Hudson Valley Heat Pump Pilot Program: Demonstrating the Emerging Technology of Cold-Climate Air Source Heat Pumps

Final Report | Report Number 22-08 | April 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.

Hudson Valley Heat Pump Pilot Program:

Demonstrating the Emerging Technology of Cold-Climate Air Source Heat Pumps

Final Report

Prepared for:

New York State Energy Research and Development Authority
Albany, NY

Scott Smith
Program Manager

Prepared by:

Energy Futures Group
Hinesburg, VT

Gabrielle Stebbins, Managing Consultant
Richard Faesy, Principal

Owahgena Consulting, Inc.
Cazenovia, NY

Hugh Henderson, Principal

Frontier Energy, Inc.
Cazenovia, NY

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

Bruce Harley Energy Consulting, Inc.
Stamford, VT

Bruce Harley, Principal

Integral Building and Design, Inc.
New Paltz, NY

Pasquale Strocchia, Principal

NYSERDA Report 22-08 NYSERDA Contract 104082 April 2022

Notice

Preferred Citation

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

Abstract

The Hudson Valley Heat Pump Pilot (HVHPP) 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 existing New York State homes. The project also sought to understand the technological and market barriers to greater adoption of this emerging technology, in order to develop and refine technology transfer approaches. Most of the ccASHP systems were ductless with a few ducted ccASHP systems installed at 20 homes representing diverse building types and fuel sources. Of the existing heating systems in the 20 houses, seven originally used fuel oil, four used natural gas, five used electric resistance, and four used propane. Both contractors and homeowners were provided additional training regarding heat pump sizing, installation, and operations. After each installation, the ccASHPs at each site received a quality assurance visit to ensure proper installation and efficient operation. Measurement and verification systems were installed to collect power measurements at 15-minute intervals in the post-retrofit period to measure electric use for the ccASHP systems, the total house, any resistance heating, and other loads. The project also collected fuel readings from utility bills and delivery logs from both the pre- and post-retrofit periods, allowing a comparison of pre- and post-retrofit energy use with a bin analysis for typical year weather conditions. The ccASHP systems displaced from 34% to 100% of the original heating system fuel use; the average fuel displacement was 85%. The implied seasonal average heating efficiency ranged from 1.7 to 2.6 with an average of 2.1. Cost savings per installed nominal cooling ton averaged +$113 and strongly depended on the type of fuel displaced. Annual GHG savings averaged 1,100 to 1,300 of CO_2 equivalent per ton of installed nominal cooling capacity, depending on the GHG factors assumed for the NYS electric grid.

Keywords

Heat pump, ductless mini-split heat pumps, cold-climate air source heat pump, field test, monitoring

Acknowledgments

Energy Futures Group (EFG) thanks Bruce Harley of Bruce Harley Energy Consulting, and the team at Integral Building Design (IBD) for overseeing the application and installation of the air source heat pumps in this research and development project, and KSV for their role in the Technology Transfer process. The team at IBD, led by Pasquale Strocchia and supported by Chris Cimino and Juravell Fontes-Janusz spent significant effort and time to ensure the completion of 20 projects. The third-party evaluating team, Frontier Energy and Owahgena, comprised of Hugh Henderson, Nick Genzel and Carina Paton, are heartily thanked for their collaborative approach to completing this project. EFG also thanks the multiple participating installer and contractor companies that supported this project. We also greatly appreciated working with Scott Smith, who has provided support in a flexible and clear manner throughout the duration of the project. Finally, we thank the 20 households who opened their homes and patiently worked through the details of this program.

Table of Contents

Notice ii
Preferred Citation ii
Abstract iii
Keywords iii
Acknowledgments iv
List of Figures vii
List of Tables viii
Acronyms and Abbreviations x
Summary S-1
1 Project Introduction and Overview 1
1.1 NYSERDA’s Original Goals for Project Opportunity Notice 3127 1
1.2 Hudson Valley Heat Pump Pilot Program Goals 1
1.3 Program Approach 2
1.4 Customer Outreach and Recruitment 8
1.5 Contractor Recruitment and Post-Installation Quality Assurance 11
2 Home Characteristics and Equipment Details 14
2.1 Home Characteristics 14
2.2 Equipment Details 17

2.3 Installation Quality Assurance Results 20
2.3.1 Outdoor Unit 22
2.3.2 Line Set 23
2.3.3 Condensate Drain 23
2.3.4 Indoor Unit 24
2.3.5 Ducts 24
2.3.6 Setup 25
2.3.7 Other Observations 26
3 Results: Energy Impacts and Cost Savings 27
3.1 Monitoring Approach 27
3.2 Weather Data and Utility Electric/Fuel Costs 29
3.3 Detailed Analysis Heating Results for Three Sites 30
3.3.1 Analysis of Site 3: Replacing Oil Heat 30
3.3.2 Analysis of Site 4: Replacing Electric Resistance Heat with Electric Utility Bills Available 36
3.3.3 Analysis of Site 2: Replacing Electric Resistance Heat when Post-Retrofit Electric Bills were Not Valid 40
3.4 Summary of Heating Results for All Sites 46
3.4.1 Measured Electric Use 46
3.4.2 Estimated Savings, Fuel Reductions, and Implied Coefficient of Performance 48
3.4.3 Installed Costs and Cost-Effectiveness 53
3.4.4 Greenhouse Gas Impacts from Heating Savings 54
3.5 Impact on Cooling 56
3.6 Observed Space Temperatures 58
3.7 Electric Demand Profiles for Heating and Cooling 60
4 Results: Customer and Contractor Surveys 70
4.1 Customer Survey Results 70
4.1.1 Survey Approach 70
4.1.2 Decision to Install 71
4.1.3 Installation Experience 74
4.1.4 Maintenance Experience 75
4.1.5 Perceived Comfort 77
4.1.6 Operation 82
4.1.7 Satisfaction 82
4.1.8 Other Feedback 83
4.1.9 Summary of Customer Survey Findings 85
4.2 Contractor Survey 86

4.2.1 Awareness of Energy Efficiency and Heat Pumps ... 86
4.2.2 Customer Approach and Perspectives ... 89
4.2.3 Business Approach ... 92
4.2.4 Summary of Contractor Survey Results ... 94
5 Technology Transfer ... 95
6 Lessons Learned ... 98
6.1 Lessons from Program Design: Customer and Contractor Recruitment ... 98
6.2 Lessons from Program Quality Assurance ... 99
6.3 Lessons from Measured Performance Data ... 102
6.4 Lessons from Homeowner Perceptions and Motivations ... 103
6.5 Lessons Learned on Contractor Perceptions and Motivations ... 104
7 References and Bibliography ... 106
Appendix A. HVHPP Program Documents Used to Identify and Recruit Sites ... A-1
Appendix B. Monitoring Installation at Each Site ... B-1
Appendix C. Analysis of Measured Data for Each Site ... C-1
Appendix D. Performance Validation Plan ... D-1
Appendix E. Surveys ... E-1
Endnotes ... EN-1

List of Figures

Figure 1. Hudson Valley Heat Pump Pilot Organizational Chart 3
Figure 2. Hudson Valley Heat Pump Pilot Stakeholder Involvement 3
Figure 3. Hudson Valley Heat Pump Pilot Project Flow Description...5
Figure 4. Hudson Valley Heat Pump Pilot Flyer—Front Page 9
Figure 5. Hudson Valley Heat Pump Flyer—Back Page 10
Figure 6. Hudson Valley Heat Pump Pilot Site Locations..14
Figure 7. Pictorial Collage of Hudson Valley Heat Pump Pilot Homes 15
Figure 8. Daily Heat Pump Energy Use versus Daily Average Temperature at S3 32
Figure 9. Analysis of Fuel Delivery Logs with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends at S3 33
Figure 10. Daily Heat Pump Energy Use versus Daily Average Temperature at S4 (Days in each month shown with a different color) 37
Figure 11. Analysis of Electric Use with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends at S4 38
Figure 12. Daily Heat Pump Energy Use versus Daily Average Temperature at S2 Days in each month shown with a different color. 42
Figure 13. Analysis of Electric Use with Temperature—Comparing Pre-Retrofit and Post-Retrofit Trends at S2 43
Figure 14. Analysis of Measured Electric Use with Temperature in the Post-Retrofit Periods at S2 44
Figure 15. Internal Gains Versus Cooling Energy Use...57
Figure 16. Average Demand Profiles for S3, Grouped by Days with Similar Outdoor Temperatures 62
Figure 17. Normalized Demand Profiles for all Sites Combined at an Outdoor Temperature of 10°F 63
Figure 18. Normalized Demand Profiles for all Sites Combined at an Outdoor Temperature of 80°F 63
Figure 19. Normalized Demand Profiles for all Sites at Various Winter Temperatures 64
Figure 20. Normalized Demand Profiles for all Sites at Various Summer Temperatures 65
Figure 21. Comparing Demand Profiles for The Levy Partnership and Energy Futures Group Sites for the Winter 67
Figure 21 continued. Comparing Demand Profiles for The Levy Partnership and Energy Futures Group Sites for the Winter 68
Figure 22. Comparing Demand Profiles for The Levy Partnership and Energy Futures Group Sites for Summer 68
Figure 22 continued. Comparing Demand Profiles for The Levy Partnership and Energy Futures Group Sites for Summer 69
Figure 23. Importance of Factors in Decision to Install an Air Source Heat Pump System 72
Figure 24. Importance of Factors in Decision to Install a Solar System 73
Figure 25. Customer Satisfaction with Work Carried Out by Heat Pump Contractor..................74
Figure 26. Customer Experience with the Installation Process 74

Figure 27. Expected and Experienced Level of Effort to Maintain Cold Climate Air Source Heat Pump in Comparison with Prior Heating and Cooling System 75
Figure 28. Perceived Levels of Effort to Maintain Previous Heating System, Previous Cooling System, and Air Source Heat Pump System 76
Figure 29. Perceived Ability of Heat Pump to Maintain Desired Winter Temperatures Compared to Previous Heating System 78
Figure 30. Perceived Distribution of Comfort Throughout Home During Winter for Previous Heating System and Cold Climate Air Source Heat Pump 79
Figure 31. Perceived Ability of Heat Pump to Maintain Desired Summer Temperatures Compared to Previous Cooling System..80
Figure 32. Perceived Distribution of Comfort Throughout Home During Summer for Previous Cooling System and Cold Climate Air Source Heat Pump..............................81
Figure 33. Perceived Distribution of Comfort in Basement..82
Figure 34. Participant Satisfaction with Previous Heat and Cooling Systems in Comparison to Heating and Cooling Provided by the Cold Climate Air Source System 83
Figure 35. Extent to Which Participation in Hudson Valley Heat Pump Pilot Increased Contractor Familiarity with Cold Climate Air Source Heat Pumps 88
Figure 36. Customer Questions About ccASHPs...91
Figure 37. Contractors Approaches to Generating Leads 93
Figure 38. Reasons for ccASHP Installations 94

List of Tables

Table 1. Initial Plan for Hudson Valley Heat Pump Pilot Project Types..4
Table 2. Hudson Valley Heat Pump Pilot Program Documents 7
Table 3. Overview of Participating Contractors 12
Table 4. Home Characteristics and Original Heating and Cooling Information...........................15
Table 5. Cold Climate Air Source Heat Pump Installation Details at Each Site 18
Table 6. Cold Climate Air Source Heat Pump Installation Costs for Each Site...........................20
Table 7. Outdoor Unit Quality Assurance Summary 22
Table 8. Line Set Quality Assurance Summary..23
Table 9. Condensate Drain Quality Assurance Summary 23
Table 10. Indoor Unit Quality Assurance Summary 24
Table 11. Duct Quality Assurance Summary 25
Table 12. Setup Quality Assurance Summary 26
Table 13. Metered Electric End Uses at Each Home 29
Table 14. Weather Data and Utility Fuel Costs 30
Table 15. Measured Electric Use for the Total House and ASHP Unit at S3..............................31
Table 16. Fuel Oil Delivery Logs at S3 (Data used in Figure 10 above)...................................34
Table 17. Bin Analysis Used to Predict Seasonal Impacts from Trendlines for S3.....................35
Table 18. Measured Electric Use for the Total House and ccASHP Unit at S4 36
Table 19. Bin Analysis Used to Predict Seasonal Impacts from Trendlines for S4.....................39

Table 20. Alternate Procedure for Determining the Implied COP w/ and w/o Resistance Heat at S4 40
Table 21. Measured Electric Use for the Total House and Air Source Heat Pump Unit at S2....41
Table 22. Bin Analysis Used to Predict Seasonal Impacts from Trendlines for S2....45
Table 23. Alternate Procedure for Determining the Implied COP with and without Resistance Heat at S2 46
Table 24. Summary of Post-Retrofit Electricity Use at Each Site 47
Table 25. Summary of Domestic Hot Water Use at Sites Where Measured 48
Table 26. Summary of Heating Results for All Sites 50
Table 27. Five Sites Where Savings and Implied Coefficient of Performance were Excluded ...51
Table 28. Results by Fuel Type—All Sites....51
Table 29. Results by Fuel Type—15 Included Sites Where Savings Could Be Calculated 52
Table 30. Results by Region—15 Included Sites Where Savings Could Be Calculated....52
Table 31. Installed Costs with Site Specific Comments 53
Table 32. Greenhouse Gas Emission Savings at 15 Included Sites Where Savings Could Be Calculated 55
Table 33. Normalized Greenhouse Gas Savings by Fuel Type—15 Included Sites Where Savings Could Be Calculated 56
Table 34. Cooling Equipment and Energy Use at Each Site 57
Table 35. Measured Space Temperatures and Standard Deviation in Heating Season—November through March....59
Table 36. Measured Space Temperatures and Standard Deviation in Cooling Season—June through August 60
Table 37. Normalized Demand Profiles for Heating 64
Table 38. Normalized Demand Profiles for Heating 66
Table 39. Responses to the Surveys at Various Stages 70

Acronyms and Abbreviations

AC	air conditioning
AHU	air handling unit
ASHP	Air source heat pump, also air-to-air heat pump
BHEC	Bruce Harley Energy Consulting
ccASHP	cold-climate air source heat pump
COP	coefficient of performance
CT	current transducer
DHW	domestic hot water
EFG	Energy Futures Group
FE	Frontier Energy (formerly CDH Energy)
ft	feet
GHG	greenhouse gas
GSHP	ground-source heat pump
HSPF	heating seasonal performance factor
HVAC	heating, ventilating and air conditioning
HVHPP	Hudson Valley Heat Pump Pilot
IBD	Integral Building and Design
kW	kilowatt
kWh	kilowatt hours
KSV	KSV Marketing and Ad Agency
MBtu	thousand Btu
MW	megawatt
NY	New York
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
PON	Project Opportunity Notice
PV	photovoltaic
QA	quality assurance
SEER	seasonal energy efficiency ratio
sq	square
TRM	Technical Resource (or Reference) Manual
W	watts

Summary

The Hudson Valley Heat Pump Pilot (HVHPP) Program, a field-demonstration effort sponsored by the by the New York State Energy Research and Development Authority (NYSERDA) and lead by the Energy Futures Group (EFG), was undertaken to:

- Demonstrate the energy and greenhouse gas savings reductions achievable by incorporating cold-climate air source heat pumps (ccASHPs) into 20 existing homes.
- Further understand New York State-specific building needs and barriers to full-market adoption of ccASHPs.
- Transfer the findings from the study through a Technology Transfer process targeted toward homeowners.

The HVHPP Program worked with six contractors to install ductless and ducted Mitsubishi ccASHPs in 20 homes located in the Hudson Valley area of New York State. Contractors were given support regarding sizing, design, and application of heat pumps, provided customer-facing materials to optimize heat pump operation by homeowners, and each site received a quality assurance (QA) visit with follow up required by contractors to correct any identified issues. Both homeowners and contractors participated in a series of pre- and post- surveys to assist in better understanding various barriers to ccASHP market adoption. Heat pump performance was monitored by Frontier Energy, who was under contract with NYSERDA to assess energy and cost savings.

Home styles included colonial, ranch, split level, contemporary, and cape. These homes were originally heated by natural gas furnaces and boilers, oil boilers, electric baseboard, wood stoves, propane boilers and in some cases heat pumps (installed prior to the HVHPP). Many houses previously used central air conditioning (AC) or window units for cooling. Heat pumps were installed in these homes in late 2017 through 2019 to either partially displace heating fuel use or to fully replace the original heating system.

Measurement and verification included collecting interval measurements of post-retrofit heat pump electric use as well as collecting both pre- and post-retrofit fuel readings from utility bills and delivery logs. This measured data allowed the team to compare pre- and post-retrofit energy use, energy costs and greenhouse gas (GHG) reductions for typical year weather conditions. Additionally, the collected data allowed the team to estimate the implied seasonal heating efficiency of the ccASHP units as well as to collect data to analyze cooling savings compared to the base case cooling system.

The results in Table ES-1 are shown for the 15 of the 20 sites in which the pre-post comparative analysis was successfully completed. For the remaining five sites, the savings analysis was confounded by behavioral or occupancy changes between pre- and post-retrofit periods as well as other issues such as imprecise fuel delivery dates and irregular woodstove use. For the 15 sites in which energy and cost savings could be determined, the ccASHP systems displaced from 34% to 100% of the original heating system's fuel use; the average fuel displacement for the sites was 85%. The implied seasonal average heating efficiency, or coefficient of performance (COP), ranged from 1.7 to 2.6, with an average of 2.1. When compared to the heating seasonal performance factor (HSPF) rating for the installed ccASHP system, the average efficiency was about 63% of the rated efficiency (the HSPF rating is based on an average United States climate which is milder than most of NYS). In contrast, the savings analysis procedure in the New York Technical Reference Manual (TRM) for ccASHPs predicts seasonal efficiencies that are 83% to 92% of the rated HSPF in these regions (Henderson 2020). Heating cost savings per installed nominal cooling ton averaged +$113 and strongly depended on the type of fuel displaced. The average heating cost savings per installed ton were -$105 for natural gas, +$23 for fuel oil, +$145 for propane, and +$320 for electric resistance.

Table ES-1. Results by Fuel Type for 15 Sites Where Savings Could be Calculated

Pre-Retrofit Fuel	No. of Sites	Percent Fuel Reduction	Implied Heating COP	Percent of HSPF	Heating Cost Savings per Ton
Oil	5	68%	2.0	58%	$23
Natural Gas	3	84%	2.3	73%	-$105
Electric	5	95%	2.1	58%	$320
Propane	2	100%	2.3	73%	$145
Total / Avg	15	85%	2.1	63%	$113

Notes: These parameters could only be determined for 15 of the 20 homes using the pre-post analysis method.
Utility rates from NYSERDA in the spring of 2020 were used to determine costs in each region.

Annual GHG emission savings from heating averaged from 1,100 to 1,300 pounds of CO_2 equivalent per ton of installed nominal cooling capacity, depending on the GHG emissions factors assumed for the New York State electric grid (i.e., either overall average or non-baseload emissions).

The results showed wide variations in the amount of seasonal energy used for cooling, ranging from 277 to 4,844 kilowatt-hours (kWh), with a median value of 628 kWh. This range was clearly driven by differences in occupant behavior and preference, as well as the amount of electricity use inside the homes that was not related to heating, cooling, or water heating (i.e., internal gains). At least in part because of these wide variations, we were not able to detect any cooling savings by comparing pre- and post-retrofit energy use at any site. At S18 in particular, where sufficient data were available to complete the pre-post bin analysis, the electric savings were found to be zero. Even though the very high SEER ratings for the installed ccASHP systems might imply that significant cooling energy savings should be expected, various independent sources, including the NY TRM analysis of ccASHPs (Henderson 2020) and results of load-based laboratory testing (Harley 2020), show that the higher SEERs for many ccASHP units do not translate into a higher seasonal cooling efficiency in practice.

Customer survey results for this set of homeowners showed that the primary motivation to install a ccASHP was driven by a desire to reduce fossil fuel use and greenhouse gas emissions. Incentives, cost savings, and increased comfort also factored into their decision to install heat pumps. Customers were generally satisfied with the installation contractor and did not find the installation process to be more inconvenient than for conventional systems. In the first year they found maintenance and operation of the heat pumps to be relatively easy, with no respondent stating maintenance was more difficult. While all 20 site owners received education from the contractor about operation and maintenance, some of the anecdotal comments indicate that homeowners may have still had additional questions after the initial training (i.e., a follow-up question-and-answer check-in might be useful).

Participants had a range of satisfaction levels with their original heating and cooling equipment. They generally all expected to see their desired temperatures improved by the heat pumps, although this wasn’t always achieved in every room of a home. The variability in responses as to how the heat pumps were performing in individual rooms as compared to the entire home may be reflective of the individual applications of the ductless heat pumps. Two respondents stated that their desired heating temperature had slightly worsened when compared to their previous heating system. Nevertheless, 16 responses to the final survey reported (1) to be “very satisfied” with their air source heat pump system, (2) the level of effort put into the project was worth the achieved benefits, and (3) that if cost and effort were not involved, they still would not switch back to old heating and cooling systems. The fact that participants were generally very satisfied, even though many of the heat pumps were not necessarily acting as a “whole home” heating solution, may be indicative of the level of communication with the customer that single-head, one-to-one heat pumps are not central heating and cooling systems, but rather address particular needs for specific spaces.

Contractor survey results show that contractors are confident in their awareness of energy efficiency and heat pumps, but still found the published materials and various installation techniques that were part of the HVHPP to be helpful and useful. Contractors stated the following when asked, "What do you think you will do differently regarding ccASHP installations as a result of participating in this program?"

- "I will slightly undersize BTU capacity of multizone outdoor ccASHP condenser units by sizing total indoor unit BTU demand to ~130% of outdoor unit BTU capacity (this increases overall operating efficiency and slightly reduces material costs)."
- "Mount head units lower from the ceiling."
- "Not much. Once results are out maybe it will change."
- "Better information for clients."

Their approach to educating customers and explaining how to efficiently operate heat pumps was augmented by the HVHPP, and they plan on continuing to use the resources made available to them. Their experience indicates that customers are interested in heat pumps for a range of reasons, but that comfort, convenience, and energy and financial savings ultimately drive the customer's decision to install. Their primary business development tool is "word of mouth," and they generally feel that New Yorkers overall, as well as other residential HVAC businesses, are not aware of the potential comfort and savings that ccASHPs can provide. Finally, regarding what would help "move the market," contractors offered the following ideas:

- "An annual energy savings calculator that compares heating and cooling operating costs for ccASHP systems versus other common heating and cooling systems."
- "Case studies of homes average savings/research program results (helpful in educating future clients)."
- "Greater customer rebates."
- "Low-cost financing options."

The results presented in this report will be used to inform and refine the messaging to be used in the Technology Transfer process. Therefore, as of the time of the writing of this report, the Technology Transfer process, focused on homeowners as the "audience" was still underway. Additionally, as of the writing of this report, the Technology Transfer process will result in deliverables that are aligned with the second bullet above, including: one to two case study videos that allow for the possibility of cut-downs to 15, 30, or 60 seconds to allow for varying applications, and one to two fact sheets that could provide (1) a comparison of ccASHP to other technologies regarding the heating and cooling applications, benefits, and operations and (2) a comparison of ccASHP to other technologies regarding costs and savings. An alternative to these fact sheets may be a series of homeowner testimonials and case studies.

1 Project Introduction and Overview

1.1 NYSERDA's Original Goals for Project Opportunity Notice 3127

New York State's residential buildings account for more than 35% of total electricity consumption, nearly 28% of net energy consumption, and emit 18% greenhouse gases (GHG) in the State. Therefore, Project Opportunity Notice (PON) 3127, the "Emerging Technologies Demonstration Projects—Residential HVAC" initiative was created to identify ways to accelerate the market uptake of commercially available, but underused building technologies and strategies in the residential sector. The PON solicited multisite demonstration or pilot projects that would achieve New York State Energy Research and Development Authority's (NYSERDA) three goals for the PON. These were: (1) to demonstrate the energy savings and GHG reductions resulting from switching to alternative heating technologies in multiple homes, (2) to further understand New York State-specific barriers to full-market adoption of the target technologies, and (3) to transfer the findings from the first two goals through a Technology Transfer process to reach market actors that could include customers, installer contractors, distributors, and manufacturers.

