596.3
Summer (Jun-Sep)		2,132.9	565.6	313.7	116.2	921.6	215.6
Winter (Oct-May)		7,749.6	2,156.1	1,742.2	203.3	2,267.2	1,380.7

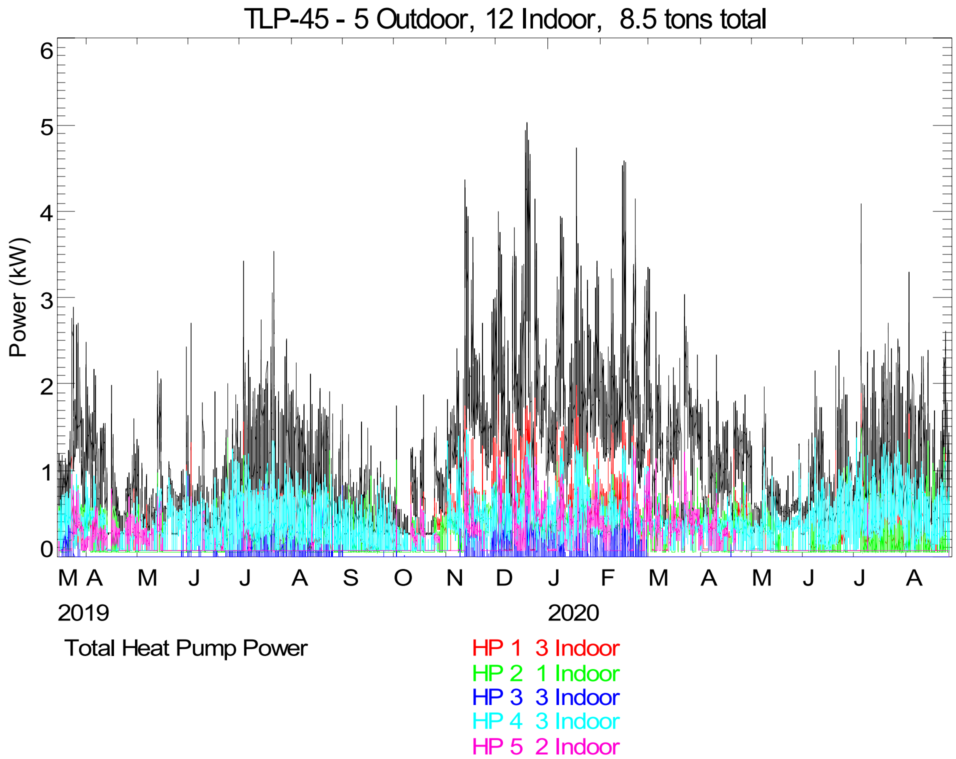


Figure 1. Plot of Power Use for All Heat Pumps at Site

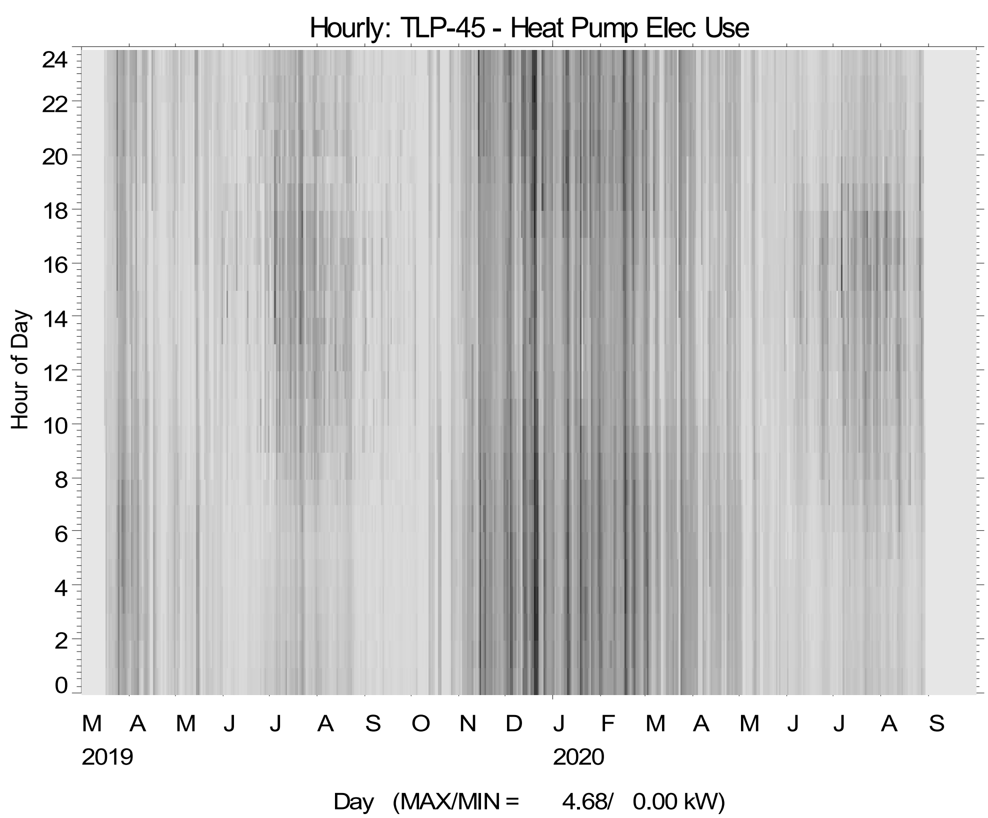


Figure 2. Shade Plot of Total Heat Pump Power

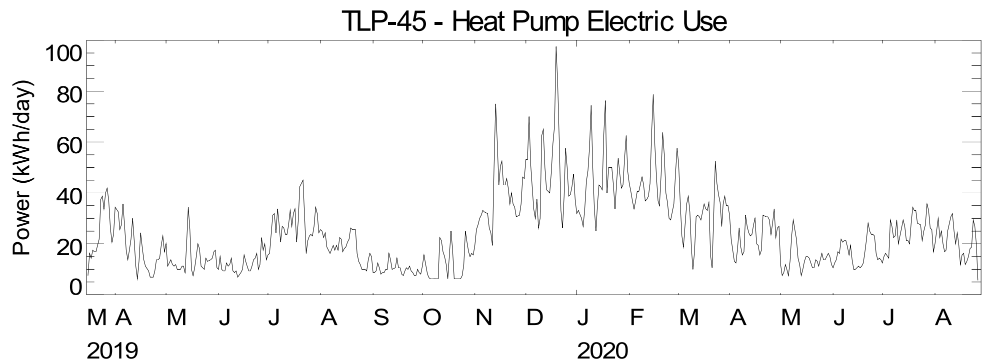


Figure 3. Plot of Daily Total HP Electric Use (and boiler runtime)

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from the LGA. The data for each month are shown with different colors. Different symbol types are used for each year.

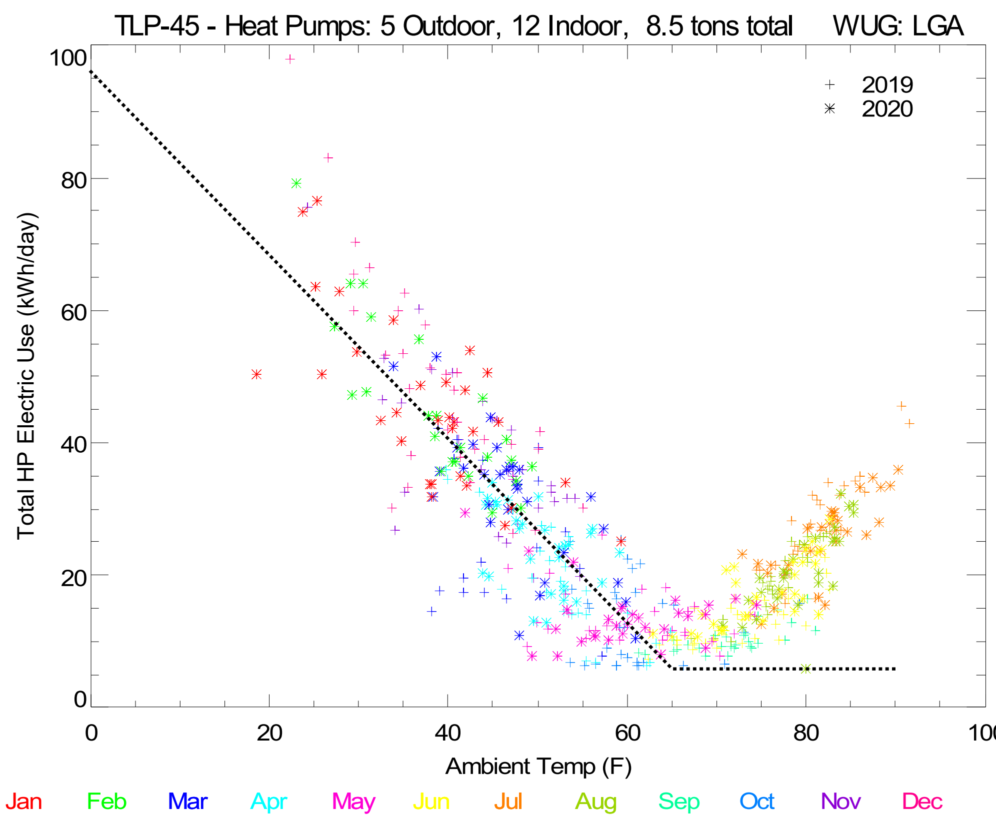


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre-retrofit oil use trend with ambient temperature based on fuel delivery logs from the previous years (before the first heat pumps were installed). Readings from different years are shown with different colors. The solid black line shows the linear best fit line to the pre-retrofit data.