1.2 Hudson Valley Heat Pump Pilot Program Goals

To achieve the three goals set forth in PON 3127, the Energy Futures Group (EFG) team took a three-pronged approach. The first goal of the Hudson Valley Heat Pump Pilot (HVHPP) Program was to demonstrate the savings that could be achieved by displacing existing heating fuel with efficient electric heating systems across 20 ccASHP installations in existing residential properties with year-round inhabitants. EFG worked with NYSERDA's third-party measurement and verification (M&V) consultant, Frontier Energy (formerly CDH Energy) to develop the "Performance Validation Plan" and install the data collection systems.[1] While not a requirement of the PON, the EFG team did seek out some heat pump sites that also had solar. This was driven by our interest to understand that interplay between solar and ccASHP in customer purchase and acquisition decisions.[2]

The second goal of identifying and further understanding market barriers in customer adoption of heat pumps was achieved through surveying customers and installation contractors, as well as through direct conversations with homeowners by the Frontier Energy (FE) and EFG teams. Survey data analysis and survey questions were designed to address:

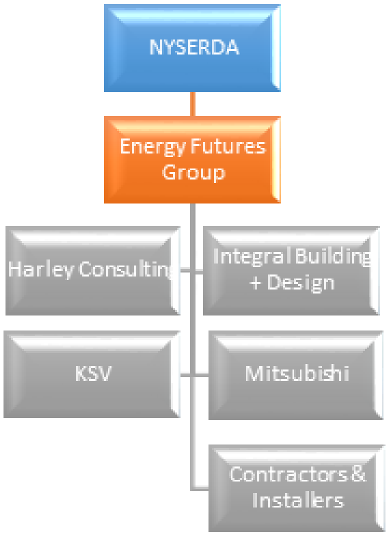
- Consumers/homeowners' desire for confidence and confirmation that the expected benefits will be achieved, namely reduced fuel bills and net energy cost savings while maintaining adequate comfort.
- Consumers' desire for confidence that ccASHP systems can perform as needed on the coldest days.
- Policymakers' desire for confirmation that expected energy impacts and GHG reductions are realized.
- Installers' desire for assurance that software tools and calculation procedures to size equipment and predict energy savings are reliable and accurate.
- Installers' desire to understand what issues motivate consumers/homeowners to purchase a ccASHP system, so that marketing strategies can be tuned to focus on key issues.
- Installers and the finance community wanting to understand the range of variation in installation costs and cost savings across a portfolio of installations, understanding the variability of cost savings at a known level of confidence.
- Utilities and policymakers wanting to understand the impact that ccASHPs will have on electric load growth, residential load shape, and peak demand.

The third and final goal to transfer findings via a Technology Transfer will be achieved through the approved Technology Transfer process, which is a targeted marketing effort focused on New York State homeowners. Much of this process has not yet been finalized and implemented, as the energy and cost saving results presented in this report needed to be completed and approved prior to developing the Technology Transfer materials. However, additional details regarding the current status of this process are outlined in section 5.

1.3 Program Approach

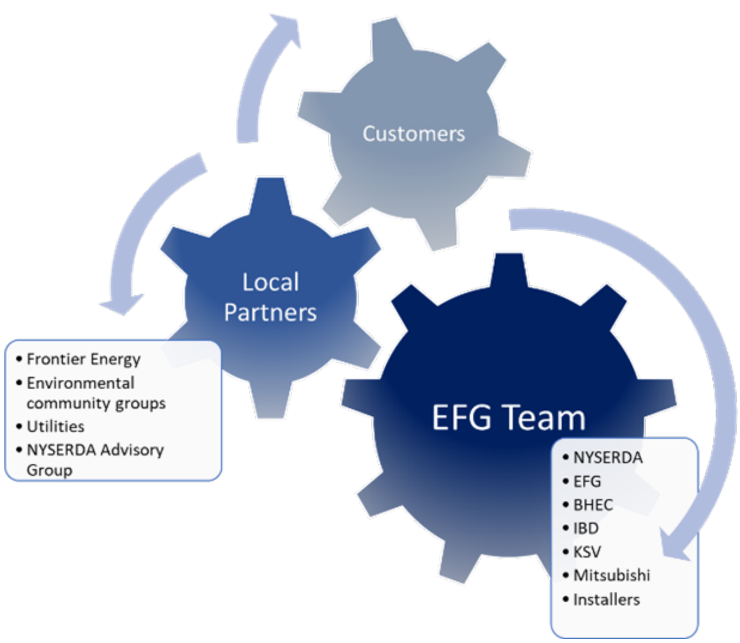
The HVHPP Program required the coordinated efforts of several different entities. The core team included EFG, Bruce Harley Energy Consulting (BHEC), Integral Building Design (IBD), KSV, and Mitsubishi. The team worked with seven local area heat pump installers to identify and recruit 20 existing homes to install Mitsubishi ducted and ductless cold-climate air source heat pumps. The project management structure for the team is depicted in Figure 1.

Figure 1. Hudson Valley Heat Pump Pilot Organizational Chart



Shown in Figure 2 are other entities who significantly assisted with the HVHPP Program but were not part of the EFG team. These include Frontier Energy, whose coordinated collaboration with the EFG team was essential to achieving the goals of the HVHPP Program. The outreach efforts of a number of local entities including environmental nonprofits, community groups, utilities and NYSERDA's Advisory Group were also key to the success of this project.

Figure 2. Hudson Valley Heat Pump Pilot Stakeholder Involvement



Typical and representative homes were recruited. If additional energy-efficient and renewable energy measures such as weatherization and solar photovoltaics were an existing part of the site (or included at the time of the ccASHP installation process), the potential energy impact resulting from these measures was included in the analysis and findings, to the degree possible via monitoring results. As mentioned above, our goal was also to learn more about the interplay between solar generation and ccASHP consumption; therefore, the EFG team attempted to find a mixture of sites with and without solar.
In addition, the goal was also to include a mixture of ductless and ducted ccASHP systems.
Table 1 shows the original plan for targeting both heat pumps and solar systems.

Table 1. Initial Plan for Hudson Valley Heat Pump Pilot Project Types

Total: 20 Projects	Projects with PV installation	Projects without PV installation
Ductless ccASHP	5	5
Ducted ccASHP	5	5

Generally, the EFG team's approach to the development and implementation of the HVHPP Program was a balancing act between thoroughly attending to detail and flexibly responding to external factors through program modification. The EFG team generally followed the "Project Flow Description" shown in Figure 3.

Figure 3. Hudson Valley Heat Pump Pilot Project Flow Description

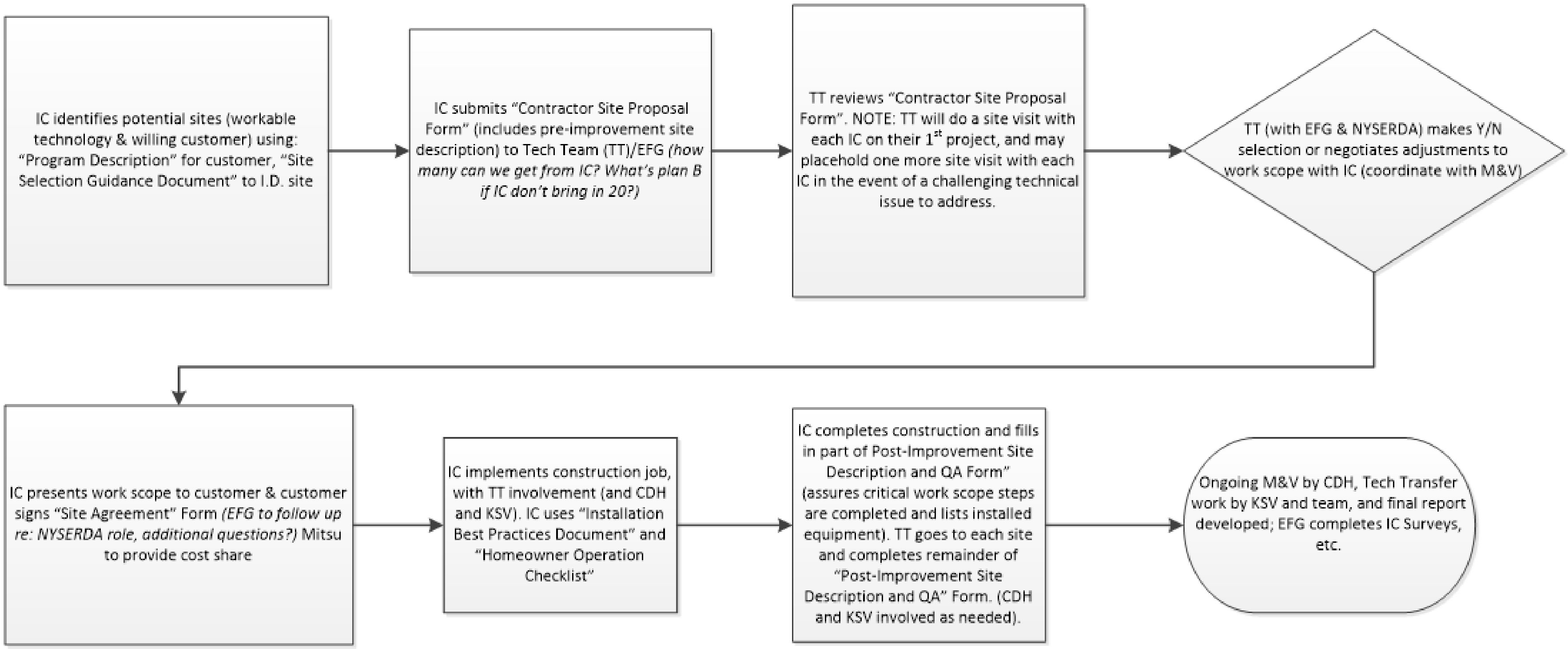


Figure 3 above articulates the eight “high-level” steps involved in achieving the three goals for the HVHPP. In this description, “IC” refers to “Installation Contractor,” “TT” refers to the “Technology Team” (Bruce Harley of BHEC and Pasquale Strocchia of IBD), “CDH” and “M&V” refer to Frontier Energy, and KSV refers to the marketing agency implementing the Technology Transfer process. While Figure 3 shows a mere eight steps, in actual practice each step involved anywhere from five to more than 30 actions on behalf of the EFG team. For example, the first step stating: “IC identifies potential sites (workable technology & willing customer)…” involved significant effort on behalf of the EFG team, as will be described more fully below. Thus, the EFG team approached the HVHPP in a thoughtful, detailed manner but ultimately had to make several modifications to achieve the project goals.

The EFG team also developed multiple project documents and tracking systems to ensure that all participants understood the program and their roles, as well as to ensure an effective data collection and site tracking system. These are listed in Table 2 below, with the complete documents provided in appendix A.

Table 2. Hudson Valley Heat Pump Pilot Program Documents

Document Name	Document Description and Purpose
Outreach List	List of Entities and Events Utilized to Market Program and Identify Participants and Sites
Program Overview (2 versions)	Program Overview's were used to describe the goals, approach, benefits, timeline, and contact information for the HVHPP. Overviews varied in level of detail and approach to "pitch" depending on the audience: customer-facing, contractor-facing, utility-facing, NYSERDA-facing.
Memorandum of Understanding (MOU)	MOUs were developed between EFG and installation contractors; EFG and Mitsubishi; EFG and Frontier Energy. The purpose of the MOU was to clearly articulate roles, responsibilities, and timelines amongst project partners.
Site Agreement Form	An agreement between EFG and the homeowner, clarifying the responsibilities and benefits of the HVHPP for both parties.
Customer Fuel Release Form	This form, completed by customers, was developed to provide proof to utilities that they could share customer energy and bill data with the EFG team.
Contractor Training Webinar	Webinar training explaining the HVHPP program purpose and goals, roles/responsibilities/benefits of all parties, qualifying homes and equipment, installation guidelines, overview of project steps and program documents. Contractors also had to show proof of having participated in Mitsubishi's installation trainings.
Site Selection Criteria Form	Document provided to installation contractors explaining which homes could be part of the program and which could not. For example, existing home, full-time residence that had been occupied and heated/cooled for a minimum of 18 months were eligible.
Pre-Improvement Site Description Form	Document filled in by installation contractors to assist the EFG team (and Frontier and NYSERDA) in understanding the existing site. For example, house size, foundation type, level of insulation, existing heating/cooling/domestic water equipment, presence, and size of solar, existing energy/fuel usage. Document is submitted along with the Pre-Improvement Site Description Form, and the Proposed Work Scope.
Contractor Site Proposal Form	Document filled in by installation contractors to assist the EFG team (and Frontier and NYSERDA) in understanding the proposed project. Document is submitted along with the Pre-Improvement Site Description Form, the Proposed Work Scope and (if applicable) a Load Calculations Report (for any zone that has no backup heat source).
Post-Improvement Site Form – QA	Document completed by the "Tech Team" (Bruce Harley and Pasquale Strocchia) reporting on installation quality including line set, condensate drain, outdoor and indoor unit(s), ducting and setup.
Homeowners Operation Checklist	Brief document for homeowners explaining how to operate the heat pumps as optimally as possible and including a technological explanation of how the heat pumps work in a "layperson" friendly manner.
Installation Best Practices	Contractors were provided with NEEP's "Installing Air-Source Heat Pumps in Cold Climates" and "Sizing and Selecting ccASHPs in Cold Climates." https://neep.org/sites/default/files/resources/InstallingASHPinCold_edits.pdf https://neep.org/sites/default/files/Sizing%20%26%20Selecting%20ASHPs%20In%20Cold%20Climates.pdf

1.4 Customer Outreach and Recruitment

Previous experience in designing, developing, and implementing unique pilot initiatives resulted in the EFG team's understanding that attempting to obtain 20 participating sites through traditional marketing efforts such as print media, radio, and/or television would be expensive and likely unsuccessful in driving customer uptake within the short time frame available for the project. Therefore, the EFG team focused on a three-pronged, targeted approach.

First, the EFG team recruited contractors interested in participating in the program and offering the program benefits to their customers. The initial idea was that these contractors would provide project leads, but that never materialized. Rather, they were generally more focused on selling and managing their projects, and recruitment for the HVHPP project ended up as somewhat of an afterthought. Because the goals of this program focused on energy savings, as well as financial savings, the EFG team's second outreach approach was to work with environmentally- and energy-focused nonprofit organizations to leverage their network in spreading the word about this opportunity. Similarly, the EFG team's third outreach approach involved attending and presenting at environmental- and energy-related public events. A list of these entities and events is included in appendix A. To provide further support, the EFG team developed a HVHPP flyer and created a landing page on EFG's website. Figure 4 and Figure 5 show the front and back pages of the flyer.

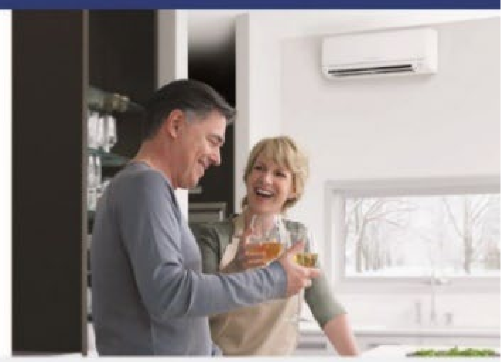
Figure 4. Hudson Valley Heat Pump Pilot Flyer—Front Page

NEW YORK STATE OF OPPORTUNITY. | NYSERDA Supported

Hudson Valley Heat Pump Project

Be part of the clean energy future with a cold-climate heat pump

Don't miss your chance to participate by installing this clean energy technology today.
Get hundreds of dollars in rebates from NYSERDA's Hudson Valley Heat Pump Project (HVHPP).



What can a cold-climate heat pump do for you?

- Improve your home comfort
- Increase your home heating efficiency
- Provide high-efficiency air conditioning
- Reduce your use of fossil fuels and help the environment
- Save on energy costs

What is the Hudson Valley Heat Pump Project?

The HVHPP, sponsored by NYSERDA and administered by Energy Futures Group, is an opportunity for Hudson Valley homeowners to experience the latest energy-saving technology with the guidance and expertise of professionals who will help you reduce operating costs, optimize comfort, and embrace a clean energy future.

HVHPP participants will receive these additional benefits when installing a cold-climate heat pump:

- **Enhanced manufacturer equipment discounts.**
  Get up to $1,750 for "best-in-class" cold-climate Mitsubishi heat pump(s)
- **Peace of mind installation.**
  Expert third-party engineering, design support, quality assurance and monitoring to help ensure optimal installation and operation and demonstrate performance
- **Track your energy use.**
  Free eGauge energy monitoring system; track your heat pump and whole-house energy use
- **Act fast.**
  These benefits are only available for up to 20 homes

Figure 5. Hudson Valley Heat Pump Flyer—Back Page

Who can participate?

Up to 20 homeowners who live in the Hudson Valley region of New York State, and who work with one of the participating heating and cooling contractors found on the Energy Futures Group website, and agree to:

- Data monitoring of your energy savings and usage for at least one year
- Brief pre-installation and post-installation surveys
- Provide fuel and electricity records for one year before, and at least one year after installation
- Quality assurance site visits upon completion of installation work
- Participate in a case study to help us promote this clean energy technology to all New Yorkers

Contact Us Today

Richard Faesy
802.482.5001 ext. 2
rfaesy@energyfuturesgroup.com

To learn more and see a list of participating contractors, visit: energyfuturesgroup.com/hvhpp

For additional information, reach out to your regional contact:

Upper Hudson Valley
Bruce Harley
bruceharleyenergy@gmail.com
802.694.1719

Mid-Lower Hudson Valley
Pasquale Strocchia
pasquale@integralbuilding.com
845.255.0418

10/2017

The EFG team recognized that participation in the program would involve additional inconvenience and intrusion in comparison to simply installing heat pumps. For example, customers needed to provide at least one year (ideally two) of electricity and fuel-use data prior to approval as a site—and then provide additional electricity and fuel-use data for at least several months after the installation. While this may sound like a simple request, it often proved to be otherwise. Acquiring the necessary data typically required multiple phone calls and emails between the customer, their energy providers and the EFG team. Additional site visits and installation of monitoring equipment was required, as well as participation in several web and phone surveys. Finally, customers were informed that the EFG team could be requesting their participation in case studies, and potentially videos.

For this reason, customers were provided a discount in the amount of $350 per ton (based on the outdoor size of the heat pump unit and up to a maximum of 5 tons at each site) at the distributor level, courtesy of Mitsubishi (one of the EFG team members). Additionally, customers were offered the opportunity to keep the eGauge monitoring unit once the project was completed. Finally, each customer was provided additional support throughout the process—and in particular with regards to the technical oversight of the heat pump installations—provided by BHEC and IBD.

To manage expectations about the program, an initial phone call was held with interested homeowners. During this call, the EFG team explained the details of the program such as goals, project partners, benefits, homeowner responsibilities and timeline. The EFG team also asked about the customer's motivation in participating. Generally, the response was a mix of wanting to reduce fossil fuel usage, seeking increased comfort, and interest in reducing heating costs. Additional details about customer experience and motivation to participate are provided in section 4.1.

1.5 Contractor Recruitment and Post-Installation Quality Assurance

The EFG team identified and recruited contractors through networking within the EFG team partners, including Mitsubishi and IBD. The EFG team also reviewed two of NYSERDA's lists (the "Home Performance with ENERGY STAR® Participating Contractors" and "Heat Pump Program Participating Contractors"), identified which contractors worked in the Hudson Valley area, and then reviewed the contractor websites to assess whether they currently installed heat pumps. An overall list of potential contractors was developed, and the EFG team identified and initially trained four heat pump contractor businesses and two solar contractors interested in partnering with heat pump contractors.

Ultimately, two additional contractors participated in the program. In both of these cases, a homeowner had heard of the HVHPP and wanted to participate, but (for example) had already selected a contractor to assist with assessing weatherization opportunities for their home. Table 3 below presents a high-level overview of the six participating contractors, services offered, and total number of projects completed as part of the HVHPP.

Table 3. Overview of Participating Contractors

Contractor Number	Services Offered	Number of HVHPP Projects Completed	Financing Offered?
1	Specializes (only) in ductless mini-split HPs.	14	Y
2	Residential and commercial heating and cooling installation, repair, and maintenance (gas and oil furnaces, boilers, ground, and air source heat pumps), and oil delivery.	2	Y
3	Boiler service and installation, ground and air source heat pump installations.	1	N
4	Whole home building analysis and retrofit (testing, air sealing, insulation, heat pump installation and maintenance).	1	Y
5	Plumbing, gas conversions, water heaters, gas, and oil boilers, well pumps.	1	Y
6	Specializes (only) in ductless mini-split HPs.	1	N

Two of the participating contractors specialize in ductless ccASHPs as their only business services offering, two offer a broad array of HVAC services to both residential and commercial customers, one offers significant plumbing services and some HVAC support, while the sixth contractor provides more of a “building science,” whole home approach, incorporating air-quality considerations and energy analyses, while also working with customers to shift from heating equipment utilizing fossil fuels to heat pumps.

To participate in the HVHPP, contractors were required to fill out an application to participate and attend a half day training (the contractor training webinar is available in appendix A). This training reviewed the goals, roles, responsibilities, program documents and timing of the HVHPP. It also provided an overview of key installation and sizing criteria. Several of the contractors were Mitsubishi Diamond contractors prior to the start of the HVHPP, while two others have since received this status. This program involves initial trainings provided by the manufacturer, as well as ongoing updates on technology and installation practices.[3]

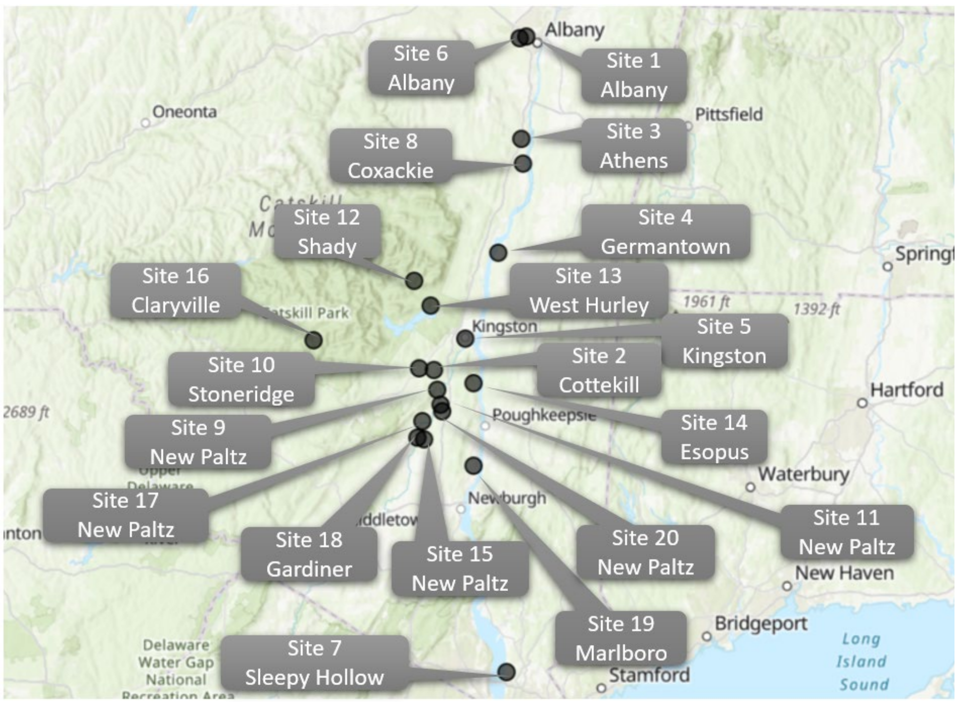
Since some of the goals presented in section 1.2 (e.g., “consumers/homeowners wanting confidence and confirmation that the expected benefits will be achieved…”, “policymakers wanting confirmation that expected energy impacts and GHG reductions are realized) are impacted by heat pump application (e.g. sizing, design, installation), the EFG team implemented QA on each project, utilizing a “Post-Improvement Site Form—Quality Assurance” document (mentioned in Table 2). QA areas of review included specific questions regarding the line set, condensate drain, placement of the outdoor and indoor units, ducting considerations, and setting up thermostat controls. The QA template is available in the appendix; results from the post-installation QA visits are presented in section in 4.3.

Contractor interest was strong at the outset of the program and during the training. However, as the program evolved, maintaining contractor interest and response proved to be challenging. Contractors are busy, and the more paperwork that is asked of them, the more challenging the program can be to implement and complete. Therefore, to incentivize contractors to “go the extra mile” with the additional paperwork, monitoring and QA process, the HVHPP paid each contractor $500 per completed project. However, this was still not enough to secure the completion of projects and associated paperwork. Ultimately, the completion of these tasks was a result of the EFG project partner, IBD, spending a considerable amount of time repeatedly following up with contractors, assisting them with moving through the program steps.

2 Home Characteristics and Equipment Details

The 20 sites participating in this project, all located in the Hudson Valley, are presented below in Figure 6. The next two subsections present original home characteristics such as building type and heating and cooling systems (section 2.1) and project installation information such as the purpose, type, and number of heat pumps installed through the HVHPP (section 2.2).

Figure 6. Hudson Valley Heat Pump Pilot Site Locations



2.1 Home Characteristics

Building styles varied, with three colonials, four ranches, four split levels, five contemporaries, two capes and two “other.” One home was built in the 1880s and the other 19 between 1949 and 2008. Multiple heating fuels are represented by the project sites including fuel oil, natural gas, liquid propane (LP), wood, and electricity. Heating systems also varied and included electric baseboard and radiant heat, furnaces, boilers (with baseboard radiators and steam), existing heat pumps, and wood stoves. Five homes had existing central air conditioning (though two of these were defunct or inoperable), while the rest relied upon window units or did not have cooling. Figure 7 presents a pictorial collage of the building types. Table 4 presents a summary of pre-existing building and equipment, by site.