There was no post-retrofit oil consumption since the boiler was removed. DHW was converted to electric at this house, so in the analysis we assume the post retrofit period had same baseline summer use as in the pre-retrofit period.

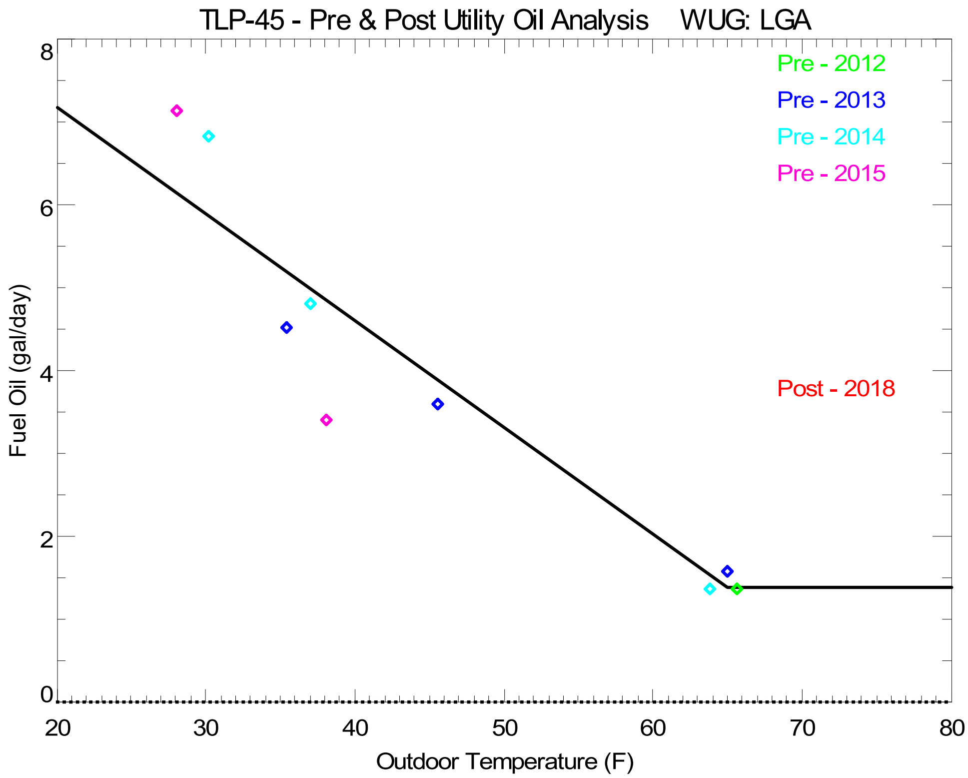


Figure 5. Trend of Oil Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

Annual Savings Analysis

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for oil use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-45** WEATHER: **New_York** $ 0.20 per kWh
FUEL: **Oil** $ 2.447 per gal

Floor Area **3600**

Temp Bin	Hours	FUEL PRE-Oil (gal/day)	FUEL POST-Oil (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Oil (gal/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Oil adjustment factor
-27.5	0	13.3	0.0	134.1	1.4	3.0	32.5	30.2	0.1
-22.5	0	12.6	0.0	127.2	1.4	3.0	30.9	28.9	0.1
-17.5	0	12.0	0.0	120.2	1.4	3.0	29.4	27.5	0.1
-12.5	0	11.4	0.0	113.3	1.4	3.0	27.8	26.1	0.1
-7.5	0	10.7	0.0	106.4	1.4	3.0	26.2	24.7	0.1
-2.5	0	10.1	0.0	99.5	1.4	3.0	24.6	23.3	0.1
2.5	0	9.4	0.0	92.5	1.4	3.0	23.1	21.9	0.1
7.5	11	8.8	0.0	85.6	1.4	3.0	21.5	20.5	0.2
12.5	22	8.1	0.0	78.7	1.4	2.9	19.9	19.2	0.2
17.5	101	7.5	0.0	71.8	1.4	2.9	18.4	17.8	0.2
22.5	167	6.9	0.0	64.8	1.4	2.9	16.8	16.4	0.2
27.5	247	6.2	0.0	57.9	1.4	2.8	15.2	15.0	0.2
32.5	475	5.6	0.0	51.0	1.4	2.8	13.6	13.6	0.3
37.5	855	4.9	0.0	44.1	1.4	2.7	12.1	12.2	0.3
42.5	708	4.3	0.0	37.2	1.4	2.7	10.5	10.9	0.3
47.5	608	3.6	0.0	30.2	1.4	2.5	8.9	9.5	0.4
52.5	880	3.0	0.0	23.3	1.4	2.4	7.4	8.1	0.5
57.5	750	2.4	0.0	16.4	1.4	2.0	5.8	6.7	0.6
62.5	814	1.7	0.0	9.5	1.4	1.2	4.2	5.3	0.8
67.5	723	1.4	0.0	6.0	1.4	0.0	3.4	4.6	1.0
72.5	751	1.4	0.0	6.0	1.4	0.0	3.4	4.6	1.0
77.5	870	1.4	0.0	6.0	1.4	0.0	3.4	4.6	1.0

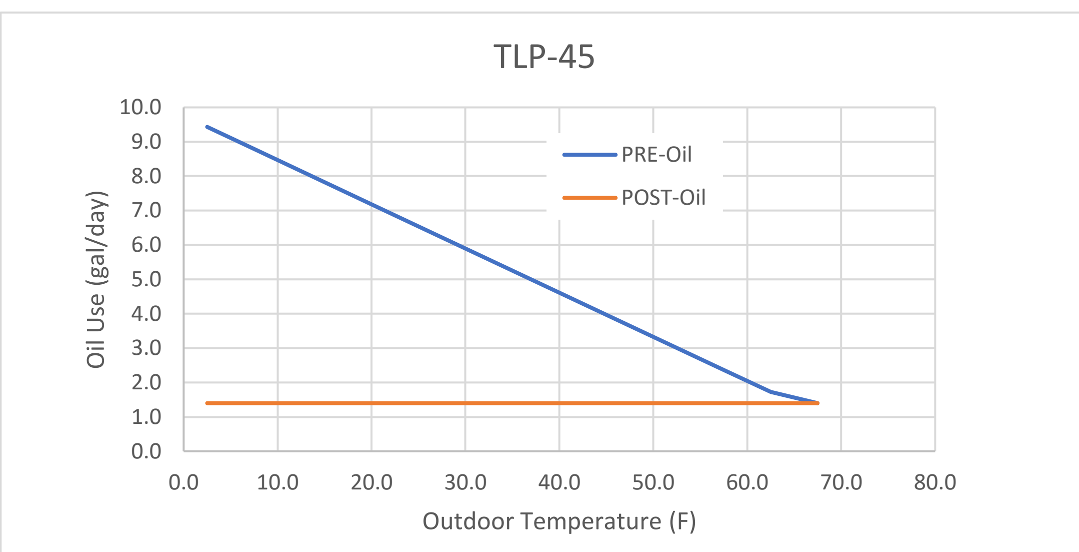


Figure 6. Trend of PRE- and POST-Retrofit Oil Use with Outdoor Temperature for Bin Analysis

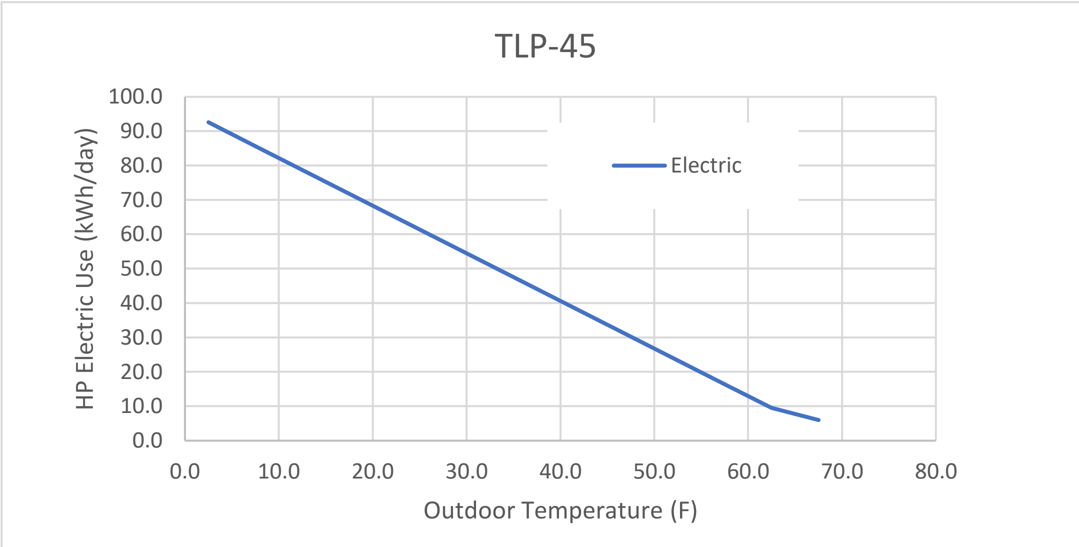


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total oil use savings for space heating are estimated to be 573 gallons per year for all improvements. However, if we subtract the oil savings from the envelope improvements, the fuel savings attributable to the heat pumps is 424 gallons per year. The heat pumps are estimated to use 7,771 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the oil savings to thermal heating output (using 84% efficiency) and dividing by the heat pump power input. In this case the implied COP is 1.9.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-45	PRE Retrofit	POST Retrofit	Envelope Savings	ASHP & Env Savings	ASHP Savings
Oil (gal/yr)	573	-	149	573	424
HP Electric (kWh/yr)		7,771		(7,771)	
Total Heating Costs	$ 1,403	$ 1,554	$ 366	$ (151)	$ (517)
Implied Seasonal COP				2.5	1.9

Summary Statistics	
0.16	Htg gal per sq ft per year
18.6	Htg MBtu per sq ft per year
100%	Reduction in Htg Fuel Use
9,149	Measured HP Electric (kWh/yr)
118%	of typical year kWh