Figure 7. Pictorial Collage of Hudson Valley Heat Pump Pilot Homes

Table 4. Home Characteristics and Original Heating and Cooling Information

Building Information					Original Heating and Cooling Systems					
Site No.	**City**	**Heated Floor Area (sq ft)**	**Type of Home & Year Constructed**	**No. of Flrs**	**Space Heating Fuel & System Type**	**No. of Space Heating Zones**	**Heating Capacity (MBtu/h)**	**Water Heating Fuel & System Type**	**Cooling System**	**PV Size**
S1	Albany	1500	Brick Ranch 1949	1	Gas boiler	1	86	Gas-fired tank	Central	4 kW
S2	Cottekill	2000	Cape 1988	2	Electric baseboard	Not recorded	51	Electric tank	Window	-
S3	Athens	2000	Colonial 1990	2	Oil boiler	2	125	Oil Boiler HX	Central	4 kW
S4	German-town	1576	Mixed additions 1970	2	Electric baseboard	7	Not recorded	Electric	Window	-
S5	Kingston	2286	Victorian Italianate 1880s	2	Gas steam boiler + (2) Existing HPs	1	187	Gas-fired tank	2 HPs (installed in 2016)	4-5 kW
S6	Albany	1700	Split Level 1975	2	Gas furnace	1	54	Gas-fired tank	Central - defunct	-

Table 4 continued. Home Characteristics and Original Heating and Cooling Information

Building Information					Original Heating and Cooling Systems					
Site No.	**City**	**Heated Floor Area (sq ft)**	**Type of Home & Year Constructed**	**No. of Flrs**	**Space Heating Fuel & System Type**	**No. of Space Heating Zones**	**Heating Capacity (MBtu/h)**	**Water Heating Fuel & System Type**	**Cooling System**	**PV Size**
S7	Sleepy Hollow	1752	Split Level 1959	2	Gas boiler HW Baseboard	1	160	Gas-fired tankless	4 Window	-
S8	Coxsackie	1600	Cape 1960	2	Oil boiler	2	120	Oil Indirect tank & HPWH	None	-
S9	New Paltz	1600	Contemporary 1970	1.5	Propane furnace	1	120	Propane tank	Window	-
S10	Stone Ridge	2233	Colonial 1949	3	Oil boiler & existing HPs	5	85	Solar Hot Water & Oil Indirect tank	Heat pump	11 kW
S11	New Paltz	1249	Split Level 1972	1.5	Electric baseboard & radiant	3	35.8	Electric HE tank	Window	-
S12	Shady	1500	Contemporary 2006	2	Oil boiler & wood stove	2	109	Oil indirect tank & HPWH	Window	2.5 kW
S13	West Hurley	1950	Colonial 1960	2	Oil boiler & wood fireplace	3	115	Indirect Tank	Window	7 kW
S14	Esopus	2600	Contemporary 2006	2	Propane HE boiler	3	85.4	Propane indirect Tank	Central	6.2 kW
S15	New Paltz	6500	Contemporary 2005	2	Propane HE boiler & existing HPs	7	193	Propane indirect tank	Central	-
S16	Claryville	2600	Contemporary 1985	2.5	Electric baseboard & Wood Stove	6	9 kW	Electric tanks (2)	None	-
S17	New Paltz	1623	Ranch 1980	1	Oil Boiler & wood stove	5	162	Electric HPWH	Window	-
S18	Gardiner	1388	Split level 2008	2.5	Oil boiler	3	120	Oil Indirect tank	Central	13 kW
S19	Marlboro	1500	Ranch 1969	1	Electric baseboard	9	42.6	Electric tank	2 Window	7 kW
S20	New Paltz	1320	Ranch 1958	1.5	Propane furnace	1	unknown	Propane tankless	Central - inactive	-

2.2 Equipment Details

Mitsubishi was part of the EFG team and provided a discount to customers through the distributor. The specific equipment selected and installed was determined by the contractor based on a site visit and a subsequent proposal approved by the homeowner. Table 5 summarizes the heat pumps installed at each site (including the originally installed Heat Pumps).

The tables include the intended heat pump (HP) Strategy for heating, which was either "Partial," "Full," or "Full, remain." These terms are consistent with the current terminology used in the statewide clean heat (CH) incentive program:

- Partial, indicating the heat pump was only intended to meet a portion of the annual heating load (i.e., HP heating capacity at 5°F sized to be less than 90% of the design heating load).
- Full, indicating the heat pump was sized to meet the full load (i.e., HP heating capacity at 5°F sized to be between 90% and 120% of the design heating load).

The "Full, remain" option indicates that the HPs were sized to meet the full-heating load, but the original heating system still remained in place. The exact heating loads and sizing ratios determined as part of the CH Program were not determined for the sites in this project.

Table 5. Cold-Climate Air Source Heat Pump Installation Details at Each Site

Site No.	City	HP Strategy* for Heating	Distribution System	No. of Sections Out / In	Nominal Cooling Capacity (tons)	Outdoor Unit(s) (quantity)	Indoor Section(s) (quantity)
S1	Albany	Partial	Ductless	1 / 1	1.5	MUZ-FE18NA	MSZ-FE18NA
S2	Cottekill	Partial	Ductless	1 / 2	2.5	MXZ-3C30NAHZ2-U1	MSZ-FH18NA2 MSZ-FH09NA
S3	Athens	Partial	Ductless	1 / 3	3	MXZ-4C36NAHZ	MSZ-FE18NA MSZ-FH09NA (2)
S4	Germantown	Partial	Ductless	1 / 1	1.25	MUZ-FH15NA	MSZ-FH15NA
S5	Kingston	Partial	Ductless	2 / 2 2 / 2**	1.5 2**	MUZ-FH09NA (2) HPs installed in 2016**	MSZ-FH09NA (2)
S6	Albany	Full, remain	Ductless	3 / 3	3	MUZ-FH18NA2 MUZ-FH12NA MUZ-FH06NA	MSZ-FH18NA2 MSZ-FH12NA MSZ-FH06NA
S7	Sleepy Hollow	Full, remain	Ductless	2 / 6	4	MXZ-3C24NAHZ2 MXZ-3C24NAHZ2	MSZ-GL06NA-U1 (3) MSZ-GL15NA-U1 MSZ-GL12NA-U1
S8	Coxsackie	Full, remain	Ductless	4 / 4	3	MUZ-FH18NA2 MUZ-FH06NA (3)	MSZ-FH18NA2 MSZ-FH06NA (3)
S9	New Paltz	Partial	Ductless	2 / 2	2.5	MUZ-FH18NA2 MUZ-FH06NA MUZ-FH06NA	MSZ-FH18NA2 MSZ-FH06NA MSZ-FH06NA
S10	Stone Ridge	Full, remain	Ductless	2 / 2 4 / 4**	2 3.25**	MUZ-FH06NA MUZ-FH18NA2 HPs already installed**	MUZ-FH18NA2 MSZ-FH18NA2

* Definitions for "HP Strategies":

"Partial" means partial load heating: The HP meets only part of heating load.

"Full" means full-load heating: The HP is intended to meet all the heating load, and the original heating system is removed.

"Full, remain" is the same as full-load heating, but the original heating systems remained in place.

** These heat pumps were installed prior to the HVHPP.

Table 5 continued

Site No.	City	HP Strategy* for Heating	Distribution System	No. of Sections Out / In	Nominal Cooling Capacity (tons)	Outdoor Unit(s) (quantity)	Indoor Section(s) (quantity)
S11	New Paltz	Full, remain	Ductless	5 / 5	4.25	MUZ-FH18NAH2 MUZ-FH12NAH	MSZ-FH-18 MSZ-FH-12 SEZ-KD-18
S12	Shady	Partial	Ductless	1 / 1	0.75	MUZ-FH09NA	MSZ-FH-09NA
S13	West Hurley	Full, remain	Ductless	3 / 3	3.5	MUZ-FH18NA2 MUZ-FH12NA (2)	MSZ-FH18NA MSZ-FH12NA
S14	Esopus	Full	Ductless / Ducted	2 / 3 Mixed	6	MXZ-4C36NAHZ PUZ-HA36NHA5	MVZ-A36AA7 MSZ-FH06NA PVA-A36AA7
S15	New Paltz	Full, remain	Ductless	2 / 2 6 / 6**	2 7**	MUZ-FH12NA (2) HPs already installed**	MUZ-FH12NA (2)
S16	Claryville	Full	Ductless	3 / 3	4	MUZ-FH12NA (1) MUZ-FH18NA2 (2)	MSZFH12NA (1) MSZFH18NA2 (2)
S17	New Paltz	Partial	Ductless	1 / 1	1.5	MUZ-FH18NA2 (1)	MSZ-FH18NA2 (1)
S18	Gardiner	Full, remain	Centrally Ducted	1 / 1 Duct	3	PUZ-HA36NHA5 (1)	PVA-A36AA7 (1)
S19	Marlboro	Full	Ductless	5 / 5	5.25	MUZ-FH18NAH2 (1) MUZ-FH12NA (3) MUZ-FH09NA (1)	MSZ-FH18NA2 (1) MSZ-FH12NA (3) MSZ-FH12NA (1)
S20	New Paltz	Full	Ductless	5 / 5	5.5	MUZ-FH18NAH2 (1) MUZ-FH12NA (4)	MSZ-FH18NA2 (1) MSZ-FH12NA (4)

* Definitions for "HP Strategies":

"Partial" means partial load heating: The HP meets only part of heating load.

"Full" means full-load heating: The HP is intended to meet all the heating load, and the original heating system is removed.

"Full, remain" is the same as full-load heating, but the original heating systems remained in place.

** These heat pumps were installed prior to the HVHPP.

Table 6 provides the installation costs for the ccASHPs for all but two of the homes.[4] The installed costs are given along with the final cost to the customer after accounting for the incentives provided in each case. The average cost per installed ton was $4,138 for all the sites. The average cost after applying all the available incentives (see the notes in Table 6) was $3,038 per ton. In both cases the median and average costs per ton were within 1%.

Table 6. Cold-Climate Air Source Heat Pump Installation Costs for Each Site

Site	City	Original Replacement Strategy	ASHP (No. out/No. in/ tons)	HP Installed Costs	Installed Costs after Incentives	Installed $ PER ton	Installed $ PER ton after Incentives
S1	Albany	Partial	1 / 1 / 1.5	$5,898	$4,873	$3,932	$3,249
S2	Cottekill	Partial	1 / 2 / 2.5	$9,770	$8,495	$3,908	$3,398
S3	Athens	Partial	1 / 3 / 3.0	$12,500	$11,450	$4,167	$3,817
S4	Germantown	Partial	1 / 1 / 1.25	$5,454	$4,499	$4,363	$3,599
S5	Kingston	Partial	4 / 4 / 3.5				
S6	Albany	Full, remain	3 / 3 / 3	$12,100	$8,950	$4,033	$2,983
S7	Sleepy Hollow	Full, remain	2 / 6 / 4.0	$26,400	$22,600	$6,600	$5,650
S8	Coxsackie	Full, remain	4 / 4 / 3.0	$16,215	$10,615	$5,405	$3,538
S9	New Paltz	Partial	2 / 2 / 2.5	$8,830	$5,105	$3,532	$2,042
S10	Stone Ridge	Full, remain	6 / 6 / 5.25	$8,450	$5,450	$1,610	$1,038
S11	New Paltz	Full, remain	5 / 5 / 4.25	$18,980	$12,493	$4,466	$2,939
S12	Shady	Partial	1 / 1 / 0.75	$3,750	$2,488	$5,000	$3,317
S13	West Hurley	Full, remain	3 / 3 / 3.5	$15,350	$10, 375	$4,386	$2,964
S14	Esopus	Full	2 / Duct / 6.0	$25,000	$21,900	$4,167	$3,650
S15	New Paltz	Full, remain	8 / 8 / 9.0				
S16	Claryville	Full	3 / 3 / 4.0	$14,450	$10,650	$3,613	$2,663
S17	New Paltz	Partial	1 / 1 / 1.5	$3,950	$2,550	$2,633	$1,700
S18	Gardiner	Full, remain	1 / Duct / 3.0	$11,450	$9,400	$3,817	$3,133
S19	Marlboro	Full	5 / 5 / 5.25	$23,545	$14,208	$4,485	$2,706
S20	New Paltz	Full	5 / 5 / 5.5	24,040	$12,615	$4,371	$2,294

Notes: Incentives included some combination of (1) cash incentives from the HVPPP Pilot, (2) a discount from the Mitsubishi, (3) utility-supplied incentive, and (4) other sources.

2.3 Installation Quality Assurance Results

Installation contractors did not always follow the Northeast Energy Efficiency Partnership (NEEP) installation guidelines, so the on-site QA by the EFG team was helpful to address issues of concern and/or deficiencies.[5] Various recommended installation specifications were often not adopted by installing contractors. Generally, when issues of serious concern were found, contractors were asked to go back and correct them before their $500 incentive was paid.

In terms of indoor conditions, it was recommended that ductless wall units be installed 8–12 inches below ceiling height for ceiling heights up to eight feet and in rooms with tall or vaulted ceilings, and that the indoor unit be mounted at about eight feet. However, this was generally not implemented. Reasons for this included (1) the manufacturer specifications did not call for what the HVHPP recommended, (2) the homeowner wanted the unit closer to the ceiling due to aesthetic concerns, and finally, in several circumstances (3) the recommendation was not applicable (e.g., due to the location of a structural beam that would have obstructed air flow). Additionally, the installation of remote wall thermostats for larger rooms was recommended instead of using hand-held controls, but this occurred only at seven of the sites (two sites were not applicable). Installing contractors complained that the additional cost for the wall thermostats was a barrier to customers agreeing to purchase the additional controller(s).

Recommended durability measures for outdoor units included installation of outdoor unit at a minimum height of 18–24 inches above grade (higher in snow country) to avoid snow; use of stable, durable and sloped material (i.e., concrete pads) beneath outdoor units installed on ground-mount stands; installation of well-drained materials beneath or around ground-mount stands; full-length refrigerant line insulation to the ports located at the side or back of the outdoor units; and proper termination of condensate lines to drain away from foundation walls. Many of these recommendations were implemented. However, the recommendation that “drain piping be properly pitched and sloped downhill; drain is terminated away from foundation walls, crawl spaces, walkways and outdoor equipment” was one that only half of the installations followed. In most of these situations, it was found that the drain tubes terminated close to the foundation wall. For many of these sites, the homeowner stated they would monitor the situation.

Additional recommendations for outdoor units covered sufficient vibration/noise control measures, including installation of outdoor units at framed walls on stands versus on wall brackets, and proper anchoring and fastening of outdoor units to brackets and/or stands. The majority of contractors had at least one installation item which needed attention to ensure “best practice,” but many of these were addressed through the QA process, as detailed below. Proper refrigerant charge procedures that could have a critical impact on performance were questionable, including evacuation, pressure testing, and charging. Some of the field QA challenges included the fact that it is impractical to field check proper procedures at time of installation and to field test for proper refrigerant charge post-installation using conventional testing methods.

Some recommended QA actions to consider include photo-documentation of actual refrigerant charging procedures for each system and developing, standardizing, and implementing alternate testing and measuring protocols.

2.3.1 Outdoor Unit

The outdoor units were generally installed well. There were only two homes in which surge suppressors were installed, but surge suppressors are considered "best practice" recommendations in the NEEP installation guide and were not required. Issues that came up in a small number of units included exterior unit mounting practices (e.g., securely mounted, level, and of adequate height above expected snow line); outdoor unit noise; and mounting location relative to defrost meltwater and possible roof drips. Table 7 presents an overview of the QA results pertaining to the outdoor unit installations.

Table 7. Outdoor Unit Quality Assurance Summary

Outdoor Unit	Y	N	N/A (or unknown)
Unit placement allows for free air flow, following manufacturers' instructions. Outdoor unit does not interfere with view through or operations of any windows or doors.	20	0	0
Outdoor unit is located in an appropriate place regarding aesthetic and noise considerations, in accordance with customer's wishes.	20	0	0
Outdoor unit is securely mounted and level.	16	3	1
If multiple outdoor units, they are not stacked above each other, or installed too closely.	11	2	7
Unit has adequate clearance above snow line (generally ≥18 inches, higher in snow country).	17	3	0
If wall-mounted: Wall mount brackets secure and stable.	15	1	4
If ground-mounted: Unit base is set on a substrate that is well-drained and will not heave with frost, or a concrete pad; Or unit is mounted on a pedestal or stand using bolts or adhesive to secure the unit.	2	2	16
Outdoor unit does not make excessive noise or vibrations, based on actual operation.	18	2	0
Outdoor unit is not adjacent to a walkway or other areas where refreezing defrost meltwater might cause a hazard.	16	4	0
Outdoor unit is not directly under any drip line from the roof or other overhang.	18	2	0
Alternately, outdoor unit has drip caps or shield to protect from rain/ice/drips.	0	0	20
Surge suppressors are installed at service disconnect (not required, though recommended).	2	17	1
Alternatively, approved surge suppressors are installed at circuit breaker box (not required, though recommended).	0	13	7
Drain pan heater is disabled or not present.	10	0	10 (unknown)

2.3.2 Line Set

Generally, line sets had few issues. A few homes had thermal insulation disturbed by the installation that was not returned to its original condition, and one had issues with the insulation not running all the way to the outdoor unit (this was corrected). Table 8, shown below, presents an overview of the QA results pertaining to the line set work. For many of these items, "N/A (or unknown)" was selected due to the line set that was located within the walls and therefore not visible.

Table 8. Line Set Quality Assurance Summary

Line Set	Y	N	N/A (or unknown)
Line-sets appear to be of appropriate length, height difference, and location.	16	3	1
Insulation covers entire line set length.	19	1	0
Exterior line set length is protected with a rigid cover with UV tape at unavoidable exposed areas.	19	1	0
Line set penetration through the building enclosure is rodent proof (e.g., PVC sleeve and cap drilled to the size of the refrigerant lines).	16	0	4
All penetrations through the shell of the home are sealed with insulating sealant/spray foam.	14	0	6
Any insulation disturbed by installed line set must be returned to original (or better) condition.	8	1	11

2.3.3 Condensate Drain

As indicated above, a number of installations were not properly drained to shed condensate away from the foundation of the homes. And in some cases, the units drained onto walkways, creating potential slip-hazards during freezing weather. These issues were addressed as much as possible through the on-site QA process. Table 9 presents an overview of the QA results pertaining to the setup of the condensate drain.

Table 9. Condensate Drain Quality Assurance Summary

Condensate Drain	Y	N	N/A (or unknown)
Drain piping is properly pitched and sloped downhill. Drain is terminated away from foundation walls, crawl spaces, walkways, and outdoor equipment.	10	10	0
Indoor air-handler units are piped to a floor drain or via a condensate pump to a drain or the exterior.	2	0	18 (N/A)

2.3.4 Indoor Unit

Indoor unit installations were rarely problematic, other than the clearance to the ceiling. At the time HVHPP began, the NEEP installation guide recommended 12 to 18 inches clearance where possible, but the NEEP guidance was revised to recommend a minimum of 6 inches when possible. Although in some cases there was not enough space to provide the 6-inch recommended clearance. In general, there is a tendency of contractors to install the units as close to the ceiling as they possibly can, typically as close as 3 inches, as allowed in manufacturer recommendations. This reduces heating efficiency by increasing return air temperature. While not a critical requirement, it is an area where installer education could improve practices. Table 10 presents an overview of the QA results pertaining to the indoor unit installation height.

Table 10. Indoor Unit Quality Assurance Summary

Indoor unit	Y	N	N/A (or unknown)
Indoor wall unit mounted units have adequate clearance from the ceiling (a minimum of 8-12 inches) for ceiling heights up to 8 feet.	5	12	3
In rooms with tall or vaulted ceilings, indoor unit is mounted at about 8 feet.	4	2	14
Other indoor distribution is used: floor mount.	0	0	20
Other indoor distribution is used: ducted.	2	0	18

2.3.5 Ducts

While the vast majority of ccASHP systems installed were ductless, there were a small number of centrally ducted systems. Although one of the sites with two centrally ducted systems performed quite well, with no installation issues of concern, there were issues with the installation of the other sites with centrally ducted systems. Many of the issues of concern were related to the installation of the heat pump air handlers in existing ductwork. Moreover, it appeared that contractors who specialized in "ductless" systems were ill-equipped to install centrally ducted systems properly. Note that no mini-duct systems (e.g., horizontal air handling units) were installed, hence the results presented in Table 11 pertaining to duct work.

Table 11. Duct Quality Assurance Summary

Ducts	Y	N	N/A
Mini-duct systems are adequately sized/minimizes fittings, air flow seems adequate from all registers.	0	0	20
Any ducts and/or air handlers in unconditioned space are thoroughly sealed with duct mastic and all components insulated to a minimum of R-8.	0	2	18

2.3.6 Setup

The two most frequent issue notations on the heat pump setup were wall-mounted thermostats and integrated controls, though both of these were best-practice recommendations rather than requirements. The NEEP guideline on wall-mounted thermostats at the time HVHPP began was for rooms over 150 square feet, but that subsequently changed to 300 square feet; presumably that would shift at least some of the "No" responses to "N/A." In terms of the integrated controls, there are few viable products on the market, but at the time HVHPP began there were virtually none (reflected by the fact that there were 0 "yes" responses to this item). It is notable that in all 18 cases in which no integrated thermostat was installed, the customer was made aware of correct operation.

The other item with a significant number of "no" responses was the recommended measure to "disable continuous fan operation." One of the primary challenges that contractors faced was that the manufacturer designed the ductless units with continuous fan operation and in order to disable that feature, an irreversible modification would need to be made to the indoor unit. Therefore, while this recommendation was not favorably received by the installing contractors—and customers were not advised of this option despite the fact that the modification was suggested by the factory representatives—it is nevertheless, supported by the manufacturer, and does not void the warranty. Table 12 presents an overview of the QA results pertaining to setup regarding temperature control.

Table 12. Setup Quality Assurance Summary

Setup	Y	N	N/A (or unknown)
In spaces > 150 sq ft, wall-mounted thermostat is installed in a representative location (i.e., instead of using hand-held remote controller).	7	11	2
If a wall T-stat is installed, it is set so that the temperature is sensed at the wall thermostat.	10	1	9 (all N/A)
Indoor unit(s) with standard hand-held remote controls (i.e., return-air sensing at indoor unit) are installed in small rooms (<150 SF) with no significant comfort issues.	14	0	6 (all N/A)
For retrofit situations where the existing heating equipment is maintained, the main zone ccASHP thermostat is mounted near the central system thermostat.	3	2	14 (N/A) 1 (unknown)
Temperature sensing/response has been adjusted to customer's satisfaction.	17	1	2
For retrofit situations where the existing heating equipment is maintained, was an integrated multi-stage control installed?	0	16	4
Customer is aware of correct operation of the two different thermostats (one for existing equipment and one for new ASHP).	18	0	2
Continuous fan operation is disabled.	3	9	8

2.3.7 Other Observations

A number of customer comments were noted during the QA visits. Each of these comments were forwarded to the installing contractor, though their replies were not provided to the broader EFG team, except in the case of a failure or serious concern. In general, the comments revealed that customers did not receive an adequate orientation about the purchased heat pump systems or related controls and features. In particular, there is significant confusion about the use of the "dry" mode, which is not the same as dehumidification because there is no humidity set-point on the controller. Moreover, this feature can only be used as part of a cooling strategy and can lead to "over-cooling" if the directions for use are not properly understood by the homeowner.

One of the significant lessons learned is the poor applicability for heat pumps as a "displacement" strategy to reduce fossil-fuel heating system use in houses with a steam boiler system. Given that steam-based systems are typically single-zone, the opportunity to off-set its use with heat pumps (rather than completely replace the boiler with heat pumps) was neither practical nor effective.

3 Results: Energy Impacts and Cost Savings

3.1 Monitoring Approach

A “Performance Validation” plan was written at the beginning of the project (see appendix D) to arrive at a common understanding of what measured data would be collected from each site and how it would be used to quantify the savings and performance of each ccASHP site.

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 setpoints and generally have similar behavior in the pre- and post-periods.[6]

In the post-retrofit period, metering was installed to measure ccASHP electric use and then correlate daily ccASHP energy use to daily outdoor temperature data from a nearby weather station in the region. 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 (after accounting for baseline fuel use by non-space-heating uses). 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 we can 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 cost savings.
- The implied seasonal average efficiency of the heat pump.
- Reductions in greenhouse gas emissions.

At most houses, metering was also installed to collect total house electric use at regular intervals. Total house use was helpful for determining internal gains in the home and was used in a load-line analysis to discern the temperature dependent portions of the electric load for both heating and cooling. For electrically heated homes, the difference between the temperature-dependent electric load in the pre- and post-retrofit periods provided an estimate of the net electric heating savings.

For homes with pre-retrofit electric baseboard heat, the on-site metering also included the resistance electric heat use where possible. This allowed us to separate the impact that the ccASHPs had on baseboard electric heater use in the post-retrofit period. This provided the means to discern the savings impact and efficiency of heat pump alone as well as the efficiency of the heat pump and the resistance heating combined.

At all these homes an eGuage power metering system (www.eguage.net) was installed to measure electric power use. Each eGuage system could accommodate 12 current transducers (CTs) that could be used to measure various 120 Volt circuits in the electrical panel. Different measurements were taken at each house. We prioritized measurements of power for: (1) all the ccASHPs in the home, (2) resistance electric heat circuits that might run for supplemental heating, (3) total house power, and (4) boiler/furnace power (to infer runtime). The next priority was to measure PV solar output (if present) and power for the electric water heater. The solar generation also allowed us to determine the total usage for the home (i.e., usage = utility purchases + solar generation). Table 13 lists the power measurements that were made at each site. Appendix B provides the metering installation details at each site along with photos of the ccASHP and other equipment in each home.