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

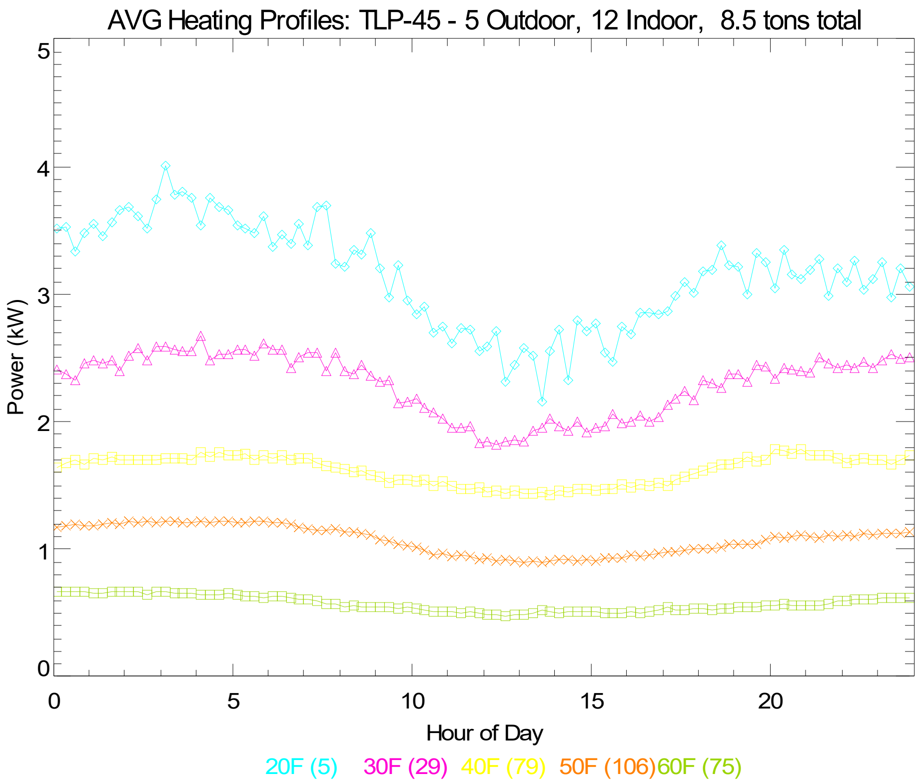


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

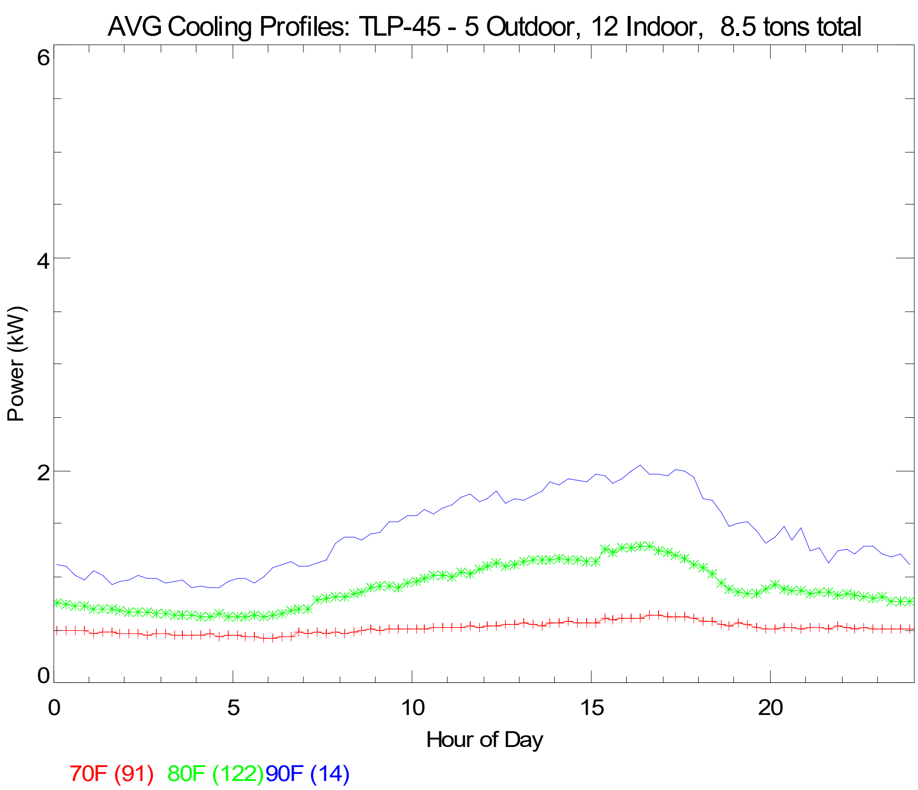


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

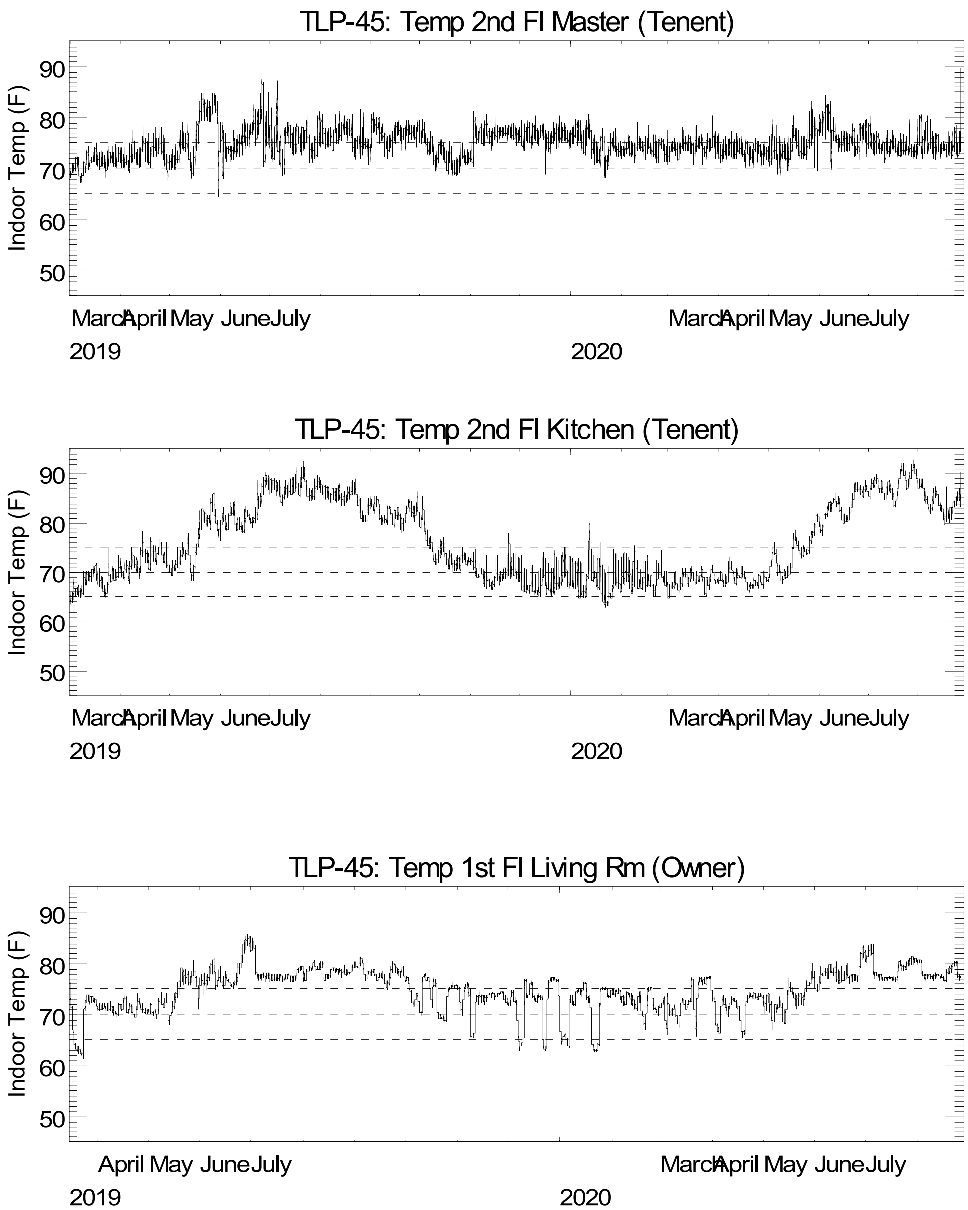


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Site 46 Savings Analysis

This 2,400 sq ft single-family home originally used a gas boiler with conventional baseboard radiation. Two electric heat pumps with a total capacity of 7 tons were added to the home in November 2018. The boiler remained in place to help meet the heating load on the coldest days. Monitoring equipment was installed on December 12, 2018 to collect data at 15-minute intervals. The house did not have any weatherization improvements.

Table 1 summarizes the energy use of the heat pumps across the period. Figure 1 shows the trend of power use for all the heat pumps. The black line represents the total of all the units.

Figure 2 is a shade plot that qualitatively shows the energy use pattern with shades of gray. Each day is shown as a vertical stripe on the plot. Successive days are shown along the x-axis. Periods with higher power are shown with darker shades of gray. Zero is shown by light gray. Missing data are shown as white.

Figure 3 shows the daily energy use of the all the heat pumps. Heat pump power use was considerably lower for the second winter.

Table 1. Summary of Monthly Heat Pump Energy Use and Boiler Runtime

	Pecent Good Data	All HPs (kWh)	HP1 (kWh)	HP2 (kWh)
Dec-18	89%	1,690.9	1,349.6	341.4
Jan-19	100%	1,979.5	1,586.8	392.7
Feb-19	100%	1,629.0	1,332.3	296.6
Mar-19	100%	1,257.1	1,025.6	231.5
Apr-19	100%	96.3	66.0	30.3
May-19	100%	379.8	163.3	216.6
Jun-19	100%	851.9	308.6	543.3
Jul-19	100%	1,431.9	566.5	865.4
Aug-19	100%	1,000.9	422.0	578.9
Sep-19	100%	736.4	337.0	399.4
Oct-19	100%	132.5	91.9	40.5
Nov-19	100%	1,255.1	1,007.3	247.8
Dec-19	100%	628.2	515.1	113.2
Jan-20	100%	49.8	49.8	-
Feb-20	100%	155.4	155.4	-
Mar-20	100%	15.7	-	15.7
Apr-20	100%	12.8	-	12.8
May-20	100%	113.5	17.3	96.2
Jun-20	100%	818.9	264.6	554.3
Jul-20	100%	1,168.8	503.7	665.1
Aug-20	82%	910.4	408.2	502.2
Annual	100%	11,378.6	7,422.4	3,956.2
Summer (Jun-Sep)		4,021.1	1,634.1	2,387.0
Winter (Oct-May)		7,357.5	5,788.3	1,569.2

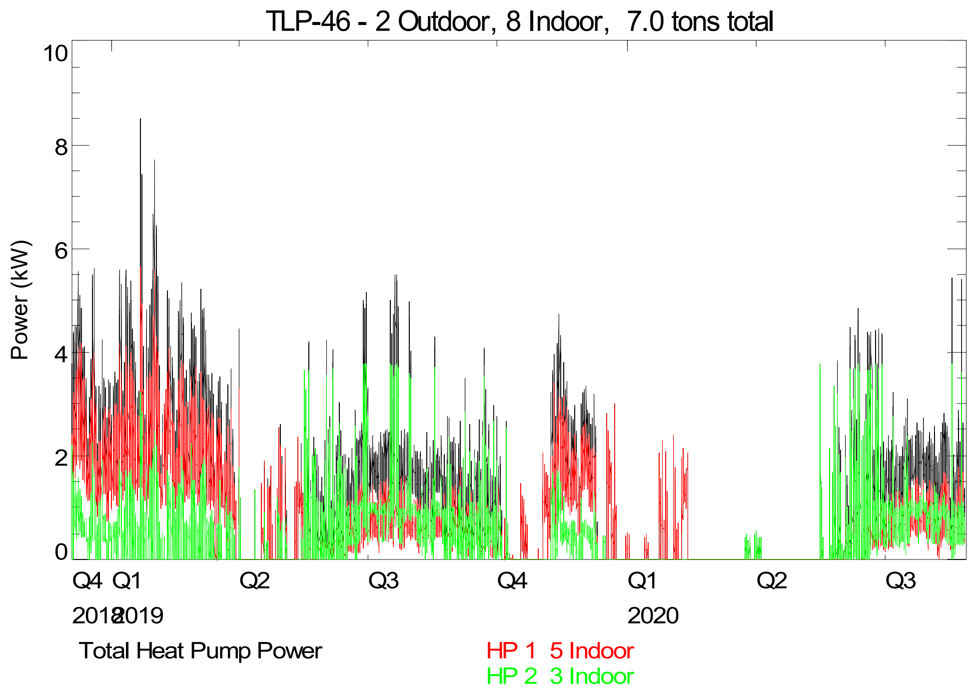


Figure 1. Plot of Power Use for All Heat Pumps at Site

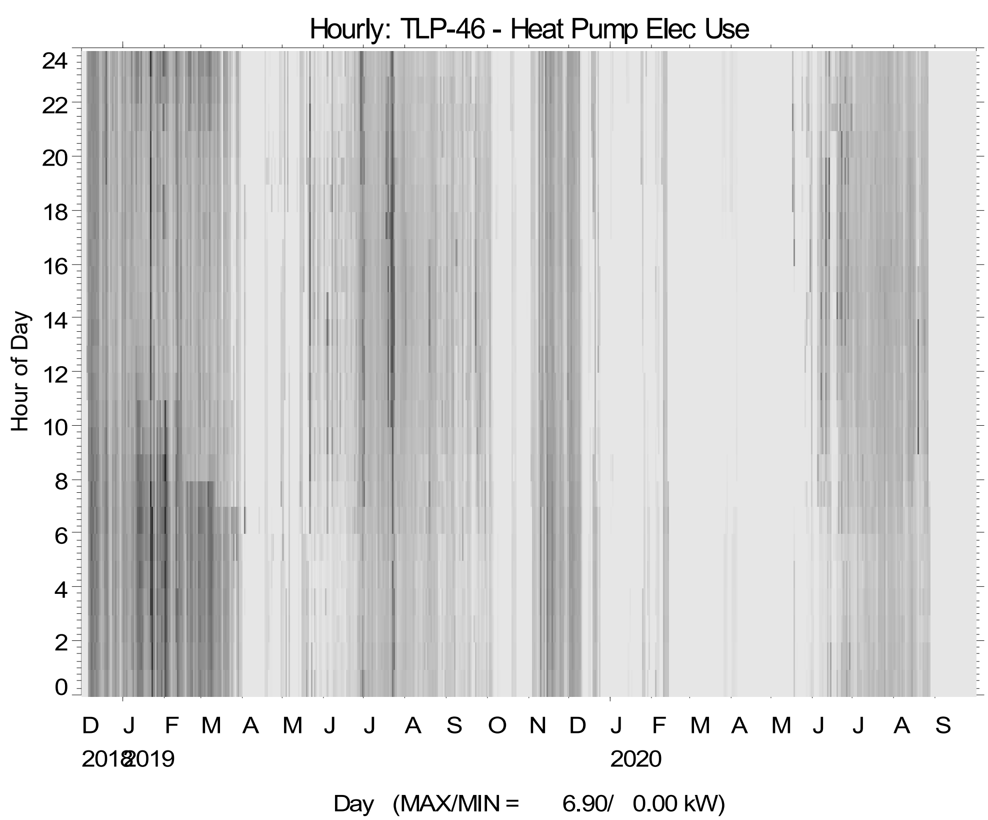


Figure 2. Shade Plot of Total Heat Pump Power

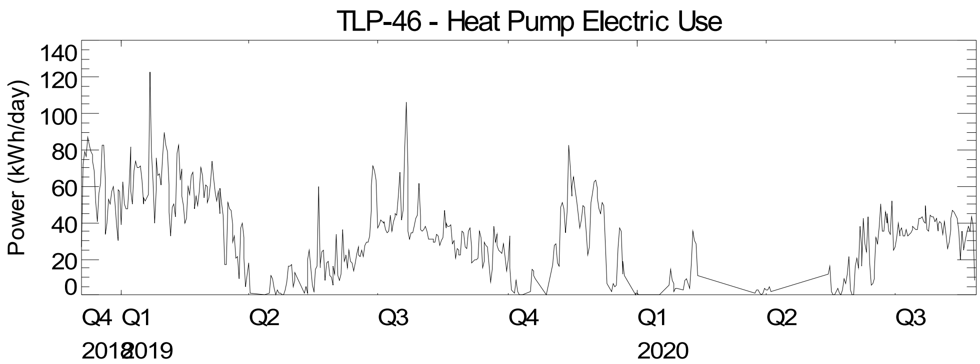


Figure 3. Plot of Daily Total HP Electric Use

Figure 4 shows daily electric use for all the heat pumps versus the daily average ambient temperature from JFK. The data for each month are shown with different colors. Different symbol types are used for each year. Electric use for the heat pumps was high in the first winter but dropped considerably in late 2019 and early 2020.

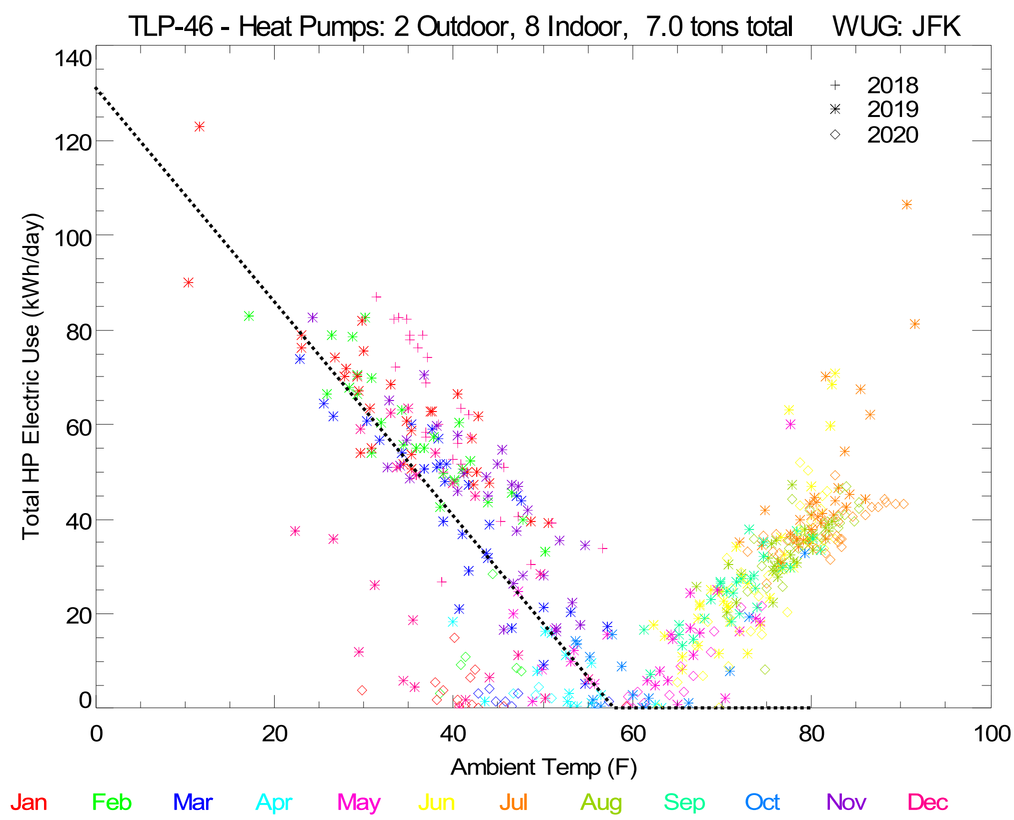


Figure 4. Daily Heat Pump Electric Use versus Outdoor Temperature

Figure 5 shows the pre-retrofit gas use trend with ambient temperature based on fuel delivery logs from the previous years. Readings from different years are shown with different colors. Pre-retrofit data are shown with diamonds. Post-retrofit data have month number shown by each point. The solid black line shows the linear best fit line to the pre-retrofit data. The dotted line is the best fit to the post retrofit readings. Table 2 lists the monthly gas use data shown in Figure 5. There was some scatter in gas use data for both the pre-retrofit and post-retrofit periods, though the trends generally make sense. The low gas use in March and April 2020 also corresponded to low heat pump energy use – this might imply another heat source was added to the building.

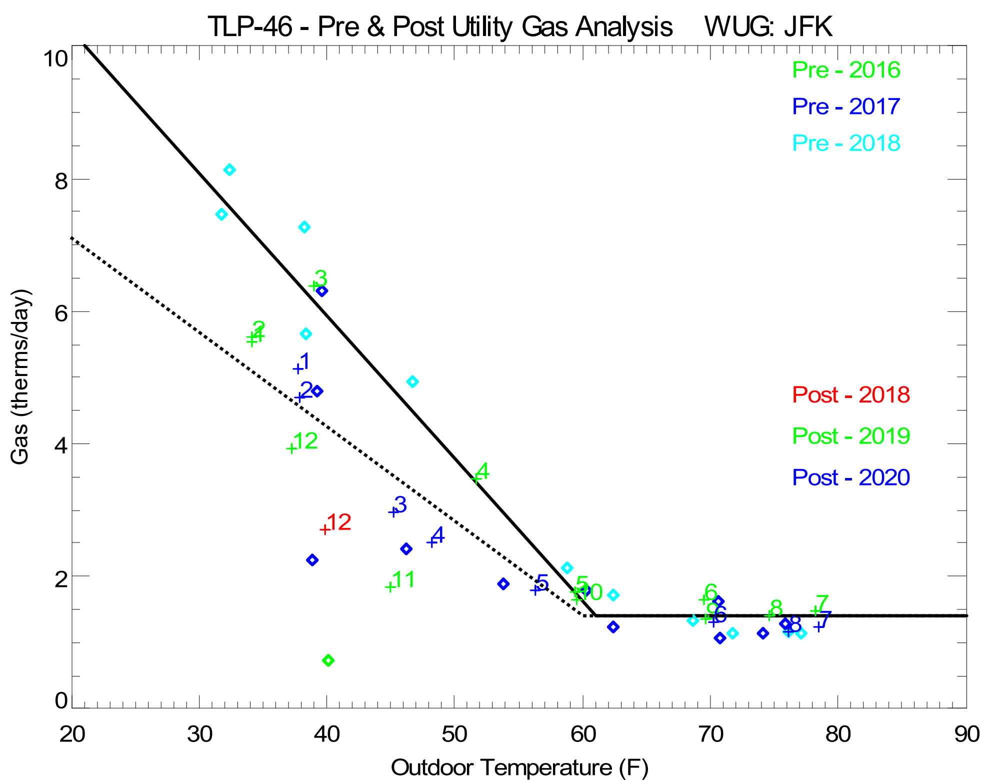


Figure 5. Trend of Gas Use with Outdoor Temperature Data, Using Fuel Delivery Logs from Pre, and Post-Retrofit Periods

Table 2. Month Gas Use Data from Pre- and Post-Retrofit Periods (same as data in Figure 5)

PRE-RETROFIT		
End Date	Avg Temp (F)	Gas Use (therms/day)
2/28/2017	39.6	6.3
3/30/2017	39.2	4.8
5/1/2017	53.9	1.9
5/31/2017	60.3	1.8
6/29/2017	70.6	1.6
7/31/2017	75.9	1.3
8/30/2017	74.2	1.1
9/29/2017	70.7	1.1
11/2/2017	62.4	1.2
1/2/2018	32.4	8.1
1/30/2018	31.7	7.5
2/28/2018	38.4	5.7
3/29/2018	38.3	7.3
4/30/2018	46.7	4.9
5/31/2018	62.5	1.7
6/29/2018	68.6	1.3
7/31/2018	76.1	1.2
8/29/2018	77.1	1.1
9/28/2018	71.7	1.1
10/29/2018	58.8	2.1

POST-RETROFIT		
End Date	Avg Temp (F)	Gas Use (therms/day)
12/31/2018	39.9	2.7
1/30/2019	34.1	5.5
2/28/2019	34.1	5.6
3/29/2019	39.1	6.4
4/30/2019	51.7	3.5
5/31/2019	59.4	1.8
6/28/2019	69.6	1.6
7/31/2019	78.2	1.5
8/30/2019	74.6	1.4
9/30/2019	69.7	1.4
10/29/2019	59.6	1.7
11/27/2019	45.0	1.8
12/31/2019	37.2	3.9
1/30/2020	37.8	5.1
2/28/2020	37.9	4.7
3/31/2020	45.2	3.0
4/30/2020	48.2	2.5
5/29/2020	56.4	1.8
6/30/2020	70.3	1.3
7/30/2020	78.5	1.2
8/28/2020	76.1	1.2

Note: Colors in the table correspond to symbol colors in Figure 5.