Table 13. Metered Electric End Uses at Each Home

Site	Monitoring Start Date	House Mains	Solar	ccASHPs (No. of circuits)	Resistance Heat (No. of circuits)	Electric WH	Boiler or Furnace
S1	12/12/2017	1	1	1			1
S2	1/11/2018	1		1	3	1	
S3	3/27/2018	1	1	1		1	1
S4	1/11/2018			1	2		
S5	3/27/2018	1	1	2			1
S6	5/21/2018	1		2			
S7	9/4/2018	1		2		1	
S8	7/19/2018	1		4		1	
S9	7/19/2018	1		2			
S10	9/27/2018	1	1	6			1
S11	2/7/2019	1		5		1	
S12	11/1/2018	1	1	1		1	1
S13	10/30/2018	1	1	3			1
S14	2/20/2019	1	1	2 + 2 AHUs			
S15	3/28/2019	1		6		1	
S16	3/7/2019	1		3	1	1	
S17	1/31/2019	1		1		1	
S18	2/26/2019	1	1	1 + AHU			
S19	3/6/2019	1	1	5	3	1	
S20	3/5/2019	1	1	5	2	1	1

Notes: Total house power could not be measured at S4. Usually, the ccASHP measured circuits corresponded to the number of outdoor ccASHP units, though in some cases multiple ccASHP units were combined on one circuit and so were measured together. For ccASHP units with ducted AHUs, a separate CT was required to measure that power use. In some cases, the AHU included resistance heating elements.

Measured readings are automatically transferred to a cloud server using each homeowner's wireless internet (WiFi). FE downloaded the power data directly from each logger that was averaged into 15-minute intervals each night. That data was then saved in a database for each site.

3.2 Weather Data and Utility Electric/Fuel Costs

We associated each site with a nearby weather station. The list of the weather stations used in this project are given in Table 14. Local utility costs were associated with each weather station as shown in the table. These costs are from NYSERDA's Energy Analysis group and were used for the ASHP Proforma Tool (circa Spring 2020) that is used to estimate calculated annual energy cost savings. These costs were consistent with the utility rate information we received from some of the customers' bills in each region.

Table 14. Weather Data and Utility Fuel Costs

Weather/Utility Region	Electric Cost ($.kWh)	Natural Gas Cost ($/therm)	Fuel Oil Cost ($/gal)	Propane Cost ($/gal)
Albany/National Grid	0.117	0.83	2.49	2.67
Newburg/Central Hudson	0.15	1.47	2.68	2.44
NY LGA/Con Ed	0.20	1.40	2.45	2.24

3.3 Detailed Analysis Heating Results for Three Sites

A detailed analysis of the data collected from each site is included in appendix C. The sections below highlight three examples where different analysis approaches were used:

- A home that installed a ccASHP to partially displace an oil-boiler (Site S3).
- A house that installed a ccASHP to partially displace baseboard electric heat (Site S4) that DID have post-retrofit electric utility bills available.
- A house that installed a ccASHP to partially displace baseboard electric heat (Site S2) that DID NOT have valid post-retrofit electric utility bills.

3.3.1 Analysis of Site 3: Replacing Oil Heat

Site 3 is a 2000 square feet (sq ft) house in Athens, NY near Albany. The house was originally heated by an oil boiler with hydronic baseboard, with the boiler also providing domestic hot water (DHW) for the home. The boiler was also used for supplemental heating after the 3-ton ccASHP with three indoor ductless heads was installed on January 19, 2018. Monitoring began in early April 2018. This unit also operated in the cooling mode.

Table 15 summarizes the measured energy use for the total house and the heat pump over the monitoring period. Heat pump power use for the heating season (May to October) was 3,416 kilowatt-hours (kWh). Electric use in June through September was 997 kWh.

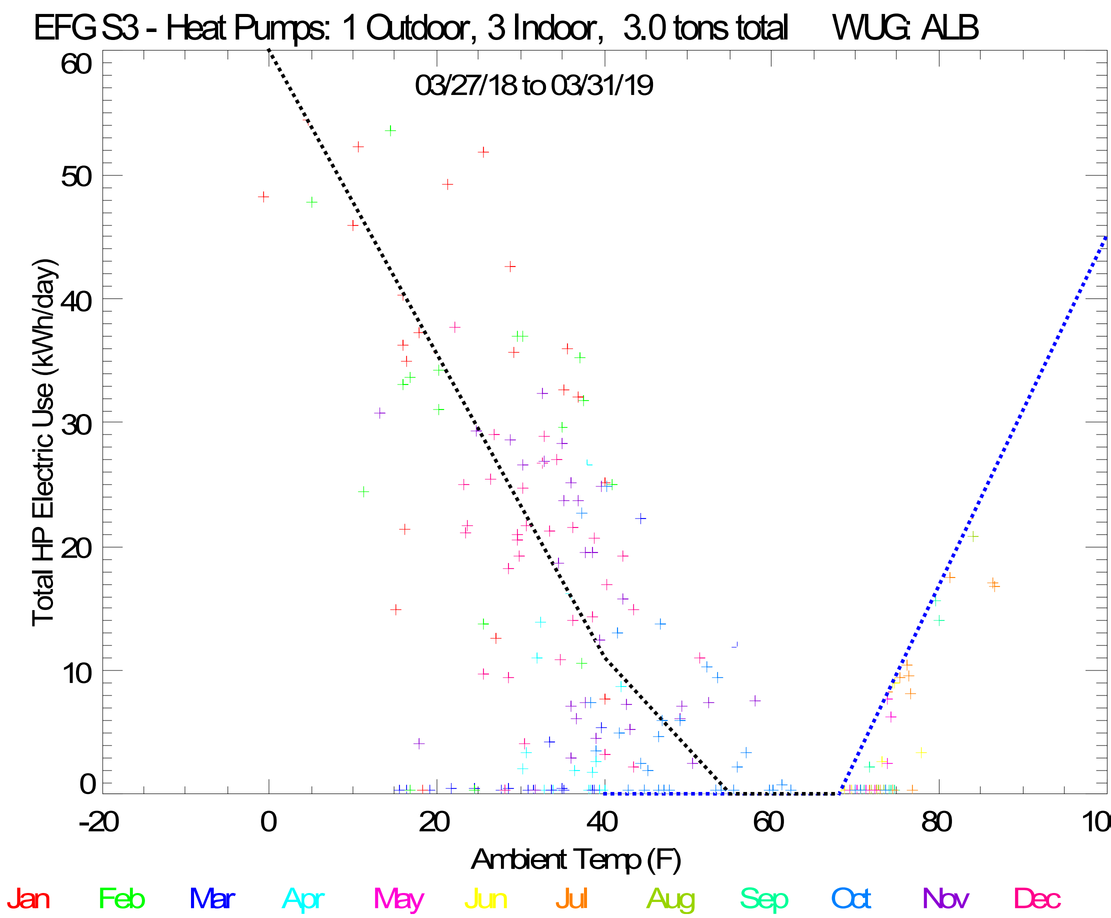
Table 15. Measured Electric Use for the Total House and ASHP Unit at S3

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)	Boiler Runtime (hrs)
Mar-18	7	128.4	58.6	-	5.3
Apr-18	30	524.5	111.0	-	54.8
May-18	31	369.3	44.3	-	14.0
Jun-18	30	480.2	146.3	-	9.0
Jul-18	31	654.2	375.9	-	9.2
Aug-18	31	743.0	383.2	-	8.7
Sep-18	30	399.4	91.9	-	9.1
Oct-18	31	705.2	142.8	-	26.6
Nov-18	30	1,140.7	462.4	-	46.6
Dec-18	31	1,273.3	562.6	-	68.6
Jan-19	31	1,757.0	1,038.1	-	65.4
Feb-19	28	1,408.9	774.2	-	56.3
Mar-19	31	763.9	280.5	-	61.9
Annual	365	10,219.6	4,413.2	-	430.2
Htg Season	243	7,942.8	3,415.9	-	394.2
Jun-Sep	122	2,276.8	997.3	-	36.0

Daily heat pump power use is shown in Figure 8 as a function of daily average outdoor temperature (from Albany Airport). There was some scatter in the daily energy use trend, probably due to daily variations in how the occupants used the ductless heat pump. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of electricity use in the summer is also apparent at this site.

Figure 8. Daily Heat Pump Energy Use versus Daily Average Temperature at S3

(Days in each month shown with a different color).



At this site, heat pump operation displaced 67% of the fuel oil use by the boiler.

Figure 9 compares the trend of fuel use with temperature for both the pre-retrofit period (◊ symbol) and post-retrofit period (+ symbol, with month number shown). The actual tabular delivery and temperature data are also given in Table 16. Temperature for a nearby weather station (Albany) was averaged across each delivery period.

The solid line represents the overall fuel-use trend that is the best-fit, change-point model to the seven deliveries in the pre-retrofit period. Note that fuel use levels off to a constant value in the summer because the boiler meets the water heating loads all year. The dotted line represents the fuel-use trend in the post-retrofit period, which is based on only three fuel deliveries in the post period. However, there was still enough data to establish a reasonable fuel-use trend. For the post-retrofit fuel-use trend, we assumed that post-retrofit fuel use for water heating was the same as in the pre-retrofit period (when there was more data). The trendlines for this site imply that the ccASHP was able to serve the entire heating load down to a balance point temperature near 40°F. Therefore, the oil boiler only started to operate to provide space heating below that balance point.

Figure 9. Analysis of Fuel Delivery Logs with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends at S3

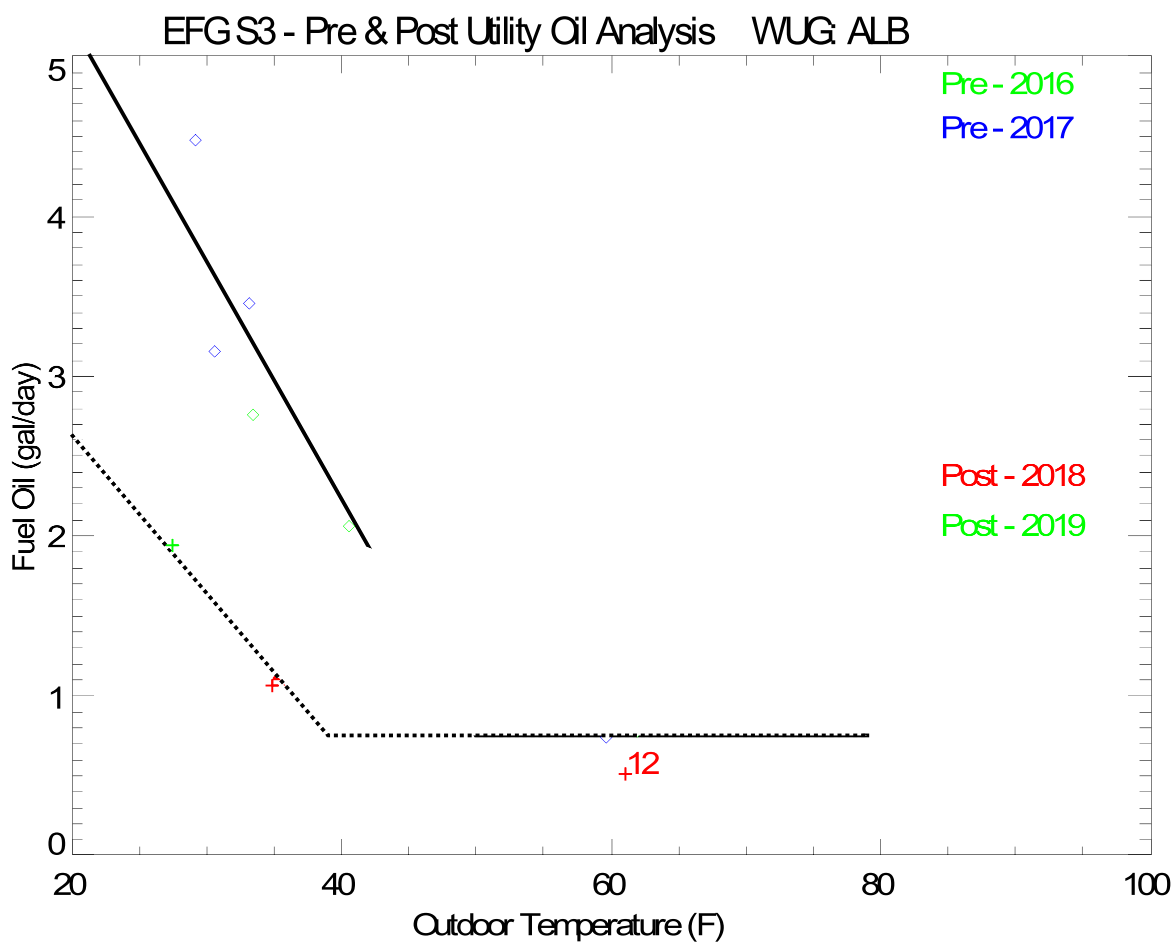


Table 16. Fuel Oil Delivery Logs at S3
(Data used in Figure 10 above).

Period	Start/ Previous Date	End/ Delivery Date	Days in Period	Delivery (gallons)	Avg Oil Use (gal/day)	Period Avg Temperature (F)
pre	12/15/2015	2/9/2016	56	154.4	2.76	33.4
pre	2/9/2016	5/3/2016	84	173.3	2.06	40.6
pre	5/3/2016	12/6/2016	217	167.8	0.77	62.0
pre	12/6/2016	1/19/2017	44	197.2	4.48	29.2
pre	1/19/2017	3/14/2017	54	186.9	3.46	33.1
pre	3/14/2017	11/16/2017	247	182.4	0.74	59.7
pre	11/16/2017	12/30/2017	44	138.9	3.16	30.6
post	2/5/2018	4/13/2018	67	71.3	1.06	34.9
post	4/13/2018	12/5/2018	236	120	0.51	61.0
post	12/5/2018	2/4/2019	61	118.3	1.94	27.4

Note: Each delivery date is assumed to occur at 12 noon. Temperature data from a nearby weather station are averaged across the period.

The trend lines in the plots above were used to generate pre- and post-retrofit oil use and electric use for a bin analysis using typical year weather data from the nearby weather station. Table 17 shows the details of bin analysis with results given at the bottom of the table. The seasonal reduction in fuel use was 337 gallons or 67% of the space heating energy. The space heating cost savings were $359 using the local utility costs given in section 3.2 above. The implied seasonal average heating coefficient of performance (COP) can also be inferred from the data, assuming a conversion efficiency for the oil-fired boiler of 79%.

Table 17. Bin Analysis Used to Predict Seasonal Impacts from Trendlines for S3

SITE:	EFG-3				WEATHER:	Albany		$ 0.117	per kWh
FUEL:	Oil							$ 2.487	per gal (oil)
Floor Area	2000				LOCATION:	Athens			

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	12.2	7.3	93.7	7.3	1.7	$ 30.4	$ 29.1	
-22.5	0	11.5	6.8	87.6	6.8	1.7	$ 28.6	$ 27.2	
-17.5	0	10.8	6.3	81.4	6.3	1.7	$ 26.8	$ 25.2	
-12.5	0	10.0	5.8	75.3	5.8	1.8	$ 24.9	$ 23.3	
-7.5	0	9.3	5.3	69.2	5.3	1.8	$ 23.1	$ 21.4	
-2.5	15	8.5	4.9	63.1	4.9	1.9	$ 21.2	$ 19.4	
2.5	36	7.8	4.4	56.9	4.4	1.9	$ 19.4	$ 17.5	
7.5	127	7.1	3.9	50.8	3.9	2.0	$ 17.5	$ 15.5	
12.5	206	6.3	3.4	44.7	3.4	2.1	$ 15.7	$ 13.6	
17.5	435	5.6	2.9	38.6	2.9	2.2	$ 13.9	$ 11.7	
22.5	498	4.8	2.4	32.4	2.4	2.4	$ 12.0	$ 9.7	
27.5	537	4.1	1.9	26.3	1.9	2.7	$ 10.2	$ 7.8	
32.5	654	3.3	1.4	20.2	1.4	3.1	$ 8.3	$ 5.8	
37.5	720	2.6	0.9	14.1	0.9	3.8	$ 6.5	$ 3.9	
42.5	550	1.9	0.8	9.2	0.8	3.9	$ 4.6	$ 2.9	
47.5	573	1.1	0.8	5.5	0.8	2.1	$ 2.8	$ 2.5	
52.5	723	0.8	0.8	1.8	0.8	0.0	$ 1.9	$ 2.1	
57.5	791	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
62.5	943	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
67.5	682	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
72.5	497	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
77.5	420	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
82.5	274	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
87.5	61	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
92.5	13	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
97.5	5	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
102.5	0	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Oil (gal/yr)	503.4	166.4	337.0
HP Electric (kWh/yr)		4,107	(4,107)
Total Heating Costs	$1,252	$893	$359
Implied Seasonal COP			2.6

Summary Statistics	
0.25	Fuel gal per sq ft per yr
27.6	Htg MBtu per sq ft per yr
67%	Reduction in Fuel Use
3,416	Measured HP for Htg (kWh/yr)
83%	Measured as % of Typical yr

In this instance the implied COP is calculated from:

$$COP = (Fuel_{pre} - Fuel_{post}) \times eff / (3.412 \times kWh_{hp}) = (503.4-166.4)*139*0.79 / (3.412*4107)$$

The data in the bin-analysis table also show there is the expected decreasing trend of the implied COP at lower temperatures.

3.3.2 Analysis of Site 4: Replacing Electric Resistance Heat with Electric Utility Bills Available

This 1576 sq ft house is in Germantown, NY, south of Albany. The house was originally heated by baseboard electric heat. The electric baseboard was also used for supplemental heating after the 1.5-ton ductless ccASHP was installed. The ccASHP was installed in December 2017. Monitoring began in January 2018. This unit only provided very modest amounts of cooling.

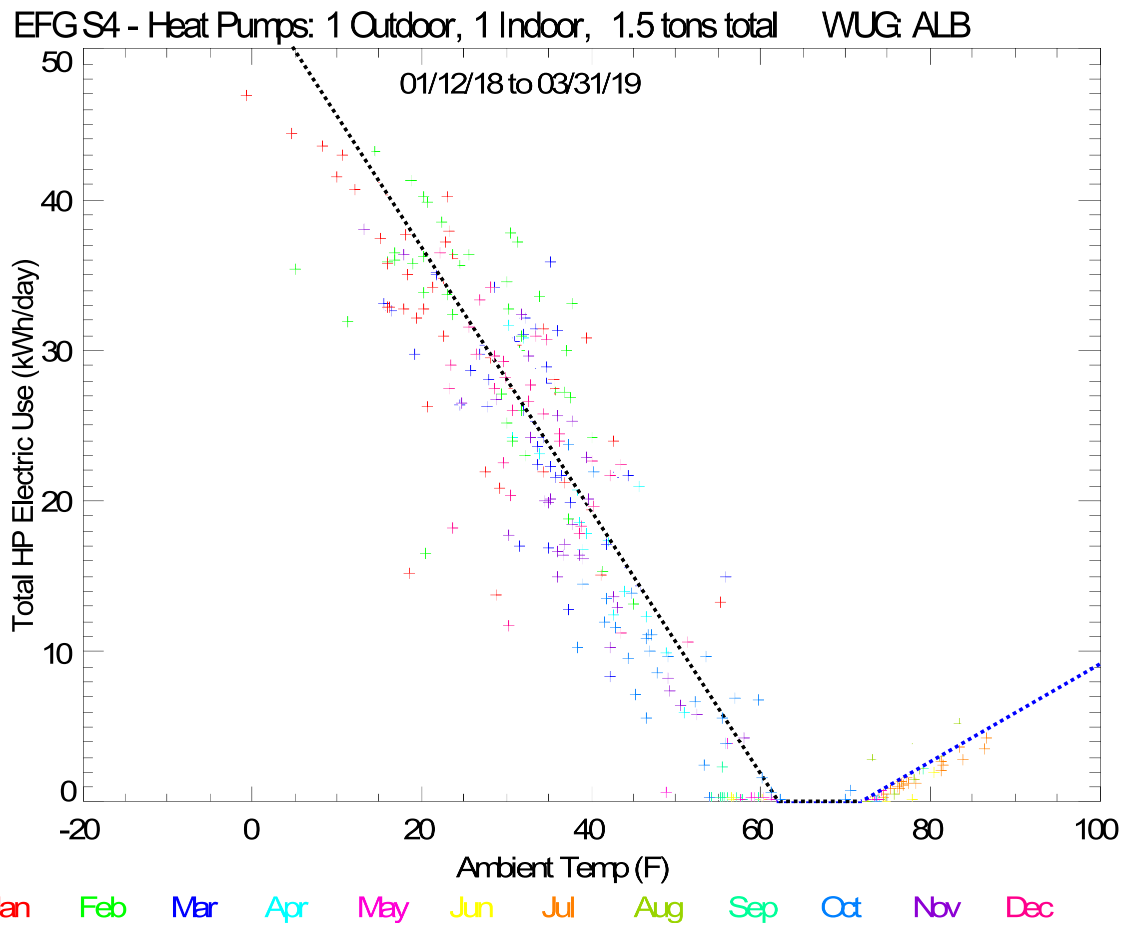
Table 18 summarizes the measured energy use for the total house and the heat pump over the monitoring period. It also includes the baseboard resistance electric heaters that were monitored. Heat pump power use for the heating season (May to October) was 4,745 kWh. Electric use in June through September was 132 kWh.

Table 18. Measured Electric Use for the Total House and ccASHP Unit at S4

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)	Boiler Runtime (hrs)
Jan-18	20	668.3	605.4	62.8	-
Feb-18	28	820.3	811.1	9.2	-
Mar-18	31	798.8	798.6	0.3	-
Apr-18	30	598.1	552.8	45.4	-
May-18	31	20.0	19.9	0.2	-
Jun-18	30	13.4	13.3	0.2	-
Jul-18	31	47.9	47.7	0.2	-
Aug-18	31	45.5	45.4	0.2	-
Sep-18	30	25.3	25.2	0.1	-
Oct-18	31	250.7	250.5	0.2	-
Nov-18	30	582.6	570.8	11.8	-
Dec-18	31	1,105.4	770.0	335.5	-
Jan-19	31	1,429.1	971.0	458.1	-
Feb-19	28	1,236.6	806.3	430.3	-
Mar-19	31	854.3	714.0	140.4	-
Annual	365	5,737.1	4,876.3	861.4	-
Htg Season	243	5,605.0	4,744.7	860.7	-
Jun-Sep	122	132.1	131.6	0.7	-

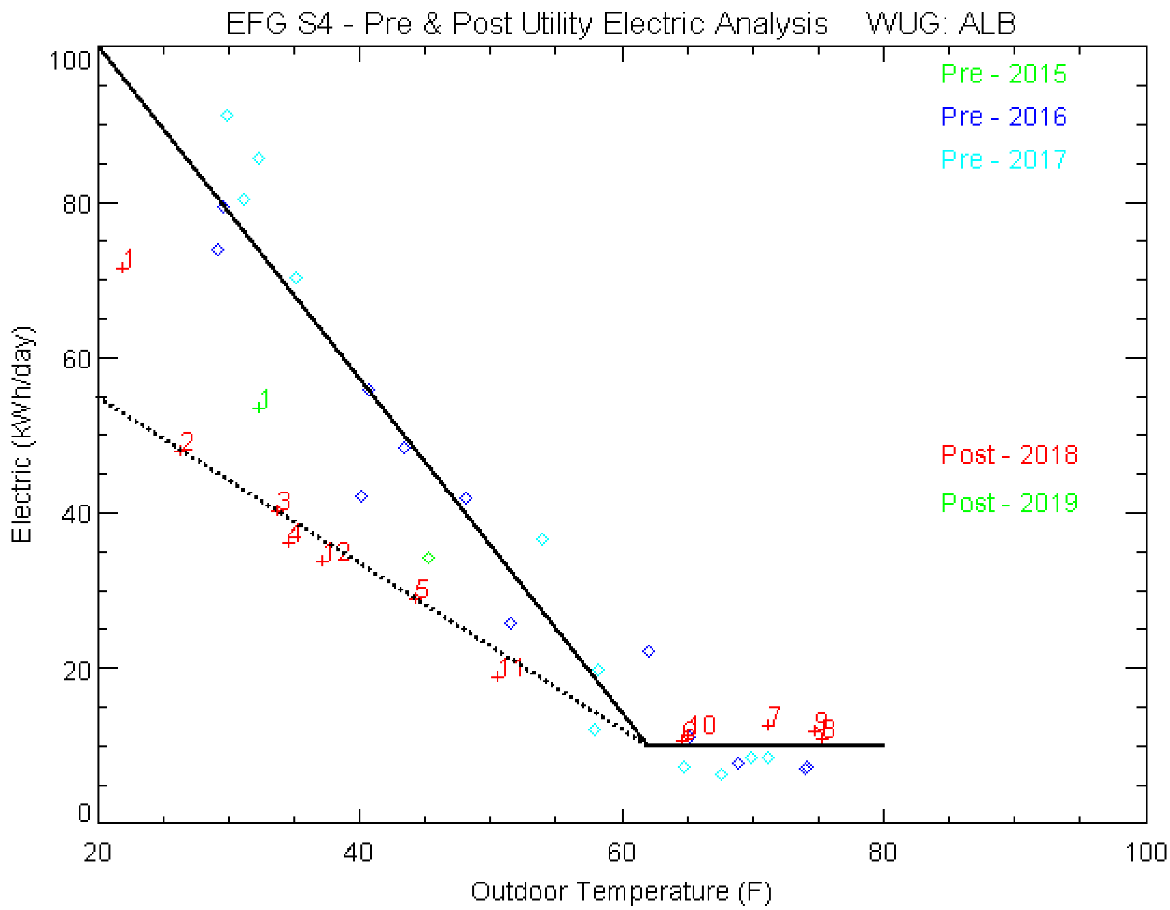
Daily heat pump power use is shown in Figure 10. as a function of daily average outdoor temperature. There is moderate scatter in the data, indicating that the occupants used the ductless heat pump in a fairly consistent manner. The dotted line on the plot represents to a best-fit trend with temperature.