Annual Savings Analysis

The trends described in the plots above were combined into a bin analysis using typical year weather (TMY3) data for JFK Airport. Figure 6 shows the linear trends assumed for gas use in both PRE- and POST-retrofit periods. Figure 7 shows the piecewise linear trend for POST-retrofit electric use of the heat pumps.

Table 3. Bin Analysis of Heat Pump Savings Using TMY3 Weather Data for NYC (JFK)

SITE: **TLP-46** WEATHER: **New_York** $ 0.20 per kWh

FUEL: **Gas** $ 1.403 per therm

Floor Area **2400**

Temp Bin	Hours	FUEL PRE-Gas (therms/day)	FUEL POST-Gas (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas (therms/day)	Implied COP (-)	PRE Costs	POST Costs	POST-Gas adjustment factor
-27.5	0	20.4	13.9	193.1	13.9	0.8	28.7	58.1	
-22.5	0	19.4	13.2	181.8	13.2	0.8	27.2	54.8	
-17.5	0	18.3	12.4	170.5	12.4	0.8	25.6	51.6	
-12.5	0	17.2	11.7	159.2	11.7	0.8	24.1	48.3	
-7.5	0	16.1	11.0	147.9	11.0	0.8	22.6	45.0	
-2.5	0	15.1	10.3	136.6	10.3	0.8	21.1	41.8	
2.5	0	14.0	9.6	125.4	9.6	0.8	19.6	38.5	
7.5	11	12.9	8.9	114.1	8.9	0.8	18.1	35.3	
12.5	22	11.8	8.2	102.8	8.2	0.8	16.6	32.0	
17.5	101	10.8	7.5	91.5	7.5	0.8	15.1	28.8	
22.5	167	9.7	6.7	80.2	6.7	0.8	13.6	25.5	
27.5	247	8.6	6.0	68.9	6.0	0.9	12.1	22.2	
32.5	475	7.5	5.3	57.6	5.3	0.9	10.6	19.0	
37.5	855	6.5	4.6	46.3	4.6	0.9	9.1	15.7	
42.5	708	5.4	3.9	35.0	3.9	1.0	7.5	12.5	
47.5	608	4.3	3.2	23.7	3.2	1.1	6.0	9.2	
52.5	880	3.2	2.5	12.4	2.5	1.4	4.5	5.9	
57.5	750	2.2	1.8	1.1	1.8	8.1	3.0	2.7	
62.5	814	1.4	1.4	0.0	1.4	0.0	2.0	2.0	
67.5	723	1.4	1.4	0.0	1.4	0.0	2.0	2.0	
72.5	751	1.4	1.4	0.0	1.4	0.0	2.0	2.0	
77.5	870	1.4	1.4	0.0	1.4	0.0	2.0	2.0	

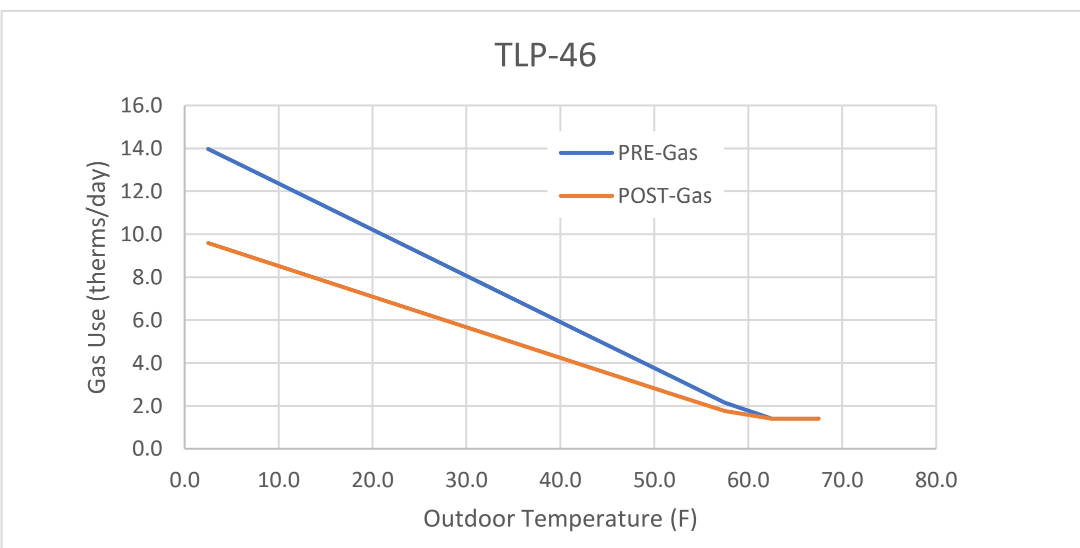


Figure 6. Trend of PRE- and POST-Retrofit Gas Use with Outdoor Temperature for Bin Analysis

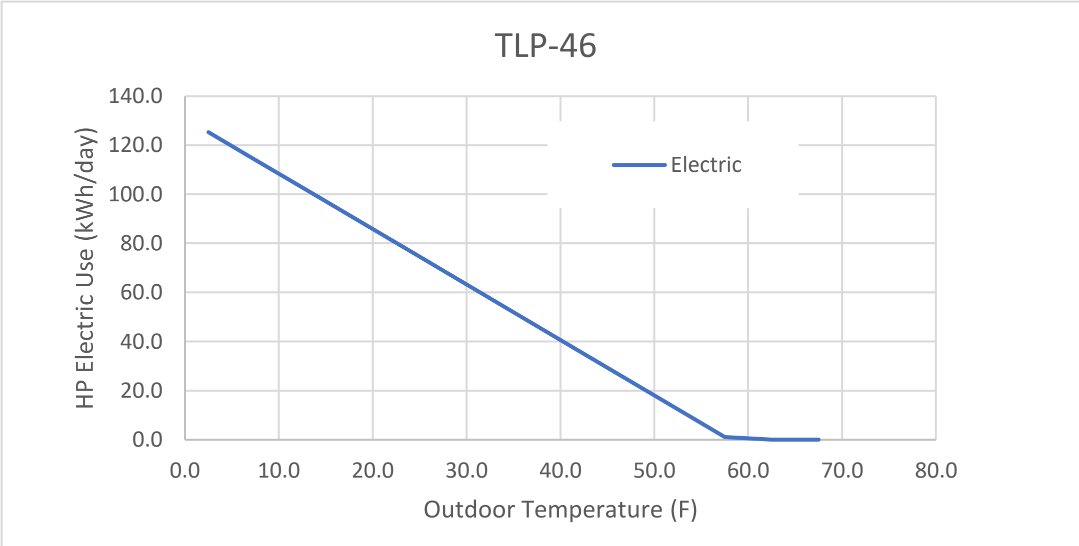


Figure 7. Trend of POST-Retrofit Electric Use with Outdoor Temperature for Bin Analysis

Table 4 summarizes the seasonal heating impacts for a typical weather year. Total gas use savings are estimated to be 288 therms per year for the heat pump. The heat pumps are estimated to use 6,712 kWh per year. From this we can estimate the implied COP of the heat pumps by converting the gas savings to thermal heating output (using 79% efficiency) and dividing by the heat pump power input. In this case the implied COP is 1.0.

Table 4. Summary of Predicted Heating Season Impacts of the Air-Source Heat Pumps

Heating Only TLP-46	**PRE Retrofit**	**POST Retrofit**	**Envelope Savings**	**ASHP & Env Savings**	**ASHP Savings**
Gas (therms/yr)	769	481	-	288	288
HP Electric (kWh/yr)		6,712		(6,712)	
Total Heating Costs	$ 1,078	$ 2,017	$ -	$ (939)	$ (939)
Implied Seasonal COP				1.0	1.0

The implied COP is very low.

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line represents the average demand profile for days at the same temperature. The key at the bottom of the plots shows the color associated with each daily average temperature bin (±5˚F). The number in parentheses indicates the number days in the bin that were averaged to make each daily profile. Figure 9 shows the same calculation process associated with cooling operation.

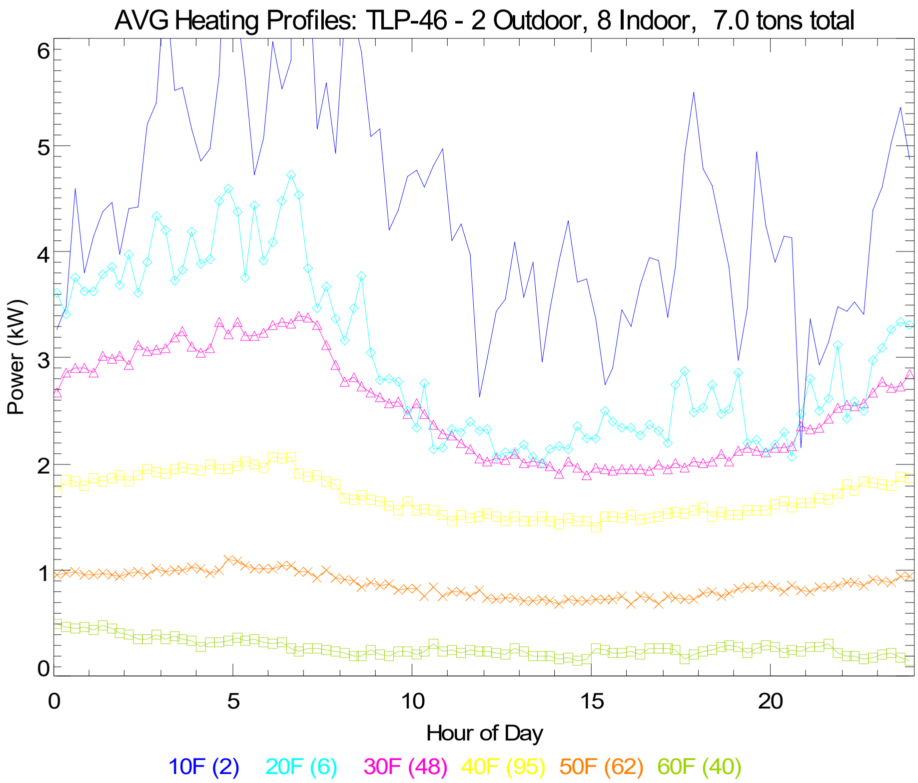


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

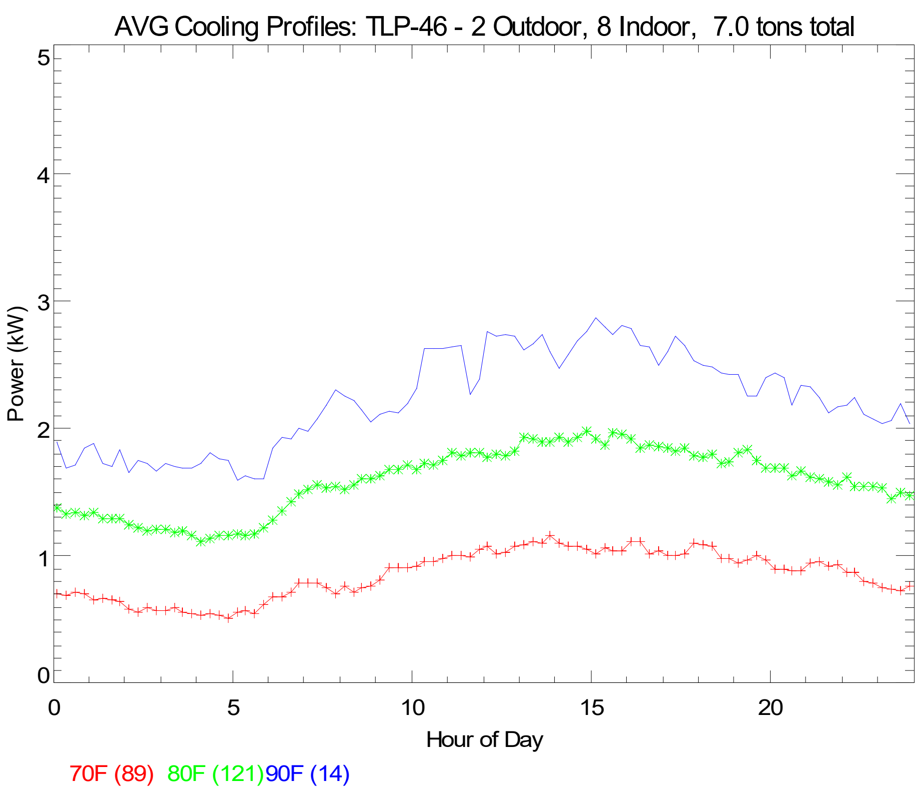


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

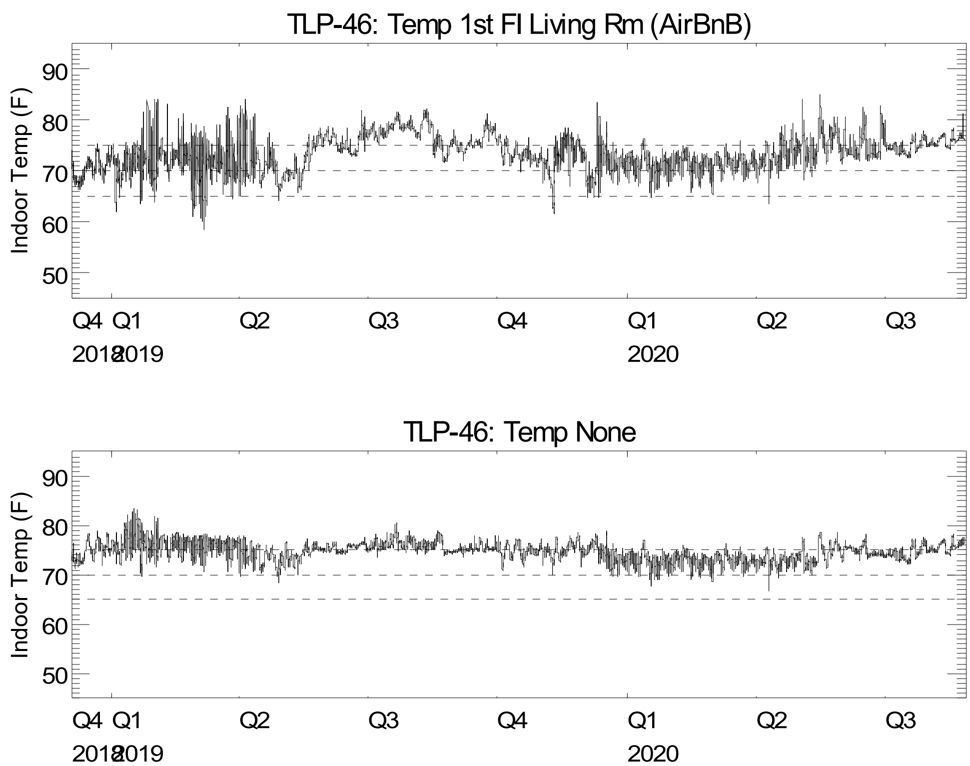


Figure 10. Plot of Space Temperatures at Various Indoor Locations

Appendix E. Technology Transfer Materials

The following pages in this appendix provide some of the technology transfer materials developed to facilitate wider adoption of heat pumps.

CASE STUDY – SYLVESTER ROWE – BROOKLYN, NY

RESIDENTIAL

Converting to heat pumps under emergency circumstances

Situation

- Gut rehab of former oil heated two-family home

Solutions

- Upgraded envelope to high performance standards, including insulation, air sealing and windows
- Used cold climate air source heat pumps for space conditioning

Benefits

- Homeowner is very satisfied with installed system, ease of operation, and ease of maintenance.
- Space heating savings of about $1,381 for entire retrofit
- More than three tons greenhouse gas emissions savings per year using average eGrid emissions factor

Photo options

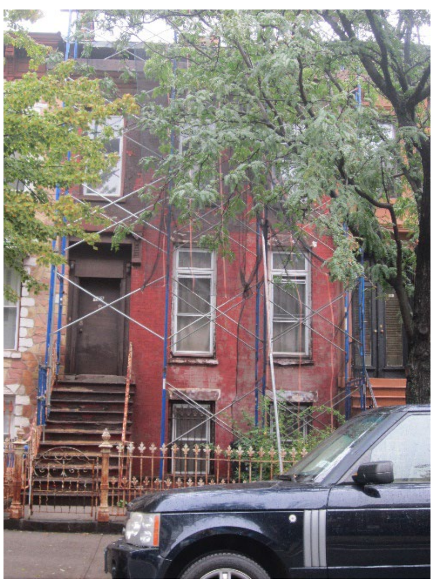


Photo caption

Four multi-head systems were installed to serve the entire four story building

Quote

"The client is extremely happy with their new heat pumps. They are far and away superior to their old oil-fired system in terms of comfort, maintenance and control." – Julie Liu, Centsible House

[Background]

This 2,950 sq ft two-family home originally used an oil boiler with conventional baseboard radiation. The building completed a gut rehab. Four electric heat pumps with a total capacity of 8 tons were added to the home in the summer 2020. The oil boiler was removed. Monitoring equipment was installed in August 2020 to collect data at 15-minute intervals.

Action

There was never a question as to what kind of space conditioning system these homeowners wanted. The home was designed to near passive house standards and air source heat pumps make the most sense in that situation because of their ability to ramp down to low capacities, when sized properly. Daikin Aurora multi-zone cold climate air source heat pump systems were used – four outdoor units serve a combination of two wall-mounted and seven ceiling cassette type indoor units.