Figure 10. Daily Heat Pump Energy Use versus Daily Average Temperature at S4
(Days in each month shown with a different color).



At this site, heat pump operation displaced more than half of the baseboard electric heat use. Figure 11 compares the trend of monthly electric use from the utility bills with temperature for both the pre-retrofit period (◊ symbol) and post-retrofit period (+ symbol, with month number shown). The solid line represents the overall electric use trend in the pre-retrofit period. The dotted line represents the electric use trend in the post-retrofit period. At this site, the linear trends were very strong in both the pre- and post-retrofit periods. The base electric use was taken to be the average of all the periods combined.

Figure 11. Analysis of Electric Use with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends at S4



The trend lines in the plots above were used in a bin analysis using typical year weather data from the nearby weather station. Table 19 shows the details of bin analysis with results given at the bottom of the table. The seasonal reduction in electric use was 6,837 kWh or 53% of the space heating energy—as determined from the pre- and post-electric utility bills. The eGuage data showed that the heat pump used 5,251 kWh and therefore the implied resistance heat use was 1586 kWh. The space heating cost savings were $798 using the local utility costs given in section 3.2 above. The implied seasonal average heating COP inferred from the data was 2.3.

Table 19. Bin Analysis Used to Predict Seasonal Impacts from Trendlines for S4

SITE:	EFG-4	WEATHER:	Albany	$	0.117	per kWh
FUEL:	Electric			$	0.117	per kWh
Floor Area	1576	LOCATION:	Germantown			

Temp Bin	Hours	FUEL PRE-Electric (kWh/day)	FUEL POST-Electric (kWh/day)	ASHP Electric (kWh/day)	Adjusted POST-Electric (kWh/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Electric adjustment factor
-27.5	0	203.5	101.6	78.2	101.6	2.3	$ 23.7	$ 21.0	
-22.5	0	192.7	96.5	73.9	96.5	2.3	$ 22.5	$ 19.9	
-17.5	0	181.9	91.4	69.5	91.4	2.3	$ 21.2	$ 18.8	
-12.5	0	171.1	86.3	65.1	86.3	2.3	$ 20.0	$ 17.7	
-7.5	0	160.3	81.2	60.8	81.2	2.3	$ 18.7	$ 16.6	
-2.5	15	149.4	76.0	56.4	76.0	2.3	$ 17.4	$ 15.5	
2.5	36	138.6	70.9	52.0	70.9	2.3	$ 16.2	$ 14.3	
7.5	127	127.8	65.8	47.6	65.8	2.3	$ 14.9	$ 13.2	
12.5	206	117.0	60.7	43.3	60.7	2.3	$ 13.7	$ 12.1	
17.5	435	106.2	55.6	38.9	55.6	2.3	$ 12.4	$ 11.0	
22.5	498	95.4	50.4	34.5	50.4	2.3	$ 11.1	$ 9.9	
27.5	537	84.6	45.3	30.2	45.3	2.3	$ 9.9	$ 8.8	
32.5	654	73.8	40.2	25.8	40.2	2.3	$ 8.6	$ 7.7	
37.5	720	63.0	35.1	21.4	35.1	2.3	$ 7.3	$ 6.6	
42.5	550	52.2	30.0	17.0	30.0	2.3	$ 6.1	$ 5.5	
47.5	573	41.3	24.8	12.7	24.8	2.3	$ 4.8	$ 4.4	
52.5	723	30.5	19.7	8.3	19.7	2.3	$ 3.6	$ 3.3	
57.5	791	19.7	14.6	3.9	14.6	2.3	$ 2.3	$ 2.2	
62.5	943	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
67.5	682	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
72.5	497	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
77.5	420	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
82.5	274	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
87.5	61	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
92.5	13	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
97.5	5	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
102.5	0	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Total Heat (kWh/yr)	12,987	6,150	6,837
		-	-
Total Heating Costs	$1,516	$718	$798
Implied Seasonal COP			2.3
HP Electric (kWh/yr)			5,251

Summary Statistics	
8.24	Fuel kWh per sq ft per yr
28.1	Htg MBtu per sq ft per yr
53%	Reduction in Fuel Use
4,745	Measured HP for Htg (kWh/yr)
90%	Measured as % of Typical yr

The implied COP in this case is calculated from:

$$COP = (kWh_{pre} - kWh_{post} + kWh_{hp}) / kW_{hp} = (12987 - 6150 + 5251) / 5251$$

Table 20 factors in the measured amount of resistance heating measured during the post-retrofit period into the calculations and separately determines the efficiency for the heat pump alone and the heat pump with resistance heat. The implied COP was slightly lower with this analysis approach using the measured resistance heating power.

$$\mathbf{COP_{ASHP} \quad = \quad (kWh_{pre} - kWh_{post,resistance}) / kW_{hp} \quad = \quad (12987 - 861) / 5251}$$

$$\mathbf{COP_{Overall} \quad = \quad (kWh_{pre}) /(kW_{hp}\ kWh_{post,resistance}) \quad = \quad 12987 / (5251 + 861)}$$

Table 20. Alternate Procedure for Determining the Implied COP w/ and w/o Resistance Heat at S4

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Resistance (kWh/yr)	12,987	861	12,126
ASHP (kWh/yr)		5,251	(5,251)
Total Heat (kWh/yr)	12,987	6,112	6,875
Total Heating Costs	$1,516	$713	$802
Implied ASHP COP			2.3
Overall COP Including Resistance			2.1

3.3.3 Analysis of Site 2: Replacing Electric Resistance Heat when Post-Retrofit Electric Bills were Not Valid

This 2000 sq ft house is in Cotekill, NY, near Newburgh. The house was originally heated by baseboard electric heat. The electric baseboard was also used for supplemental heating after the 2.5-ton ccASHP with two ductless sections was installed. The ccASHP was installed in November 2017. Monitoring began in January 2018. This unit was also used for cooling.

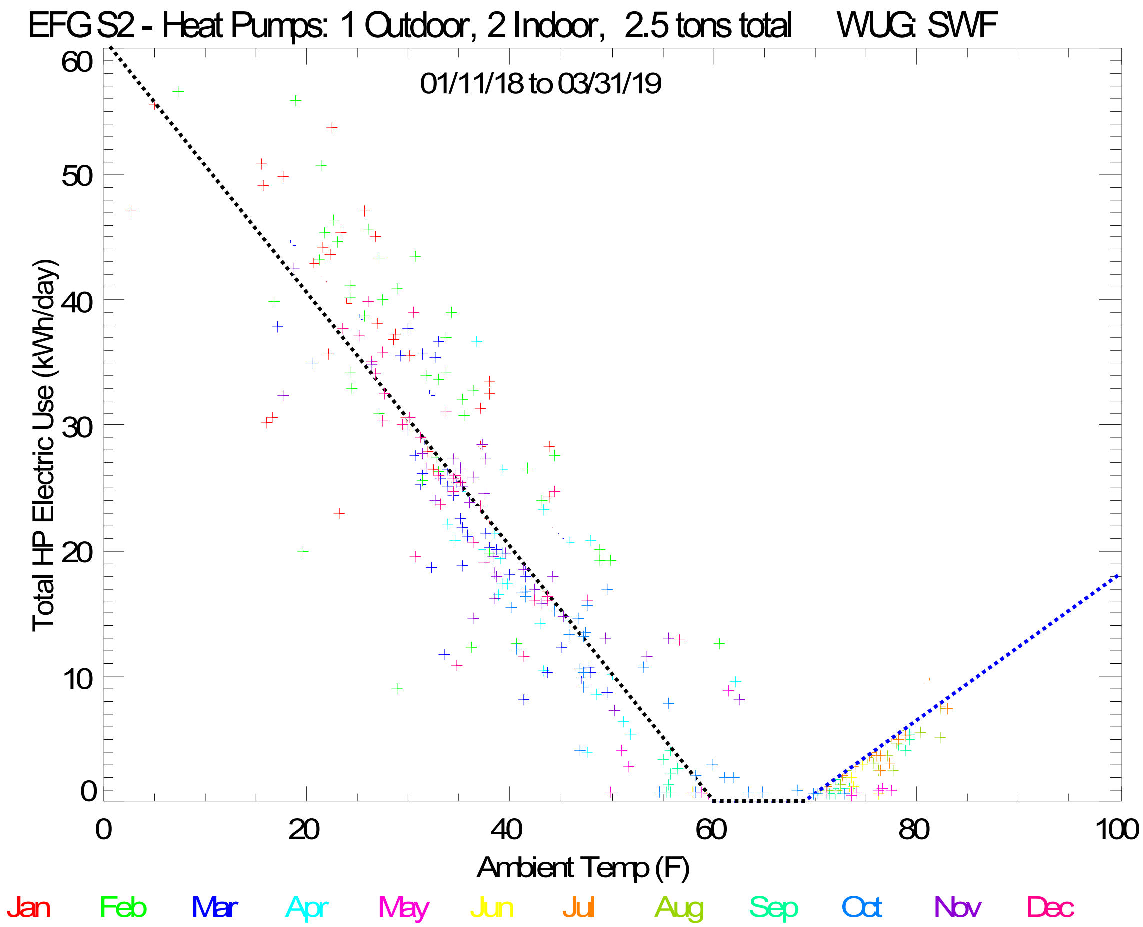
Table 21 summarizes the measured energy use for the total house and the heat pump over the monitoring period. It also includes the baseboard resistance electric heaters that were monitored. Heat pump power use for the heating season (May to October) was 5,042 kWh. Heat pump electric use in June through September was 329 kWh. The resistance heaters used 791 kWh.

Table 21. Measured Electric Use for the Total House and Air Source Heat Pump Unit at S2

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)
Jan-18	21	1,177.5	675.3	96.2
Feb-18	28	1,391.0	910.4	104.6
Mar-18	31	1,192.6	787.4	43.1
Apr-18	30	843.5	497.5	7.1
May-18	31	406.8	37.1	0.2
Jun-18	30	351.3	49.5	0.1
Jul-18	31	502.1	127.7	0.2
Aug-18	31	469.6	100.4	0.2
Sep-18	30	438.9	51.5	2.0
Oct-18	31	708.8	267.5	18.4
Nov-18	30	1,093.5	640.8	72.3
Dec-18	31	1,391.6	802.1	158.9
Jan-19	31	1,863.2	1,099.4	384.1
Feb-19	28	1,507.3	837.1	304.5
Mar-19	31	1,379.8	686.0	306.7
Annual	365	10,652.9	5,371.3	791.2
Htg Season	243	8,891.0	5,042.2	788.7
Jun-Sep	122	1,761.9	329.1	2.5

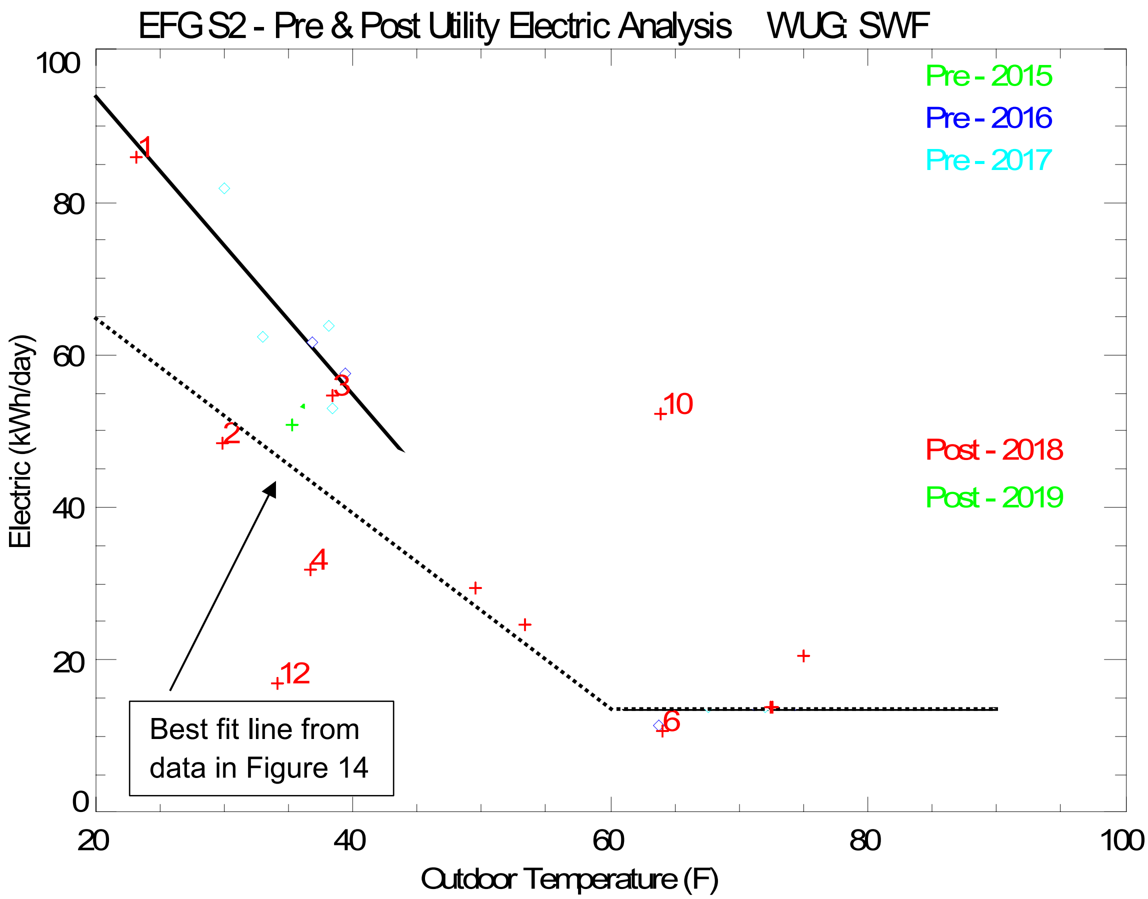
Daily heat pump power use is shown in Figure 12 as a function of daily average outdoor temperature. There is moderate scatter in the data, indicating that the occupants used the ductless heat pump in a fairly consistent manner. The dotted line on the plot represents to a best-fit trend with temperature.

Figure 12. Daily Heat Pump Energy Use versus Daily Average Temperature at S2 (Days in each month shown with a different color).



At this site, heat pump operation displaced baseboard electric heat use. Figure 13 compares the trend of monthly electric use from the utility bills with temperature for both the pre-retrofit period (◊ symbol) and post-retrofit period (+ symbol, with month number shown). The solid line represents the overall electric use trend in the pre-retrofit period. The dotted line represents the electric use trend in the post-retrofit period.

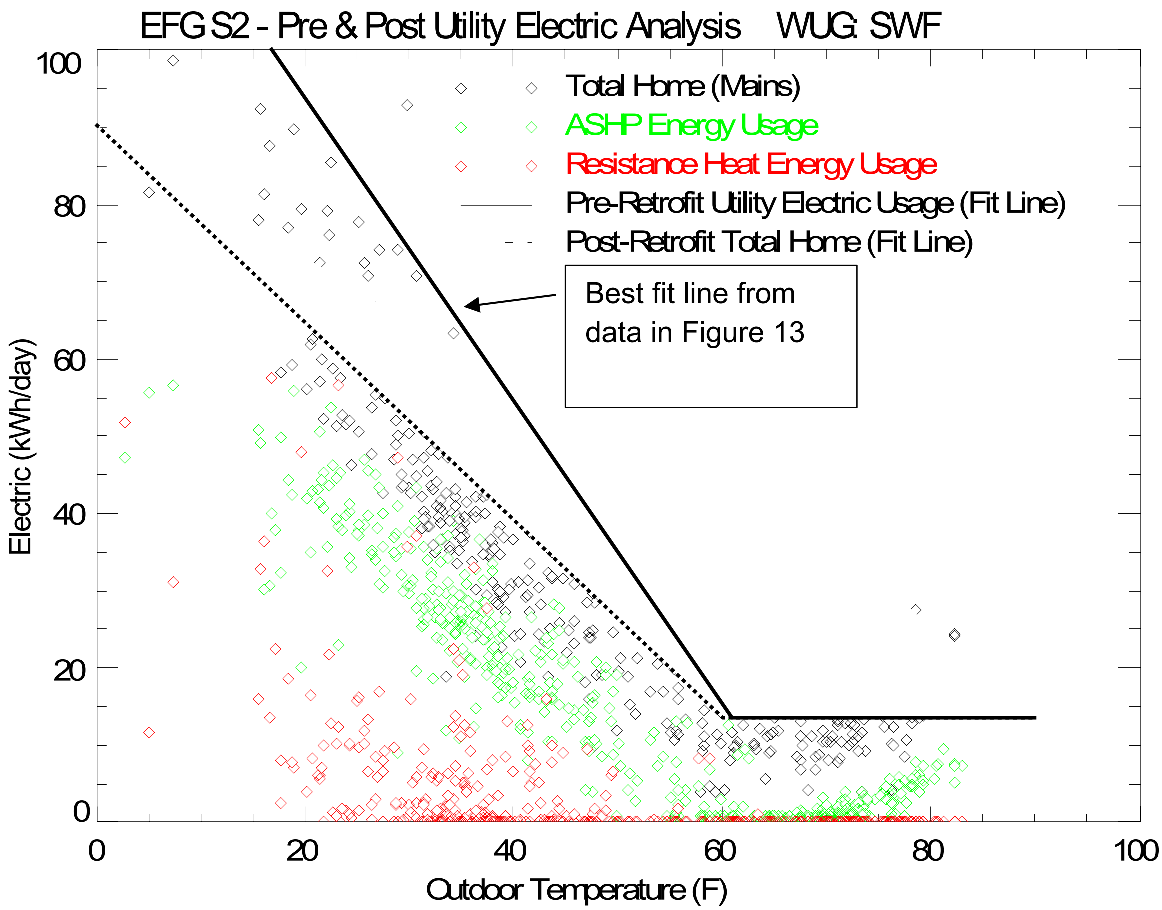
Figure 13. Analysis of Electric Use with Temperature—Comparing Pre-Retrofit and Post-Retrofit Trends at S2



While there was a reasonably good linear trend in the pre-retrofit period, the electric bills appear to have changed to be estimated readings in the post-retrofit period. As a result, those post-retrofit readings are highly scattered. Therefore, we determined the trend for the total house usage in the post-retrofit period from the eGauge-measured daily readings versus outdoor temperature in Figure 14.

Figure 14. Analysis of Measured Electric Use with Temperature in the Post-Retrofit Periods at S2

Total house, resistance heat, and heat pumps.



The trend lines in the plots in Figure 14 were used in a bin analysis using typical year weather data from the nearby weather station. Table 22 shows the details of bin analysis with results given at the bottom of the table. The seasonal reduction in electric use was 3,611 kWh or 38% of the space heating energy. The space heating cost savings were $542 using the local utility costs given in section 3.2. The implied seasonal average heating COP inferred from the data was 1.8.

Table 22. Bin Analysis Used to Predict Seasonal Impacts from Trendlines for S2

SITE:	EFG-2	WEATHER:	Newburgh	$ 0.150 per kWh
FUEL:	Electric			$ 0.150 per kWh
Floor Area	2000	LOCATION:	Cottekill	

Temp Bin	Hours	FUEL PRE-Electric (kWh/day)	FUEL POST-Electric (kWh/day)	ASHP Electric (kWh/day)	Adjusted POST-Electric (kWh/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Electric adjustment factor
-27.5	0	186.79	125.27	88.96	125.27	1.69	$ 28.0	$ 32.1	
-22.5	0	177.01	118.90	83.88	118.90	1.69	$ 26.6	$ 30.4	
-17.5	0	167.23	112.52	78.79	112.52	1.69	$ 25.1	$ 28.7	
-12.5	0	157.45	106.14	73.71	106.14	1.70	$ 23.6	$ 27.0	
-7.5	1	147.67	99.77	68.63	99.77	1.70	$ 22.2	$ 25.3	
-2.5	13	137.89	93.39	63.54	93.39	1.70	$ 20.7	$ 23.5	
2.5	36	128.11	87.01	58.46	87.01	1.70	$ 19.2	$ 21.8	
7.5	45	118.33	80.64	53.38	80.64	1.71	$ 17.7	$ 20.1	
12.5	113	108.55	74.26	48.29	74.26	1.71	$ 16.3	$ 18.4	
17.5	222	98.77	67.88	43.21	67.88	1.71	$ 14.8	$ 16.7	
22.5	367	88.99	61.51	38.13	61.51	1.72	$ 13.3	$ 14.9	
27.5	373	79.21	55.13	33.04	55.13	1.73	$ 11.9	$ 13.2	
32.5	764	69.43	48.75	27.96	48.75	1.74	$ 10.4	$ 11.5	
37.5	814	59.65	42.38	22.88	42.38	1.76	$ 8.9	$ 9.8	
42.5	727	49.87	36.00	17.79	36.00	1.78	$ 7.5	$ 8.1	
47.5	668	40.09	29.62	12.71	29.62	1.82	$ 6.0	$ 6.3	
52.5	480	30.31	23.25	7.63	23.25	1.93	$ 4.5	$ 4.6	
57.5	748	20.53	16.87	2.54	16.87	2.44	$ 3.1	$ 2.9	
62.5	831	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
67.5	902	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
72.5	538	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
77.5	603	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
82.5	358	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
87.5	134	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
92.5	23	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
97.5	1	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
102.5	0	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Total Heat (kWh/yr)	9,555	5,944	3,611
		-	-
Total Heating Costs	$1,433	$892	$542
Implied Seasonal COP			1.8
HP Electric (kWh/yr)			4,739

Summary Statistics	
4.78	Fuel kWh per sq ft per yr
16.3	Htg MBtu per sq ft per yr
38%	Reduction in Fuel Use
5,042	Measured HP for Htg (kWh/yr)
106%	Measured as % of Typical yr

The implied COP in this case is calculated from:

$$\mathbf{COP} = (\mathbf{kWh_{pre}} - \mathbf{kWh_{post}} + \mathbf{kWh_{hp}}) / \mathbf{kW_{hp}} = \mathbf{(9555 - 5944 + 4739) / 4379}$$

Table 23 factors in the amount of resistance heating measured during the post-retrofit period into the calculations and separately determines the efficiency for the heat pump alone and the heat pump with resistance heat. An implied COP including resistance heating is provided. The implied overall COP of 1.7 was just slightly lower by this method. The COP for the ccASHP alone was 1.8. The savings of $604 calculated by this method are used as summary values in the next section (Table 26).

$$COP_{ASHP} = (kWh_{pre} - kWh_{post,resistance}) / kW_{hp} = (9555 - 791) / 4379$$

$$COP_{Overall} = (kWh_{pre}) /(kW_{hp}\ kWh_{post,resistance}) = 9555 / (4379 + 791)$$

Table 23. Alternate Procedure for Determining the Implied COP with and without Resistance Heat at S2

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Resistance (kWh/yr)	9,555	791	8,764
ASHP (kWh/yr)		4,739	(4,739)
Total Heat (kWh/yr)	9,555	5,530	4,025
Total Heating Costs	$1,433	$829	$604
Implied ASHP COP			1.8
Overall COP Including Resistance			1.7

3.4 Summary of Heating Results for All Sites

The per-site analysis shown in the previous section for three sites was repeated for all 20 test sites (the per-site analysis is given for each site in appendix C). Tables 24 and 25 summarize the results for all 20 sites. Some parts of the analysis could only be completed for 15 of the test sites.

3.4.1 Measured Electric Use

Table 24 summarizes annual electricity use at all of the sites. Total house electric use in Table 24 was measured at each site except for S4 (where CTs could not safely be installed). Total power consumption of the installed ccASHPs was measured at all sites. For the two sites with ducted ccASHPs, the power use of the air handler unit (AHU) was also measured and included in the total heat pump power. At the electrically heated sites (S2, S4, S11, S16, S19), the team also measured the dedicated resistance heat circuits to determine how much electric heat was still used after the ccASHPs were installed. S20 was heated primarily by propane, but also used some electricity in the basement, so the resistance heat was measured as well.

Nine sites had photovoltaic solar arrays installed. The solar sites generally produced slightly less than the expected amount of energy: the average full-load hours (annual kWh divided by array size in kW) was 976 hours, compared to values of 1100–1300 hours often used in the typical proposal proforma offered to consumers. The solar inverter at S12 actually consumed 126 kWh of parasitic power annually, reducing the gross power production from 1,676 kWh to 1,550 kWh. This parasitic consumption was 7.5% of the gross output. The inverters at other sites had little or no parasitic consumption.

Table 24. Summary of Post-Retrofit Electricity Use at Each Site

Site	Days of Data	House Energy Use (kWh/yr)	Total HP Energy Use (kWh/yr)	Winter HP Energy Use (kWh/yr)	Summer HP Energy Use (kWh/yr)	Resistance Heat Energy Use (kWh/yr)	Solar Output (kWh/yr)
S1	365	6,785	3,745	3,724	21	-	3,895
S2	365	10,653	5,371	5,042	329	791	-
S3	365	10,220	4,413	3,416	997	-	3,597
S4	365	Not available	4,876	4,745	132	861	-
S5	331	6,196	2,656	1,549	1,107	-	5,205
S6	366	10,633	4,472	3,968	504	-	-
S7	364	20,268	11,567	10,810	757	-	-
S8	359	10,067	3,478	2,851	628	-	-
S9	365	8,989	1,837	1,523	315	-	-
S10	350	18,062	6,259	5,744	515	-	7,890
S11	366	13,901	5,540	5,053	487	-	-
S12	365	6,534	2,732	2,451	281	-	1550
S13	347	8,654	5,747	4,745	1,002	-	5,248
S14	359	17,585	9,898	8,680	1,218	-	7,004
S15	366	58,870	16,425	11,581	4,844	-	-
S16	263	16,945	12,540	12,264	277	353	-
S17	366	9,617	1,670	1,419	251	-	-
S18	359	10,001	6,251	5,507	744	-	11,643
S19	366	21,325	8,806	7,676	1,130	1,204	8,237
S20	366	16,576	6,758	6,000	758	8,061	-
Avg		14,836	6,252	5437	814		

Notes: Total house not measured for S4. Sites with less than a full year of contiguous data shown in grey.
Summer HP use corresponds to June through September. Winter corresponds to the remainder of the year.

At eleven sites we also measured the electric use of the electric water heater (EWH) tank or the heat pump water heater (HPWH) tank. Table 25 shows the monthly energy use profile across the year. The data is from different 12-month periods for each site. The results show the expected variation in electric use as colder entering water temperatures in the winter result in higher electric use. HPWH units tend to use less electricity, although since hot water use is not measured, it is not possible to make direct comparisons between sites to estimate HPWH efficiency. However, the average for the six active EWH sites (excluding S20) was 2,241 kWh per year while the average for the two HPWH sites with around-round operation was 1,041 kWh per year. The hybrid HPWH sites included S8 that normally uses the boiler in the winter for DHW, so it only runs the HPWH in the other months. The monthly HPWH electric use goes to zero in the summer for S12, indicating that the house has a solar collector for hot water.

Table 25. Summary of Domestic Hot Water Use at Sites Where Measured

	EHW S2	EHW S3	HPWH S7	HPWH-Summer Only S8	EHW S11	HPWH +Solar S12	EHW S15	EHW S16	HPWH S17	EHW S19	EHW S20
Jan	203.4	170.8	150.5	-	317.7	97.2	222.0	181.8	68.8	205.1	5.0
Feb	-	165.6	129.9	-	296.9	84.5	244.1	148.6	53.1	170.1	4.6
Mar	70.4	112.4	140.6	-	282.0	39.5	272.3	102.2	73.9	206.4	5.4
Apr	174.9	184.2	117.9	28.3	383.4	0.1	278.0	147.8	85.2	177.9	5.0
May	182.8	122.0	98.8	41.4	315.8	-	269.1	159.6	77.7	186.9	4.9
Jun	127.9	110.9	87.5	55.9	256.0	-	324.5	126.6	70.1	170.0	4.6
Jul	142.6	87.6	67.8	44.0	172.3	26.9	293.9		57.3	163.7	5.7
Aug	136.0	118.1	58.5	40.9	189.8	58.4	287.3	missing data	66.1	142.8	5.4
Sep	135.2	99.2	65.9	43.5	200.2	65.6	227.5		73.7	167.5	4.8
Oct	168.2	127.3	95.4	49.5	227.9	85.8	236.1	107.1	81.0	148.1	4.9
Nov	184.0	149.6	107.6	-	255.0	92.3	254.4	147.2	62.0	201.0	4.7
Dec	193.1	150.1	134.7	-	296.3	92.7	230.9	180.7	58.3	204.3	5.2
Annual	**1,719**	**1,598**	**1,255**	**304**	**3,193**	**643**	**3,140**	**1,652**	**827**	**2,144**	**60**

3.4.2 Estimated Savings, Fuel Reductions, and Implied Coefficient of Performance

Table 26 compares key characteristics for each site to higher level calculated results. The nominal capacity of the installed heat pumps is shown along with the number of outdoor and indoor sections (No. out/No. in per tons). The annual space heating load is determined using the pre-retrofit fuel-use trends in the bin analysis to isolate the portion of the annual fuel use that is attributable to space heating in a typical year. The result is normalized per square foot of floor area. The space heating loads range from 12.8 to 77.1 thousand British thermal units (Mbtu) per sq ft per year, with an average of 32 and a median of 31. Other results include:

- The team members also show the annual electric consumption of the ccASHP for heating normalized per installed ton, determined from the bin analysis with typical year data. Consumption for heating ranged from 563 to 4,201 kWh per nominal cooling ton, with an average of 1,805 and a median of 1,369.
- The percentage in heating fuel reduction before and after ccASHP installation is also given and compared to the original replacement strategy. For consistent comparison across heating fuels, the electric fuel reduction is only for the resistance heating and does not include impact of added electric use by the heat pump. In a few cases the ccASHP was expected to displace all of the fuel use but did not (S8). In other cases, the ccASHP system was only intended to displace part of the fuel-fired system but ended up displacing all fuel use (S12).

- The heat pumps at S8 did not run as much as expected for the first winter, only displacing 33% of fuel use. In the second winter, the homeowners changed their boiler thermostat settings (based on coaching by the EFG team) so that the ccASHPs met more of the heating load and displaced 61% of fuel use. Therefore, the table shows three separate values for S8 for all the data combined and the first and second winters.

Five sites (S5, S9, S12, S15 and S17) were deemed to have issues with the pre- or post-retrofit results and therefore some of the calculated values for implied COP, the percent heating seasonal performance factor (HSPF), and cost savings are not given. The specific reasons for excluding the results for these sites are summarized in Table 27. The data given for the 15 included sites show that:

- The implied heating COP is calculated using the change in fuel consumption, the assumed fuel conversion efficiency and the ccASHP power use. This approximate value ranges from 1.6 to 2.9 for the 15 sites with an average of 2.1. Two of the HPs were ducted units with resistance heating elements (S14 and S18). In these cases, resistance use was included with HP power. For these sites we corrected the COP slightly to eliminate the impact of resistance heat from the COP.
- The implied heating COP is divided by the rated HSPF value for each site to determine the percent of HSPF. HSPF is known to be a poor predictor of seasonal heating efficiency, especially in colder climates such as New York State. The values range from 48 to 80%, with an average of 63%.
- Cost savings are also given in the table. These are calculated using the regional utility and fuel costs. Cost savings are highest for the sites with expensive fuels (electric, propane, and fuel oil). Savings compared to natural gas are typically less than zero.

Anecdotally, the homeowner at S4 reported that she kept the temperature setpoint very low (reportedly 60°F or lower) when she had electric resistance heat prior to heat pump installation. The space temperature data in appendix C for this home showed a highly variable setpoint—with HPs installed, the average setpoint was near 65°F. In spite of this “take-back-effect” of higher setpoints with the HP, the implied COP of 2.3 for the HP was above the average value of 2.1.

Table 26. Summary of Heating Results for All Sites

Site	City	Pre-Retrofit Fuel	ASHP (No. out/No. in per tons)	Original Replacement Strategy	Space Htg Load (MBtu/ ft2-yr)	ASHP Heating Use (kWh/ton)	Percent Fuel Reduction	Implied COP	Percent of HSPF	Annual Costs Savings
S1	Albany	Gas	1 / 1 / 1.5	Partial	37.0	2,570	57%	2.4	80%	-$119
S2	Cottekill	Electric	1 / 2 / 2.5	Partial	16.3	1,895	92%	1.8	55%	$604
S3	Athens	Oil	1 / 3 / 3.0	Partial	27.6	1,369	67%	2.6	80%	$359
S4	Germantown	Electric	1 / 1 / 1.25	Partial	28.1	4,201	93%	2.3	65%	$802
S5	Kingston	Gas	4 / 4 / 3.5	Partial	77.1	563	34%			
S6	Albany	Gas (HE)	3 / 3 / 3	Full, remain	24.1	1,560	94%	2.4	65%	-$194
S7	Sleepy Hollow	Gas	2 / 6 / 4.0	Full, remain	44.3	2,581	100%	2.2	75%	-$686
S8	Coxsackie	Oil	4 / 4 / 3.0	Full, remain	38.0	1,304 1,073 1,748	42% (all data) 33% (1st winter) 61% (2nd winter)	1.9 1.7 1.9	50% 45% 50%	$89 $11 $100
S9	New Paltz	Propane	2 / 2 / 2.5	Partial	12.8	897	34%			
S10	Stone Ridge	Oil	6 / 6 / 5.25	Full, remain	15.2	978	100%	1.9	52%	$8
S11	New Paltz	Electric	5 / 5 / 4.25	Full, remain	32.3	1,199	100%	2.4	63%	$1,011
S12	Shady	Oil	1 / 1 / 0.75	Partial	37.5	3,791	100%			
S13	West Hurley	Oil	3 / 3 / 3.5	Full, remain	22.8	1,369	69%	1.9	52%	-$10
S14	Esopus	Propane (HE)	2 / Duct / 6.0	Full	34.8	1,549	100%	2.9	98%	$1,331
S15	New Paltz	Propane (HE)	8 / 8 / 9.0	Full, remain	14.9	1,297	100%			
S16	Claryville	Electric	3 / 3 / 4.0	Full	24.1	3,319	98%	1.6	46%	$1,277
S17	New Paltz	Oil	1 / 1 / 1.5	Partial	57.0	1,174	23%			
S18	Gardiner	Oil	1 / Duct / 3.0	Full, remain	41.2	2,083	64%	1.8	56%	-$95
S19	Marlboro	Electric	5 / 5 / 5.25	Full	34.8	1,221	92%	1.9	52%	$839
S20	New Paltz	Propane	5 / 5 / 5.5	Full	29.3	1,170	100%	1.8	49%	$369

Results were excluded for five sites for the reasons given in Table 27

Table 27. Five Sites Where Savings and Implied Coefficient of Performance were Excluded

Site	Implied COP	Reason or Issue
S5	>8	Changes in ownership/occupancy resulted in a very poor pre-post comparison. Likely due to differences in setpoints and/or usage patterns between the occupants.
S9	1	Propane delivery dates were only given to nearest month, so the exact fuel delivery periods could not be determined.
S12	5.8	Changes in secondary fuel use (i.e., wood use) between the pre- and post-periods appear to have confounded the results.
S15	2.4	We do not have pre-retrofit propane use before the first ASHP was installed in 2013.
S17	3.0	There were no post-retrofit oil bills for this site. Site also used a pellet stove as a secondary fuel in both the pre- and post-periods.

Table 28 summarizes the results for all 20 sites by heating fuel. The space heating load and percent fuel reduction are given for each pre-retrofit fuel. The houses with more expensive fuels (electric and propane) tended to require less space heating per square foot—as might be expected as homeowners with more expensive costs would strive over time to lower their usage via either envelope improvements or energy conservation.

Table 28. Results by Fuel Type—All Sites

Pre-Retrofit Fuel	No. of Sites	Spacing Heating Load (MBtu/ft2-yr)	Percent Fuel Reduction
Oil	7	34.2	66%
Natural Gas	4	45.6	71%
Electricity	5	27.1	95%
Propane	4	23.0	84%
Total / Avg	20	32.5	78%

The breakdown by pre-retrofit fuel is shown in Table 29 for the 15 included sites where COP and savings could be determined. The homes that use more expensive fuels tended to displace more of their fuel use. The average implied COP is 2.1 and there is no significant variation in the implied COP with fuel type. As mentioned above, cost savings per installed ton are mostly dependent on the cost of the pre-retrofit fuel, and to the degree of fuel reduction as a secondary effect. Cost savings per ton were highest for the electric sites, followed by propane and fuel oil. Natural gas does not result in positive savings because of its low cost.

Table 29. Results by Fuel Type—15 Included Sites Where Savings Could Be Calculated

Pre-Retrofit Fuel	No of Sites	Percent Fuel Reduction	Implied COP	Percent of HSPF	Cost Savings per ton
Oil	5	68%	2.0	58%	$23.30
Natural Gas	3	84%	2.3	73%	-$105.30
Electricity	5	95%	2.1	58%	$320.10
Propane	2	100%	2.3	73%	$144.50
Total / Avg	15	85%	2.1	63%	$112.70

Table 30 shows the results breakdown by region. COPs were not systematically higher in warmer climates as might have been expected. In fact, the opposite was true: COPs are slightly higher in Albany. This may imply that partial-load operation of the HPs at milder conditions in colder climates may result in higher overall average COPs. The regional differences in fuel and electricity prices were overwhelmed by the much larger differences in cost by fuel type as shown in Table 29.

Table 30. Results by Region—15 Included Sites Where Savings Could Be Calculated

Region	No. of Sites	Implied Heating COP	Percent of HSPF	Heating Cost Savings per ton
Albany/National Grid	5	2.3	68%	$129.30
Newburgh/Central Hudson	9	2.0	59%	$135.0
New York/Con Ed	1	2.2	75%	-$171.60
Total/Avg	15	2.1	63%	$112.70

The heating analysis described above was careful to only consider the change in space heating fuel use. However, in some cases we did note that when the fuel-fired boiler was fully removed—and a new electric DHW system was installed to replace it—there was a significant drop in baseline or non-space-heating fuel use. For the propane sites, baseline use averaged 1.8 gallons per day and ranged as high as 2.8 gallons per day. For natural gas, the average baseline use was 0.7 therms per day with a maximum of 1.4 therms per day. For both propane and natural gas, the baseline use may have also served other loads in addition to DHW such cooking, clothes driers, etc. For oil, where the baseline use could only be associated with DHW, the average was 0.4 gallons per day with a maximum of 0.7 gallons per day. In contrast, the hypothetical fuel use to make 50 gallons of hot water per day would be 0.4 therms of gas, 0.4 gallons of propane, and 0.3 gallons of oil. While it is difficult to make a definitive judgement since actual hot water use was not measured, it appears that getting rid of a fuel-fired boiler entirely may eliminate significant standby losses on an annual basis and provide even greater annual savings.

3.4.3 Installed Costs and Cost-Effectiveness

Table 31 shows the installation costs (after incentives) from Table 6 and compares it to the annual cost savings to determine simple payback. The simple payback for the five sites replacing electric heat ranged from 6 to 14 years, with an average of 12 years. For the two oil-heated sites the best payback was 32 years with an average over 200 years. The average simple payback for the two propane sites was 25 years. None of the three gas sites had a simple payback that was positive since none of the sites had positive savings.

Table 31. Installed Costs with Site Specific Comments

Site	City	Pre-Retrofit Fuel	Annual Costs Savings	Installed Cost after Incentives	Simple Payback
S1	Albany	Gas	-$119	$4,873	<0
S2	Cottekill	Electric	$604	$8,495	14
S3	Athens	Oil	$359	$11,450	32
S4	Germantown	Electric	$802	$4,490	6
S5	Kingston	Gas			
S6	Albany	Gas (HE)	-$194	$8,950	<0
S7	Sleepy Hollow	Gas	-$686	$22,600	<0
S8	Coxsackie	Oil	$100	$10,615	106
S9	New Paltz	Propane		$5,105	
S10	Stone Ridge	Oil	$8	$5,450	681
S11	New Paltz	Electric	$1,011	$12,493	12
S12	Shady	Oil		$2,488	
S13	West Hurley	Oil	-$10	$10, 375	<0
S14	Esopus	Propane (HE)	$1,331	$21,900	16
S15	New Paltz	Propane (HE)			
S16	Claryville	Electric	$1,277	$10,650	8
S17	New Paltz	Oil		$2,550	
S18	Gardiner	Oil	-$95	$9,400	<0
S19	Marlboro	Electric	$839	$14,208	17
S20	New Paltz	Propane	$369	$12,615	34

3.4.4 Greenhouse Gas Impacts from Heating Savings

We also used the measured energy savings to predict the reduction in GHG emissions resulting from the ccASHP system installations. We used the eGrid 2018 data for upstate New York to determine GHG emissions from electric use.[7] eGrid publishes the overall average emissions rate as well as the non-baseload emission rate. Generally, in GHG analyses for building efficiency technologies, we use the non-baseload emission factors to determine the impact of the marginal change in energy use. The non-baseload factors are higher than the overall average emission factors, since they reflect the impact of incremental or marginal changes in energy use. For upstate New York, the overall average factor is 0.254 lb of CO_2 equivalent for each kWh. The non-baseload factor is 0.924 lb of CO_2 equivalent per kWh. GHG CO_2 equivalent factors for the fossil fuels are 11.7 lb/therm for natural gas, 12.8 lb/gal for propane and 22.4 lb/gal for fuel oil.

Table 32 shows the resulting GHG emission reductions for each site in absolute terms as well as normalized per installed nominal ton, using both the overall average and non-baseload GHG emission factors. GHG savings are only shown for the 15 sites where savings could be calculated (see the notes at the bottom of Table 26). The average GHG savings are 4,499 lb CO_2 equivalent per year using the overall average emission factor (0.254 lb/kWh). The average value normalized for HP size is 1,304 lb/ton-yr. The average GHP savings are 3,274 lb CO_2 equivalent per year using the non-baseload factor (0.924 lb/kWh). The average value normalized for HP size is 1,093 lb/ton-yr.

Table 32. Greenhouse Gas Emission Savings at 15 Included Sites Where Savings Could Be Calculated

				GHG Savings (lb/yr)		Normalized GHG Savings (lb/yr per installed ton)	
Site	Pre-Retrofit Fuel	Annual Fuel Savings	Annual HP Electric Use (kWh)	Overall Avg based on 0.254 lb/kWh	Non-baseload based on 0.924 lb/kWh	Overall Avg based on 0.254 lb/kWh	Non-baseload based on 0.924 lb/kWh
S1	therms	400	3,854	3,700	1,078	2,466	719
S2	kWh	4,025	4,739	1,022	3,760	409	1,504
S3	gallons oil	337	4,107	6,512	3,719	2,171	1,240
S4	kWh	6,875	5,251	1,746	6,421	1,396	5,137
S5	therms						
S6	therms	426	4,679	3,794	612	1,265	204
S7	Therms	983	10,325	8,875	1,853	2,219	463
S8	gallons oil	219	3,912	3,921	1,261	1,307	420
S9	propane						
S10	gallons oil	290	5,136	5,195	1,702	990	324
S11	kWh	6,740	5,095	1,711	6,295	403	1,481
S12	gallons oil						
S13	gallons oil	264	4,791	4,698	1,439	1,342	411
S14	propane	1,117	9,293	11,925	5,605	1,987	934
S15	propane						
S16	kWh	8,517	13,277	2,162	7,954	541	1,989
S17	gallons oil						
S18	gallons oil	314	6,250	5,449	1,198	1,816	399
S19	kWh	5,593	6,409	1,420	5,224	270	995
S20	propane	547	6,433	5,359	984	974	179
			AVG	4,499	3,274	1,304	1,093

Note: Results only given for 15 sites where savings could be calculated. GHG CO_2 equivalent factors for the fossil fuels are 11.7 lb/therm for natural gas, 12.8 lb/gal for propane and 22.4 lb/gal for fuel oil. GHG savings for fuels = [fuel savings] x Kf – [HP electric] x Ke. GHG savings for electric = [Net electric savings] x Ke

Table 33 summarizes the GHG savings by base fuel type normalized per installed ton. Using the overall average GHG factor (0.254 lb/kWh) results in greater savings for the fossil fuel cases and smaller savings when ccASHPs replace resistance electric heat. The non-baseload GHG emissions factor (0.924 lb/kWh) results in higher GHG savings for the electric heat cases, since more carbon is associated with the electric grid.

Table 33. Normalized Greenhouse Gas Savings by Fuel Type—15 Included Sites Where Savings Could Be Calculated

		Normalized GHG Savings (lb/yr per installed ton)	
Pre-Retrofit Fuel	**No. of Sites**	**Overall Avg based on 0.254 lb/kWh**	**Non-baseload based on 0.924 lb/kWh**
Oil	5	1,525	559
Natural Gas	3	1,983	462
Electricity	5	604	2,221
Propane	2	1,481	556
Avg	15	1,304	1,093

3.5 Impact on Cooling

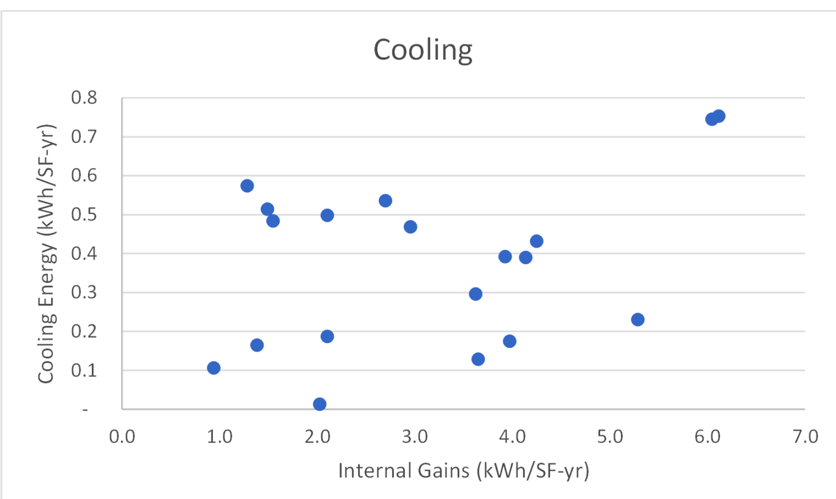
At some sites, the ccASHPs installed at the site displaced a central cooling system or window air conditioners that had been used previously. At other sites, the home had cooling available for the first time with the ccASHPs installed. Table 34 shows the original cooling systems details for each site, as well as heat pump energy use in June through September from Table 24—which we used as an approximate estimate for the energy use associated with cooling. There are wide variations in the amount of energy used for cooling, ranging from 277 kWh at S16 to 4,844 kWh at S15. One site (S1) did not have any cooling at all with the ccASHPs (they continued to use the original central AC). The average of the remaining 19 sites for cooling was 857 kWh. The median was 628 kWh for cooling. The wide range of cooling energy use is clearly driven by occupant behavior and choice, but also can be driven by the electricity consumption within the house (defined as total house use minus HP, resistance heat, and DHW use). Figure 15 shows the normalized cooling energy use per square foot compared to the internal gains per square foot. Clearly the very highest cooling energy use is associated with large internal gains (sites 15 and 19). However, the trend was not as well correlated at the other sites with lower internal gains. We also found that the houses with the highest internal gains also had among the lowest normalized heating loads.

Table 34. Cooling Equipment and Energy Use at Each Site

Site	Pre-Retrofit Cooling System	Pre-Retrofit Cooling Capacity (MBtu/h)	Pre-Retrofit SEER or EER	ASHP Summer Energy (kWh)	ASHP Energy kWh per sq ft per year
S1	Central AC	30	8	21	0.01
S2	Room AC	-	-	329	0.16
S3	Central AC	36	9	997	0.50
S4	Room AC	12	-	132	0.08
S5	None	-	-	1,107	0.48
S6	Central AC-Not Serviceable	-	-	504	0.30
S7	Room AC	57	-	757	0.43
S8	None	-	-	628	0.39
S9	None	-	-	315	0.17
S10	None	-	-	515	0.23
S11	Room AC	12	8.4	487	0.39
S12	Room AC	8	9	281	0.19
S13	Room AC	20	9	1,002	0.51
S14	Central AC	24	15	1,218	0.47
S15	Central AC	30	-	4,844	0.75
S16	None	-	-	277	0.11
S17	Room AC	16.5	11	251	0.13
S18	Central AC	36	13	744	0.54
S19	Room AC	-	-	1,130	0.75
S20	Central AC-Inactive	-	-	758	0.57

Note: Shaded rows indicate cooling was not previously provided.

Figure 15. Internal Gains Versus Cooling Energy Use



The team also looked for pre-retrofit total house electric trends at all the sites to determine if the temperature-dependent energy consumption associated with cooling could be discerned. At S18, a site with central air conditioning (AC), there was some correlation and developed a linear trend of cooling energy use with outdoor temperature (see the detailed cooling analysis of S18 in appendix C). A similar linear trend of ccASHP energy use in the summer months (post-retrofit) was then developed. When a bin analysis for cooling with these two trends was complete, the prediction was that there would be no cooling savings of the new ccASHP compared to the original central AC that was estimated to be a 13 seasonal energy efficiency ratio (SEER). Even though the new ccASHP had a rated SEER of 17.8 Btu/Wh, no energy savings could be detected. At the other sites a strong pre-retrofit linear trend was not discernable enough to determine cooling savings using the bin analysis.

This finding is consistent with results from lab-based studies and other analyses that have shown that SEER values over-predict actual seasonal efficiency for various types of heat pumps. Results from lab-based studies of load-based laboratory testing procedures developed as part of the Canadian Standards Association (EXP07:19) that have shown current SEER values over-predict actual seasonal cooling efficiency for various types of heat pumps (Harley 2020). Similarly, a detailed bin analysis using NEEP-listed data for cold-climate air source heat pumps in the white paper developed to support the NY Technical Resource Manual (Henderson 2020) showed similar discrepancies between the rated SEER and the predicted seasonal cooling performance. In general, the very high SEER ratings of many ductless ccASHP do not actually result in higher seasonal cooling efficiency to the degree the SEER rating would suggest.

3.6 Observed Space Temperatures

Table 35 and Table 36 summarize the measured space temperatures in the winter and summer seasons. Appendix C provides plots of the space temperature data for each site. The standard deviations in each period are also given in the tables. Generally, temperatures were within expectations and any variations were presumably driven by occupant preference.

Table 35. Measured Space Temperatures and Standard Deviation in Heating Season—November through March

	Living Room Avg & Std Dev (F)		Master Bedroom Avg & Std Dev (F)		Kitchen Avg & Std Dev (F)		Other Avg & Std Dev (F) & Space		
S1	66.5	1.9	61.1	3.3					
S2	70.0	2.8	64.1	3.9					
S3	65.7	3.7	64.4	2.7					
S4	64.2	4.1							
S5	69.7	4.6	71.4	4.6			70.8	2.5	Apartment (2nd flr)
S6			67.7	2.6			67.7	2.6	Basement Bedroom
S7			69.9	2.0			69.8	2.0	Family Room
S8			65.5	2.9	67.6	3.8	65.7	3.3	Guest Room
S9	69.5	2.4			61.2	4.1	70.9	3.3	Upstairs Office
S10	69.5	4.7	66.8	4.9			65.6	4.5	Bedroom/Office
S11			72.8	2.1	72.6	1.8	71.6	2.4	Finished Basement
S12	73.2	1.9			70.6	2.0	72.4	2.1	Second Floor Hall
S13			64.8	1.8	75.0	2.7	72.7	3.0	Guest Bedroom
S14	67.7	1.1	64.5	2.0			72.1	2.3	Basement Living
S15	72.4	3.1	66.8	3.5			71.4	6.1	Bedroom
S16	70.9	7.1					74.0	2.1	Finished Basement
S17	70.0	4.3	70.2	3.7	70.5	5.4			
S18	69.1	1.3	69.3	1.0			69.1	1.9	Finished Basement
S19	72.4	2.2	72.8	1.3					
S20	73.3	1.4					73.2	1.6	Hallway / Bedroom

Table 36. Measured Space Temperatures and Standard Deviation in Cooling Season—June through August

	Living Room Avg & Std Dev (F)		Master Bedroom Avg & Std Dev (F)		Kitchen Avg & Std Dev (F)		Other Avg & Std Dev (F)and Location		
S1	75.3	3.5	74.3	3.7					
S2	75.9	2.7	77.1	3.6					
S3	74.1	3.7	73.0	3.2					
S4	73.0	3.3							
S5	75.2	2.4	74.4	3.0			75.1	3.2	Apartment (2nd flr)
S6	77.6	2.3	75.1	1.6			72.7	2.2	Basement Bedroom
S7									Family Room
S8			67.0	2.3	70.6	1.8	72.6	3.4	Guest Room
S9	78.0	2.8			75.2	3.8	79.6	3.6	Upstairs Office
S10	73.6	1.3	72.8	1.3			74.5	1.5	Bedroom/Office
S11			72.4	1.9	72.1	1.7	71.7	1.8	Finished Basement
S12	72.0	2.9			72.7	3.3			Second Floor Hall
S13			67.2	1.8	69.3	1.8	69.3	3.0	Guest Bedroom
S14	75.0	2.1	74.2	2.8			71.6	1.4	Basement Living
S15	71.3	2.1	68.5	1.8			74.4	3.1	Bedroom
S16	74.9	5.3					69.4	2.2	Finished Basement
S17	76.1	3.5	78.0	4.2	77.3	3.7			
S18	77.8	3.0	76.5	2.7			74.8	1.7	Finished Basement
S19	72.6	2.2	71.0	2.3					
S20	73.1	1.1					73.4	0.8	Hallway / Bedroom

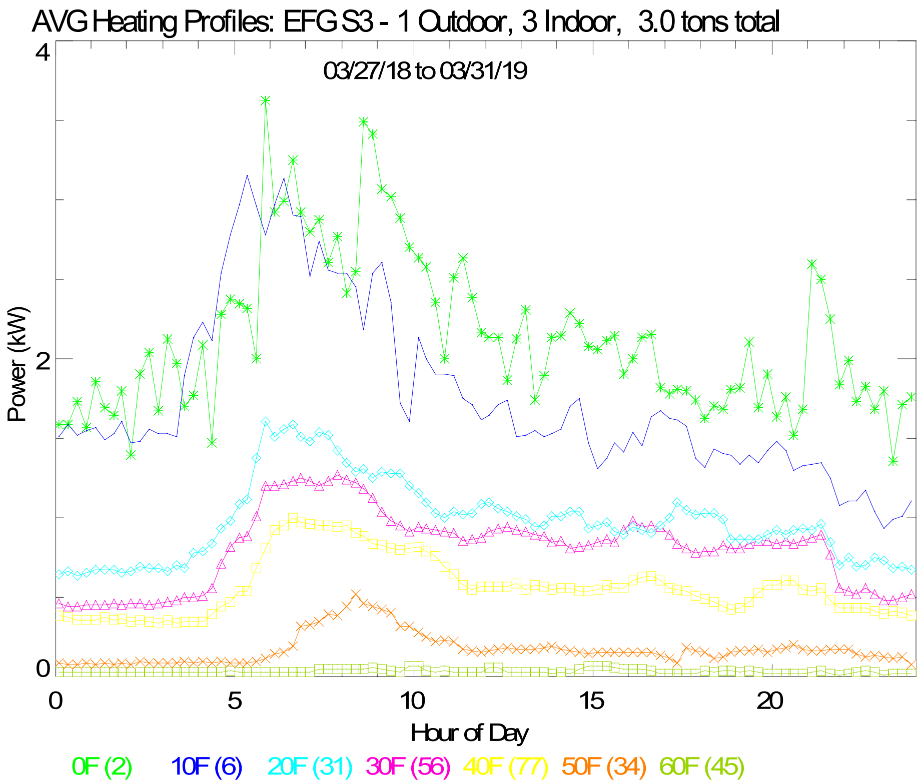
3.7 Electric Demand Profiles for Heating and Cooling

The average demand profiles for all of the heat pumps at S3 are shown in Figure 16. The daily profiles shown on the plot correspond to days with similar outdoor temperatures that were grouped together and averaged. For the heating plot at the top of Figure 16, the blue line corresponds to a temperature of 10°F and includes days in which the average outdoor temperature was between 5°F and 15°F (±5°F). As shown at the bottom of the plot, there were six days that met this criteria and were averaged together. Similarly, there were 31 days that were averaged together to make the average profile at 20°F.

If we normalize the demand profiles by dividing by the installed tons (i.e., the nominal rated cooling capacity), then we can combine and compare the average demand profiles from each site. Figure 17 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 two of the 20 sites, 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 62 days were used to make this weighted-average profile of the normalized demand at 10°F, from all of the sites.

Figure 18 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 711 days when the daily average temperature criteria was met.

Figure 16. Average Demand Profiles for S3, Grouped by Days with Similar Outdoor Temperatures



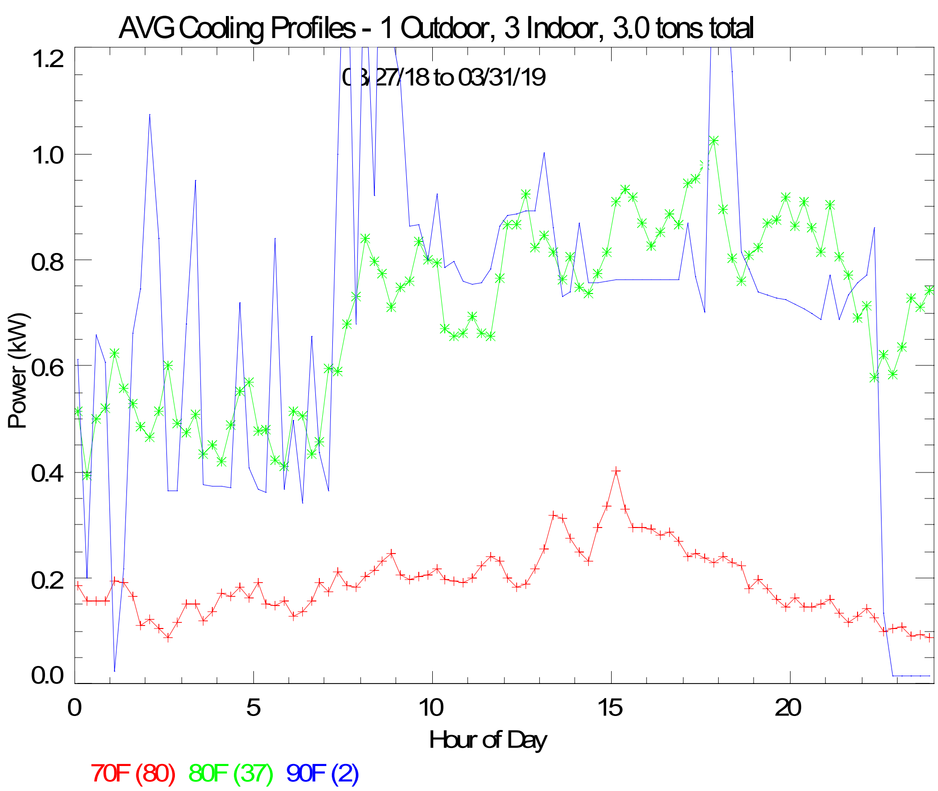


Figure 17. Normalized Demand Profiles for all Sites Combined at an Outdoor Temperature of 10°F

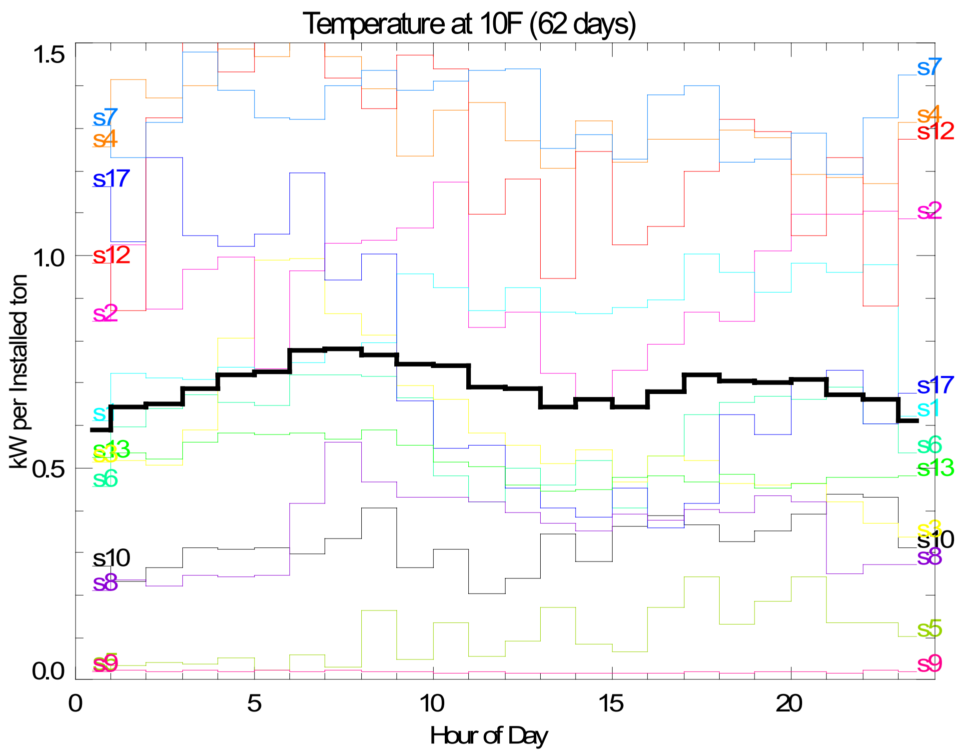


Figure 18. Normalized Demand Profiles for all Sites Combined at an Outdoor Temperature of 80°F

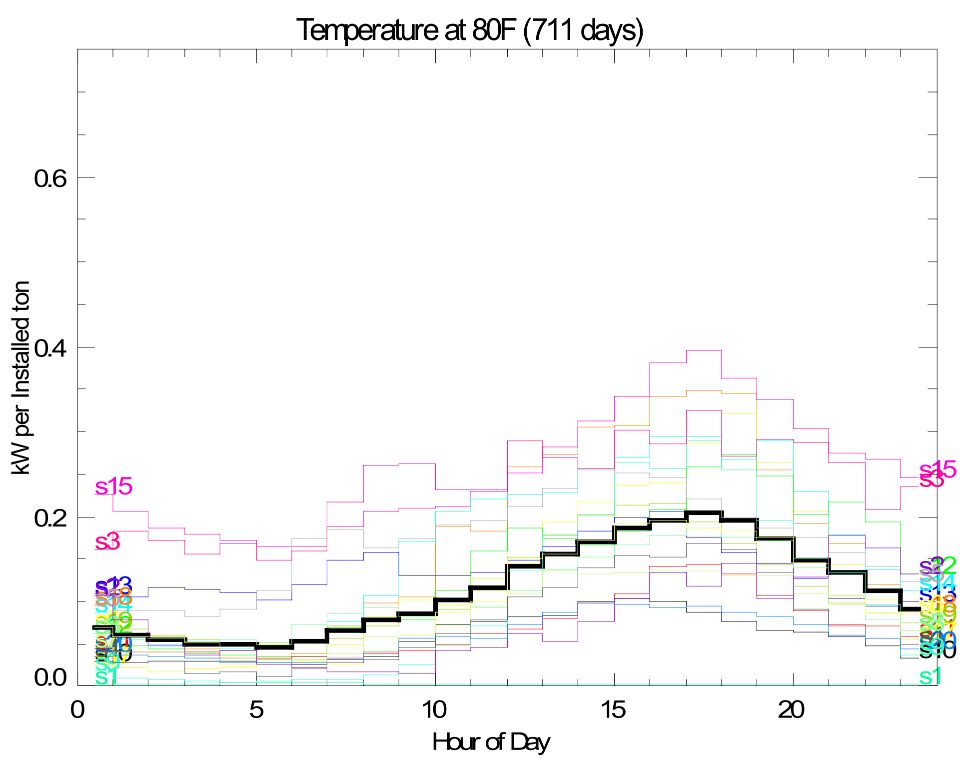


Figure 19 repeats the process for each winter daily temperature bin and shows the average normalized demand at each temperature. Table 37 shows the 24 normalized demand values for each hour of the day at each temperature.

Figure 19. Normalized Demand Profiles for all Sites at Various Winter Temperatures

Number of days and number of sites given in parentheses.

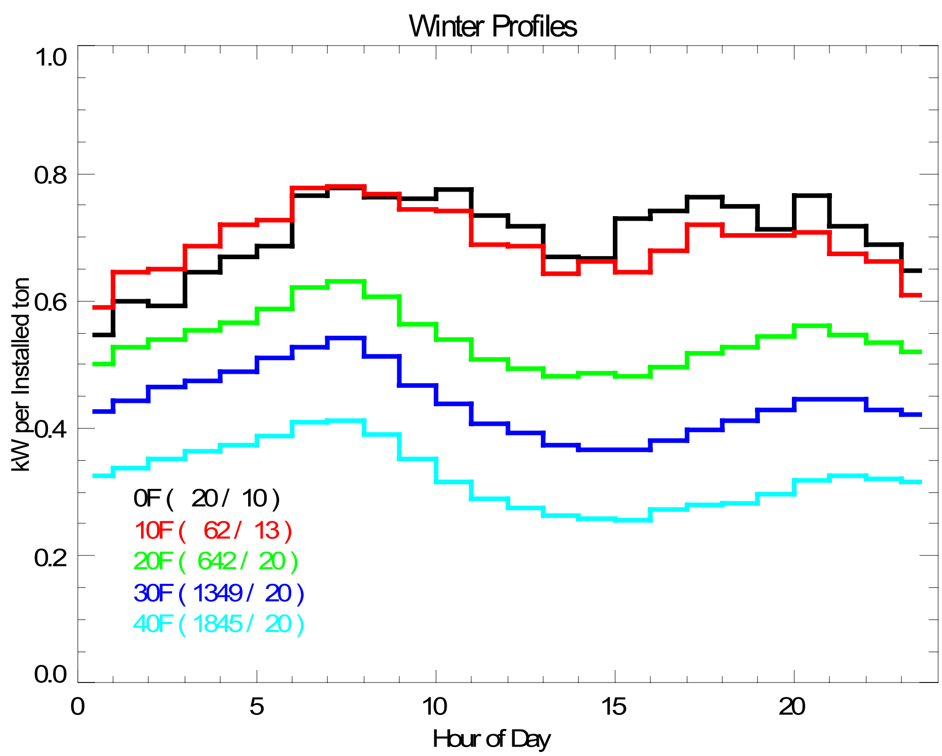


Table 37. Normalized Demand Profiles for Heating

Data from Figure 19.

Temp (F)	Average Normalized Demand for Each Hour - 1 to 24 (kW per nominal ton)											
0	0.55	0.60	0.59	0.65	0.67	0.69	0.77	0.78	0.76	0.76	0.78	0.74
	0.72	0.67	0.67	0.73	0.74	0.76	0.75	0.71	0.77	0.72	0.69	0.65
10	0.59	0.65	0.65	0.69	0.72	0.73	0.78	0.78	0.77	0.74	0.74	0.69
	0.69	0.64	0.66	0.64	0.68	0.72	0.70	0.70	0.71	0.67	0.66	0.61
20	0.50	0.53	0.54	0.55	0.57	0.59	0.62	0.63	0.61	0.56	0.54	0.51
	0.49	0.48	0.49	0.48	0.50	0.52	0.53	0.54	0.56	0.55	0.53	0.52
30	0.43	0.44	0.46	0.47	0.49	0.51	0.53	0.54	0.51	0.47	0.44	0.41
	0.39	0.37	0.37	0.37	0.38	0.40	0.41	0.43	0.45	0.45	0.43	0.42
40	0.33	0.34	0.35	0.36	0.37	0.39	0.41	0.41	0.39	0.35	0.32	0.29
	0.28	0.26	0.26	0.26	0.27	0.28	0.28	0.30	0.32	0.32	0.32	0.31

The normalized demand profile corresponding to 0°F is essentially the same at the profile at 10°F, indicating that heat pumps are all running continuously once the daily average temperature drops below 10°F. The slightly lower demand for the 0°F profile in the early morning may imply that the heat pump power is running continuously (without diversity) and has lower steady-state power consumption due to the colder temperatures.

Figure 20 repeats this process for each summer temperature bin and shows the average normalized demand at each temperature. Table 38 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 mostly driven by heating operation rather than cooling.

Figure 20. Normalized Demand Profiles for all Sites at Various Summer Temperatures

Number of days and number of sites given in parentheses.

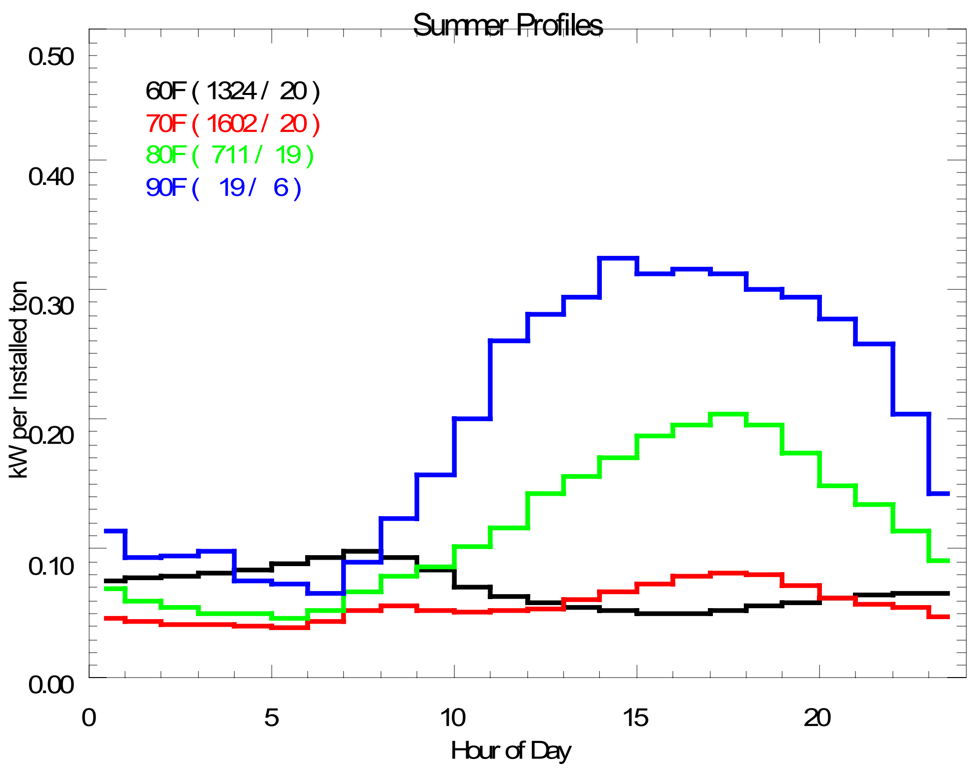


Table 38. Normalized Demand Profiles for Heating

Data from Figure 20.

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	0.09	0.09	0.10	0.09	0.08	0.07	0.06
	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.07	0.07
70	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.06	0.05	0.05	0.05
	0.05	0.06	0.07	0.07	0.08	0.08	0.08	0.07	0.06	0.06	0.05	0.05
80	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.07	0.08	0.09	0.10	0.12
	0.14	0.16	0.17	0.19	0.20	0.20	0.20	0.17	0.15	0.13	0.11	0.09
90	0.11	0.09	0.09	0.10	0.08	0.07	0.07	0.09	0.12	0.16	0.20	0.26
	0.28	0.29	0.32	0.31	0.32	0.31	0.30	0.29	0.28	0.26	0.20	0.14

The peak cooling demand profile at 90°F is consistently high between noon and 8:00 pm, as would be expected. This cooling load shape is consistent with the overall utility load shape from the NY Independent System Operator (ISO). In contrast, the peak generation from solar would be centered around noon with a duration of approximately ± 4 to 5 hours. Therefore, the electric generation provided by solar, which is strongly biased toward the summer months, would not totally offset the demand associated with cooling. Instead, the solar generation profile would offset cooling demand in the early afternoon but leave the cooling demand after 4:00 to 5:00 pm. This is similar to the so-called "duck curve" utility load profile that has been observed in California as more solar generation has been added to the electric grid in recent years.[8]

The generalized demand profiles in the Tables 38 and 39, and Figures 19 and 20, may be useful for understanding the impact that heat pumps will have on the electric grid. Each normalized demand profile shows the average diversified electric demand (kW) per ton of installed cooling capacity at the specified daily average temperature. This approach is expected to be more useful than the traditional utility load research method of developing average demand profiles for each month and day type (weekend/weekday). Clearly heat pump demand is primarily driven by temperature-dependent heating and cooling loads, so temperature-dependent demand profiles are expected to provide utilities with more complete understanding of demand impacts. These profiles also have the advantage of being somewhat climate independent. Therefore, the data can be combined with typical year weather data for any New York State city to generate annual demand profiles for that location.

The process would include:

- Determining the average daily temperature using the hourly Typical Meteorological Year 3 (TMY3) data.
- Determining the demand profile for each day by one of two methods: (1) assigning a profile to each day using the ±5°F temperature bin or (2) linearly interpolating each hourly value of each profile based on the actual temperature.[9]

This process would be used to develop demand profiles for the entire year for any location. Then traditional month-by-month, weekend/weekday profiles could be developed for a typical year (or an actual year).

This same demand profile analysis for the sites in this report (identified as EFG in Figure 21 below) was also completed for the 20 Brooklyn-Queens sites in The Levy Partnership (TLP) field test project (NYSERDA Report 22-04). The plots in Figure 23 compare the average normalized demand profiles from the EFG and TLP studies for winter days with the same average 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 that are 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 21. Comparing Demand Profiles for The Levy Partnership and Energy Futures Group Sites for the Winter

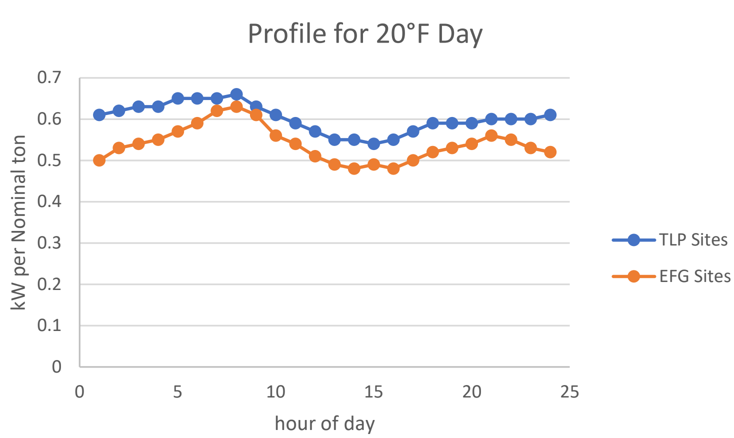


Figure 21 continued

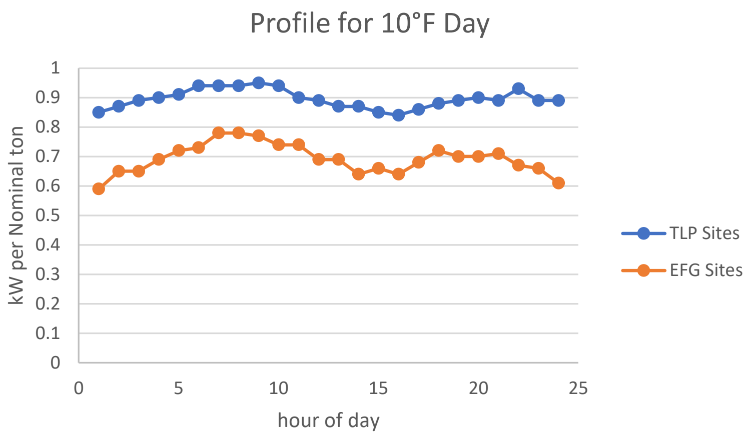


Figure 22 compares the normalized average profiles for the summer days with the same temperature. The summer days have similar peaks for both locations but drop to lower values at night for the site in this study. This might be due to the upstate locations having wider temperature variations or diurnal swings for days with the same average temperature.

Figure 22. Comparing Demand Profiles for The Levy Partnership and Energy Futures Group Sites for Summer

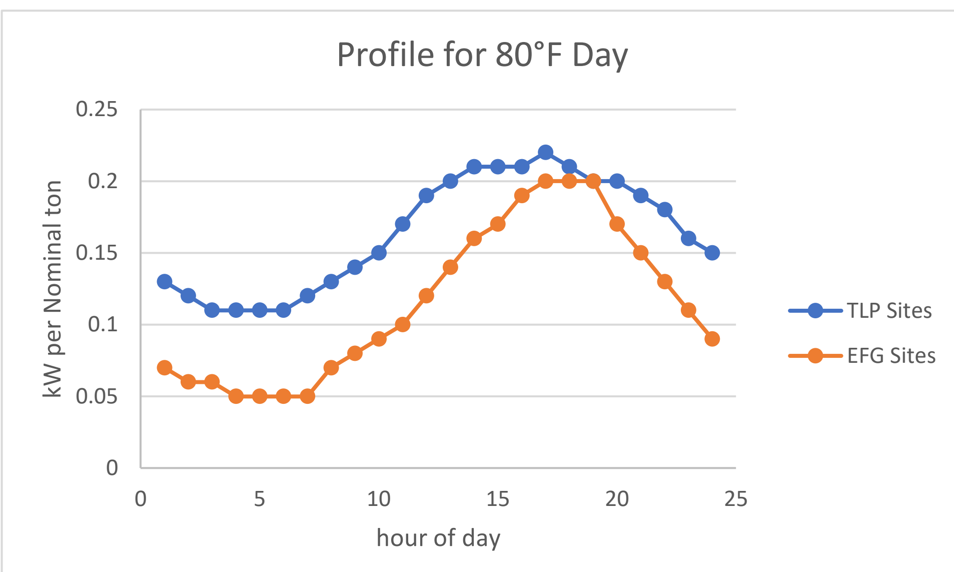
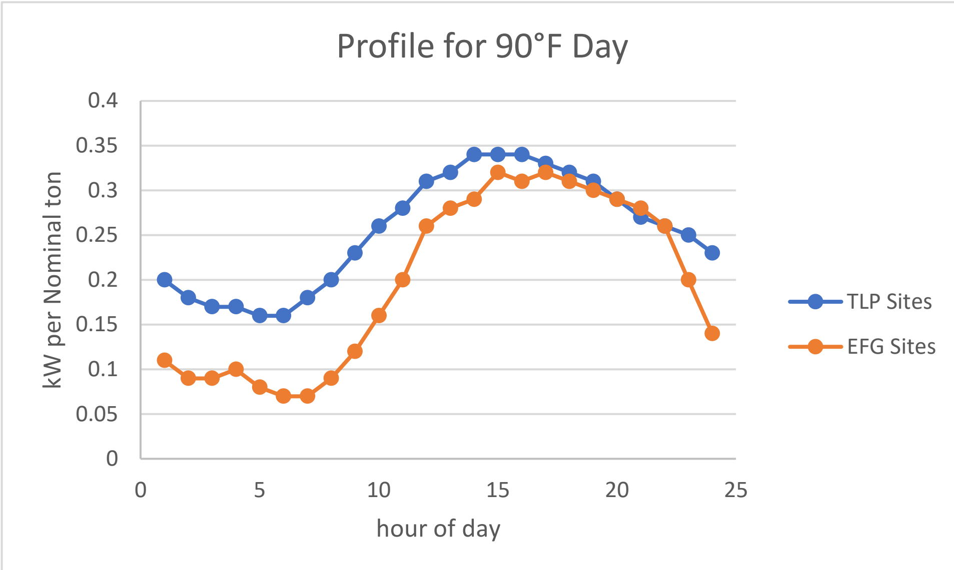


Figure 22 continued



4 Results: Customer and Contractor Surveys

This section presents the results from the customer surveys completed by Frontier Energy (FE). It also includes the results of a survey of contractors completed by EFG.

4.1 Customer Survey Results

4.1.1 Survey Approach

FE administered a two-part survey of participating residents using SurveyMonkey®. A web survey was first given around the time of the ccASHP (Web Survey 1) installations 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 is available as an addendum to the Performance Validation Plan in appendix D.

The survey results are presented below. FE received 19 responses on the Web Survey 1 and 19 on Web Survey 2. Specific survey response results are provided in Table 39.

Table 39. Responses to the Surveys at Various Stages

	Responses	Out of	Completion
Web Survey 1	19	20	95%
Phone Survey 1	8	10	80%
Web Survey 2	19	20	95%
Phone Survey 2	8	10	80%

Notes: S5 did not complete Web Survey 1 and S16 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.

4.1.2 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 15 factors that respondents had to choose from can be broadly grouped as follows: two related to climate change, five 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.”

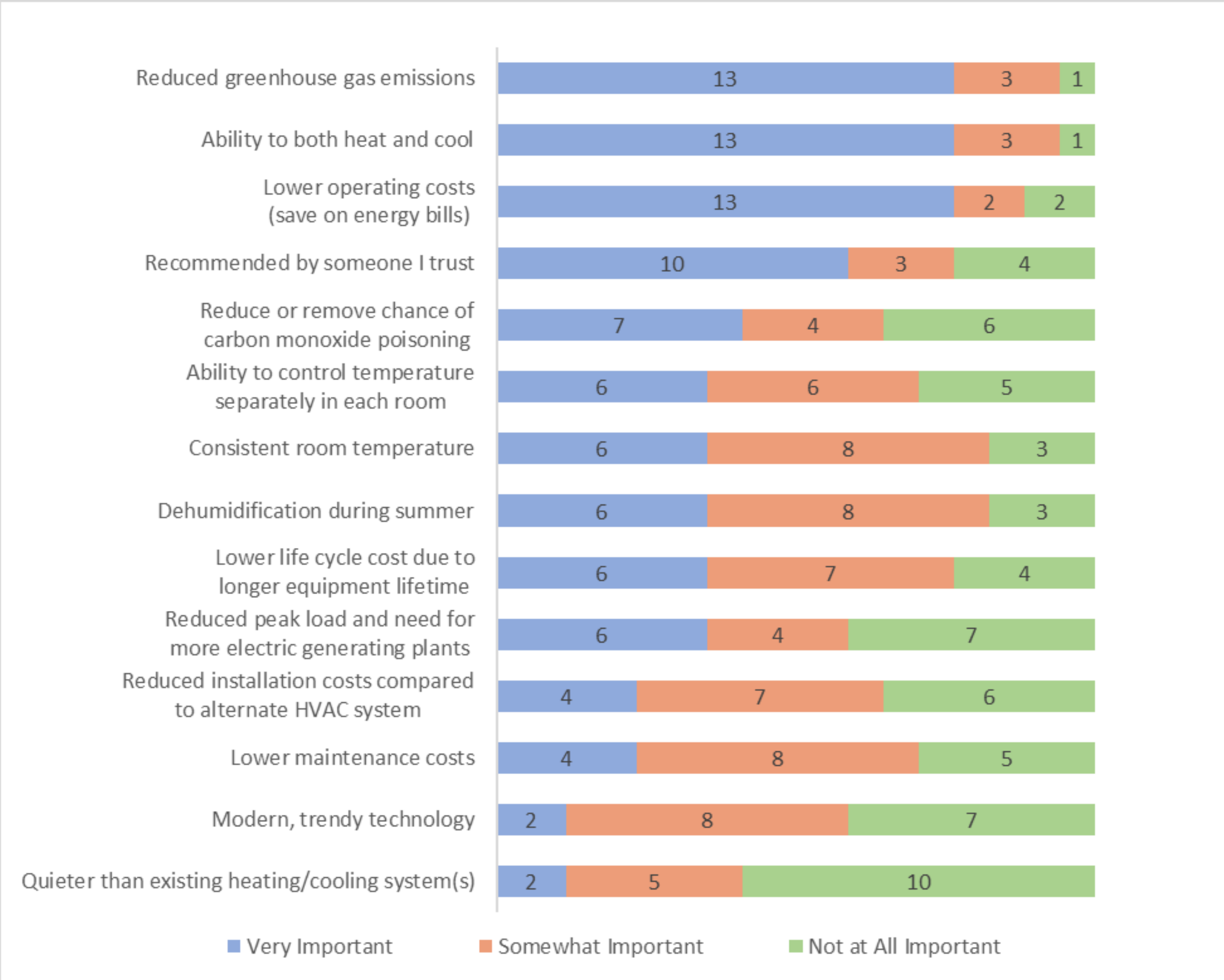
As shown in Figure 23, “reduced greenhouse gas emissions,” “ability to both heat and cool,” and “lower operating costs” received the most “very important” responses at 76% of the respondents (13 out of 17).

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 35% (six total) of respondents selecting these factors as “very important.” This difference may be due to many homeowners’ lack of awareness about the role peak demand plays in greenhouse gas emissions.

Thirteen out of 17, or 76%, of respondents also felt that the “ability to both heat and cool” and “lower operating costs (save on energy bills)” were very important in their decision-making process. Meanwhile, 10 out of 17 (or 59%) felt that “recommended by someone I trust” was also very important. Having a system that was “quieter than existing heating/cooling system(s)” was not at all important to 10 respondents (59%), somewhat important to only five (29%) and very important to only two respondents (12%).

Figure 23. Importance of Factors in Decision to Install an Air Source Heat Pump 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 in order to obtain their fuel records for data analysis purposes):

- "I did it to see if a heat pump can work on what is typical for the existing inventory of housing in this country. I am a builder of zero energy homes and live in the last crappy home I built (meaning what everyone else builds)."
- "I am very excited to have the opportunity to get off fossil fuels and use such wonderful heating/cooling technology. Having a separate unit in three distinct parts of my house is quite a luxury, as is being able to turn the fan higher/lower. This system gives me a lot more control than my previous one. I appreciate all the rebates I was able to get for this installation too."

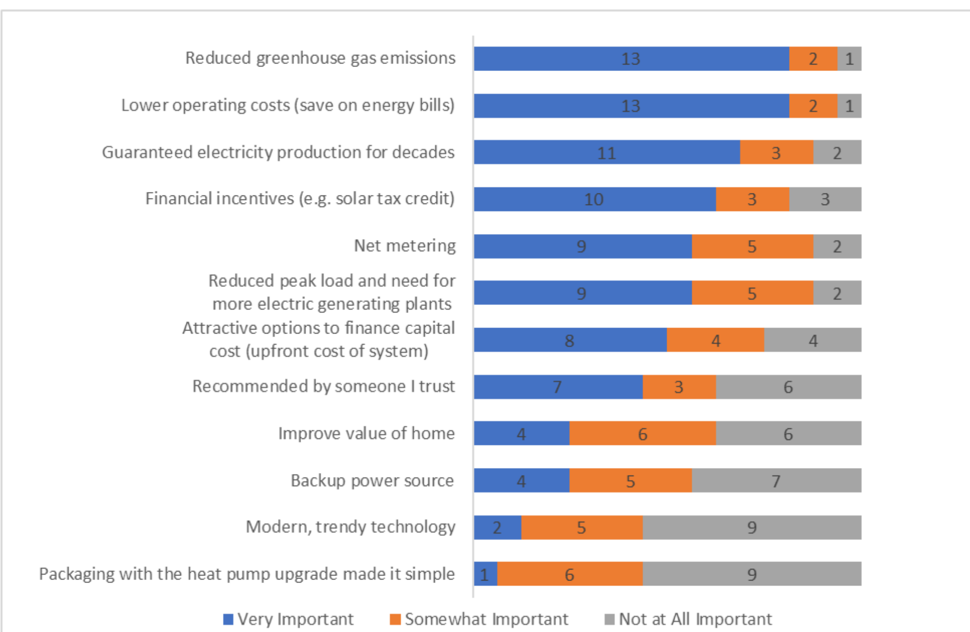
- “I think that I am helping the environment by moving away from natural gas as the heat source.”

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

- “We just sold the house and it's a desirable feature to advertise.”
- “I think it’s generally a bit less stuffy, because there’s a fan on so much more often. I also have more options for rearranging furniture because I don’t have to rely on the baseboards.”
- “I adore the heat pump in my bedroom because I can change its setting as I need to without changing any other unit’s setting in the house. It's like having my own, personal high-efficiency heating and cooling unit.”
- “It seems like it's easier to breathe in my house.”

Customers were also asked whether they had considered installing solar and if so, why. All customer participants had considered installing solar, with reduced greenhouse gas emissions and reduced costs playing the most important roles in that consideration. Figure 24 shows how important certain factors were for participants as they deliberated whether or not to install solar (the numbers represent the number of respondents who selected each option). While 16 participants answered the question, “How important were the following in your decision to install a solar PV system?” only nine sites actually had solar (all had been installed prior to participating in the HVHPP). Additionally, pairing heat pump installations with solar installations was considered the least important factor.

Figure 24. Importance of Factors in Decision to Install a Solar System



4.1.3 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 25, 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 with most agreeing it was less invasive or there was little to no difference (Figure 26).[10]

Figure 25. Customer Satisfaction with Work Carried Out by Heat Pump Contractor

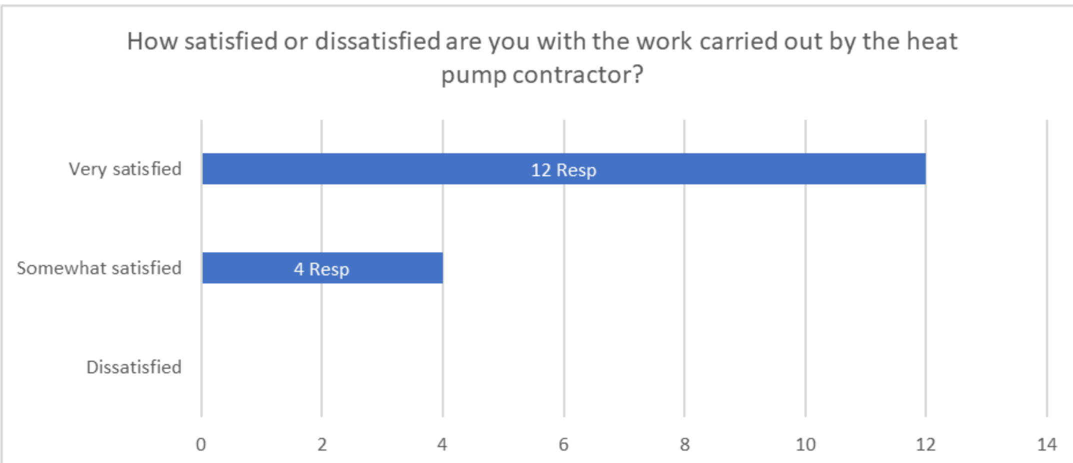
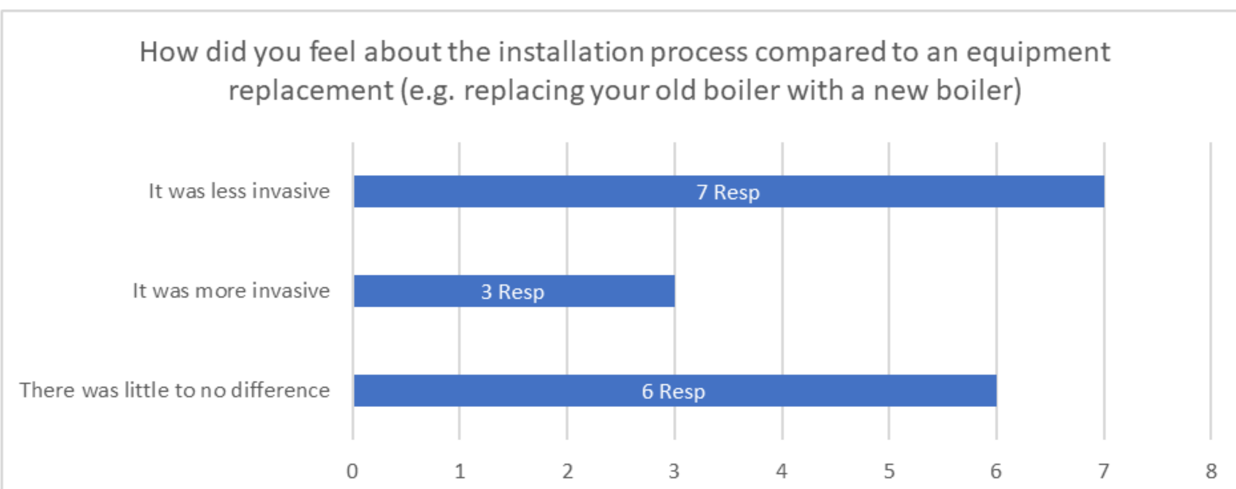


Figure 26. Customer Experience with the Installation Process



4.1.4 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, the questions related to how much effort it took them to maintain the new heat pumps.

As shown in Figure 27, 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 47% expecting them to be slightly or much easier, and the remaining 24% expecting the maintenance to be about the same. After a year or more of experience with the ccASHP pump system, 63% stated it was slightly to much easier, with three stating it was "about the same" and another three stating it was "slightly more difficult." Not one respondent stated that it was much more difficult than their original systems.

Figure 27. Expected and Experienced Level of Effort to Maintain Cold-Climate Air Source Heat Pump in Comparison with Prior Heating and Cooling System

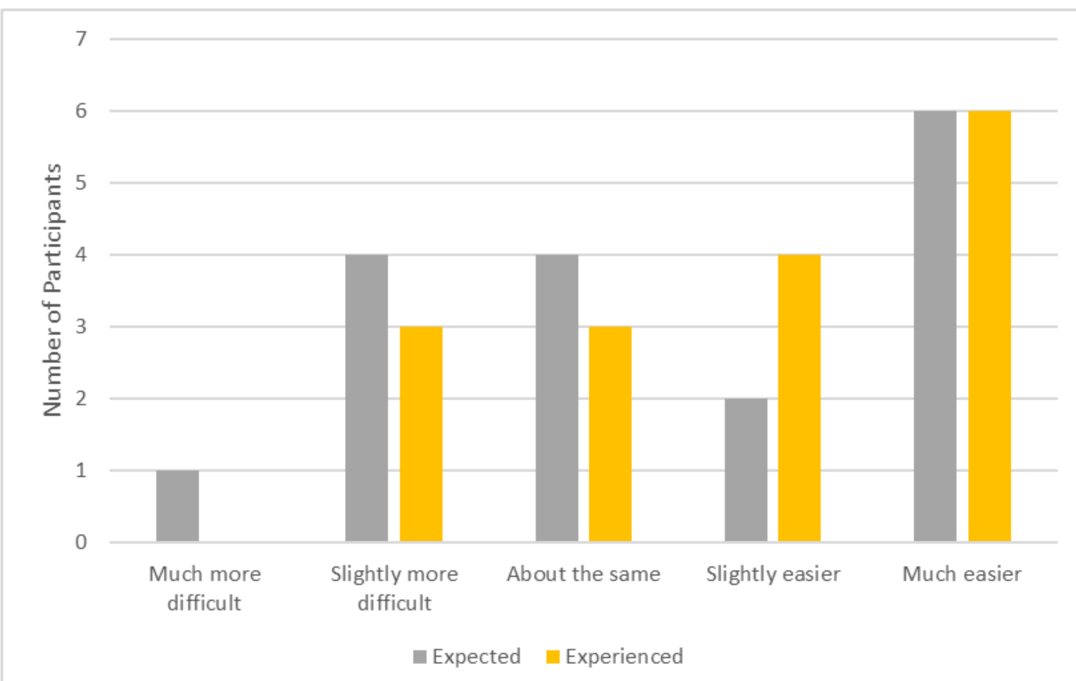
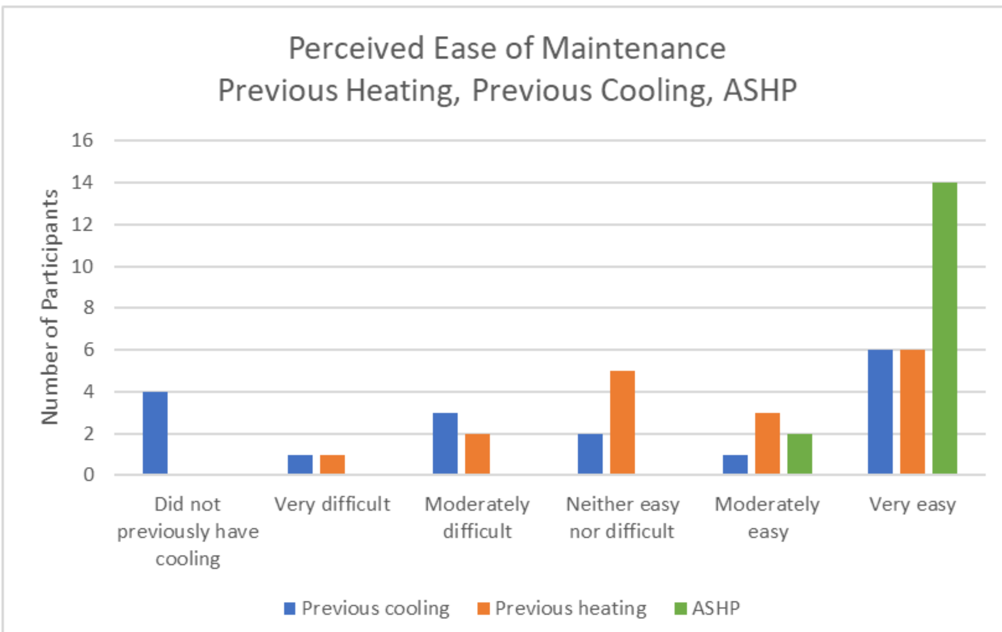


Figure 28 supports this result, with participants overall finding the ccASHP system easier to maintain than both the previous heating and cooling systems. Generally, customers felt that the level of effort needed to maintain their original heating (53%) and cooling (41%) equipment was moderately to very easy, as shown in Figure 26. The question pertaining to cooling equipment saw fewer responses since many of the participants did not have any cooling system, or only used window units, prior to the installation of the heat pumps. Almost all respondents felt that maintaining their heat pump was "very easy" with two of the respondents maintaining their heat pump was "moderately easy."

Figure 28. Perceived Levels of Effort to Maintain Previous Heating System, Previous Cooling System, and Air Source Heat Pump System



These results show that the participants felt that generally, maintenance was both easier than they expected and easier than their conventional systems. This potential barrier to uptake could easily be addressed by incorporating information on the ease of maintaining air source heat pumps compared to other heating and cooling systems into potential customer outreach campaigns.

When asked in the final survey if they gained any unexpected benefits or experienced any unexpected problems, respondents had the following to say:

- "I like the ease of cleaning the filters."
- "No problems, but do need to remind myself to clean the filters which are different left and right."

4.1.5 Perceived Comfort

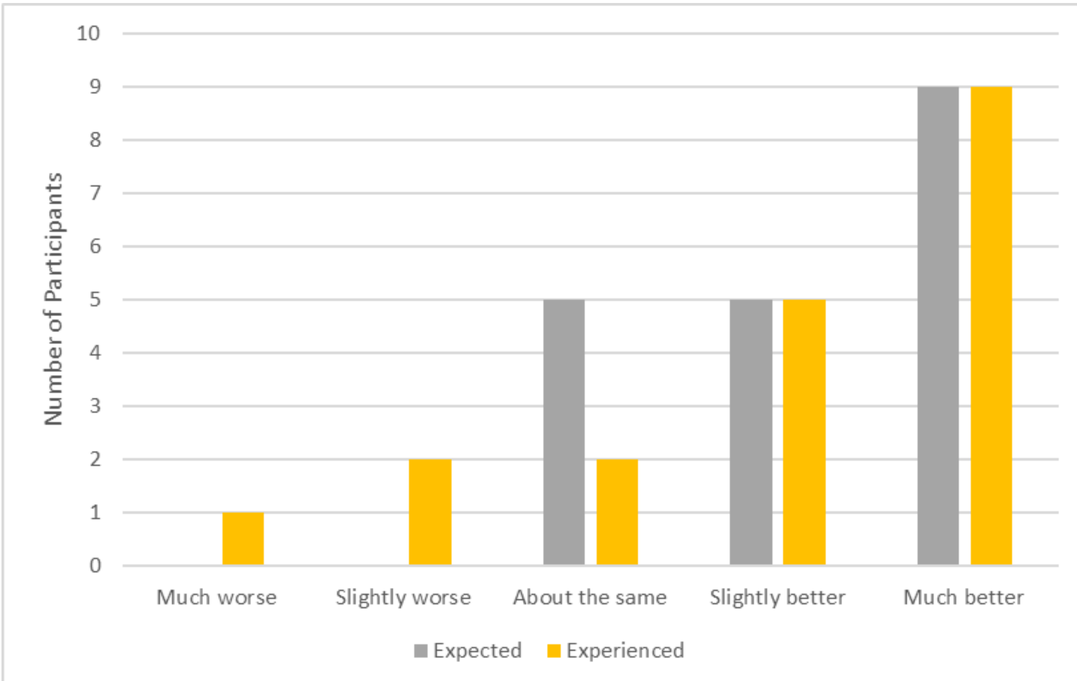
Customers were asked a series of questions related to comfort. Web Survey 1 asked whether their desired temperature was reached with their original heating/cooling system prior to the heat pump installation. Web Survey 1 also asked what their expectations were in terms of the heat pump system providing them with 