Air sealing and insulation included:

- Roof was insulated with 4" XPS above the sheeting and R-30 Roxul between roof joists
- Walls were insulated with R-23 Roxul
- Air sealing where exterior walls meet roof was done with spray foam at roof plate and joist pockets
- Air sealing where exterior walls meet roof at the exterior was done with Hydro stop roofing membrane turned down on exterior walls 10"
- Air sealing at windows on the interior was done with OSB box foamed in place and the window foamed into box, plus air sealing tape from window to the box.
- Air sealing and waterproofing at windows on the exterior was done with sealant, covered with exterior grade tape from window to brick and covered with brick mold.

- The floor between the cellar and garden level was insulated with R-30 Roxul between floor joists

Conclusion

Results from comfort survey indicate the homeowner is highly satisfied with the upgrade.

Savings estimated at about $1,380 per year

Get started

Visit nyserda.ny.gov/home or call 1-866-NYSERDA to learn how you can reduce your energy consumption and costs.

CASE STUDY – RISEBORO COMMUNITY PARTNERSHIP – BROOKLYN, NY

RESIDENTIAL

Converting to heat pumps for increased control and comfort

Situation

- Two-family Brooklyn frame house

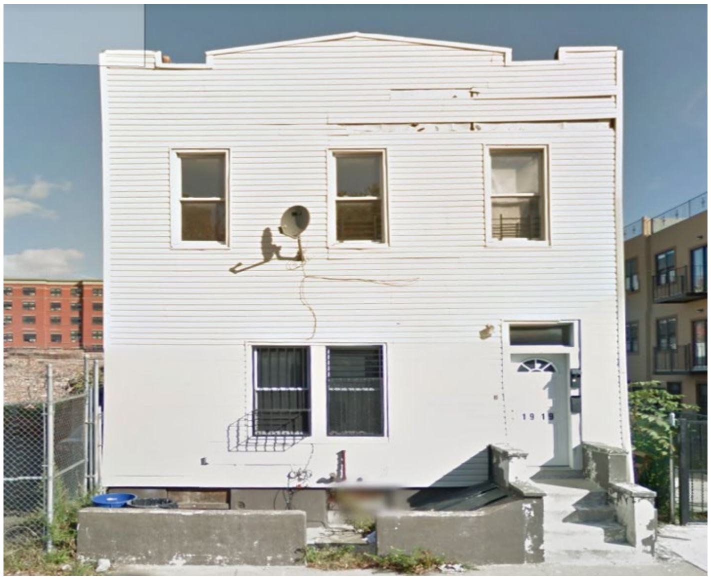
Solutions

- Replaced broken oil boiler with heat pumps
- Added electric water heater

Benefits

- Residents satisfied, no heating complaints to landlord
- Utility costs roughly the same as pre-retrofit, but now residents are responsible for their heating costs
- No more coordinating oil deliveries
- Can remove the window shakers

Photo options



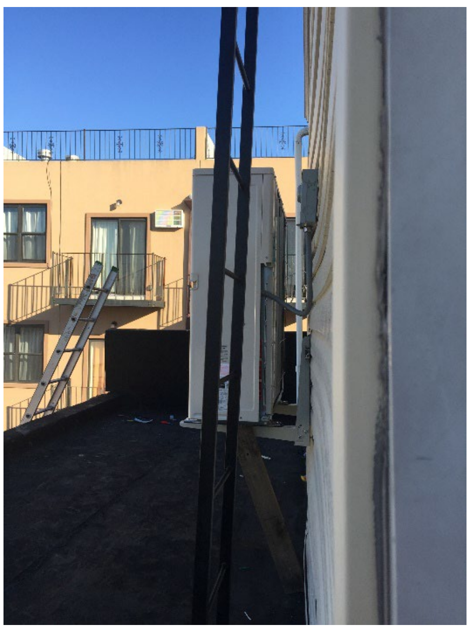


Photo caption

Two multi-head systems were installed – one for each apartment.

Quote

According to Ryan Cassidy, Riseboro's Director of Sustainability and Construction, "rents were paid and we have no issues currently or in the past on complaints to the system."

[Background]

Affordable housing non-profit Riseboro Community Partnership owns and operates this two story duplex home built in 1905 in the Weeksville section of Brooklyn, and maintains it as rental housing for two low-income families. The oil-fired boiler that provided space and water heating failed in 2017. Rather than replace it with a new oil boiler and lock in an inefficient fossil fuel system for the foreseeable future, Riseboro contacted The Levy Partnership (TLP) and Centsible House who were running a NYSERDA cold climate air source heat pump demonstration program. TLP enrolled the home in the program and was thereby able to provide additional discounts on the heat pump systems.

Avoiding the typical reaction to quickly install a new oil boiler

Fortunately, Riseboro had the foresight, and the time, to plan and install a new space heating system that could bring the home's systems into the 21st Century. Once a new electric water heater was quickly installed to provide DHW service, they took their time to rethink the space heating system. Riseboro concluded that heat pumps were the way to go because they would provide easily controllable comfort, reduce greenhouse gas emissions, and potentially dovetail with a future solar energy installation on the home. One system was installed for each of the two apartments. Each system included an indoor head in the living/dining room and one in each bedroom. Mitsubishi M-Series hyper heat cold climate heat pumps were used.

From NYSERDA’s standpoint, electrification of residential energy systems advances New York’s long-term greenhouse gas emissions reductions goals.

Mini-splits provide more efficient cooling as well, reducing summer electric bills.

A satisfied homeowner

Results from comfort survey and feedback to Riseboro indicate no complaints with the new space conditioning system.

Overall energy costs were similar after the retrofit at utility rates of the time.

Get started

Visit nyserda.ny.gov/home or call 1-866-NYSERDA to learn how you can reduce your energy consumption and costs.

CASE STUDY – DERRICK O'SHEA – BRONX, NY

RESIDENTIAL

Upgrading to 21st century performance with envelope improvements and heat pumps

Situation

- Drafty home and high energy bills

Solutions

- Added insulation to walls, attic knee walls and ceiling
- Installed heat pumps to use instead of oil boiler
- Added natural gas water heater

Benefits

- Results from comfort survey
- Savings $645 per year on energy bills

Photo options


Photo caption

Heat pump condenser was mounted outside the home and window ACs were removed

Quote

The homeowner says, "The area is much more comfortable in both winter and summer months and such a difference. Love it!!"

[Background]

Family of four with two teens live in this two and a half story single-family detached home. Built in 1920 on a corner lot in the quiet Bronx neighborhood of Pelham Bay, the home contained minimal insulation and so was drafty and uncomfortable on cold days. The oil-fired space and water heating and window and through-wall room air conditioners led to high energy bills for this homeowner in winter and summertime.

The homeowners contacted the Association for Energy Affordability, who enrolled them in the DOE Weatherization Assistance Program, which allowed the homeowner to receive new insulation, air sealing and a water heater. AEA was also partnering with The Levy Partnership and Centsible House on a NYSERDA cold climate air source heat pump demonstration program, which provided additional support, allowing a new heat pump system to be installed, substituting for the oil boiler.

Upgrading envelope and systems to achieve holistic benefits

At first the homeowners were reluctant to convert from hot water heat, but when they learned that heat pumps, in combination with weatherization, would result in greater comfort, plus room-by-room temperature control and quite operation, they were convinced it was the right solution.

Weatherization improvements included nearly 3,000 square feet of cellulose exterior wall insulation, nearly 1,000 square feet of cellulose ceiling insulation, and air sealing to reduce drafts and energy leakage.

The oil fired boiler will no longer be used and in its place a natural gas water heater and two Fujitsu air source heat pump systems were installed (model AOU36RLXFZ1H). Seven indoor wall-mounted indoor heat pump air handlers were placed in the four bedrooms, the living room, kitchen and basement.

A satisfied homeowner

Results from comfort survey indicate homeowner “very satisfied” with the heat pump system. Installation was less intrusive than a new boiler, maintenance is very easy, and overall satisfaction is much higher than with the old oil boiler. Heating costs are similar to pre-retrofit, but cooling costs are lower than expected.

Savings estimated at about $645 per year

Get started

Visit nyserda.ny.gov/home or call 1-866-NYSERDA to learn how you can reduce your energy consumption and costs.

Endnotes

1 The 2018 eGrid factors are nearly four years old. NREL has projections for future eGrid factors that are lower, which would increase emissions reductions going forward, eGrid factors available at: https://www.epa.gov/sites/production/files/2020-01/documents/egrid2018_summary_tables.pdf

2 S19 and S35 did not answer the question regarding installation experience.

3 The team believes this issue may have been due to a lack of homeowner understanding or to a lack of training.

4 https://www.levypartnership.com/selected-publications

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on Twitter, Facebook, YouTube, or Instagram.

New York State Energy Research and Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov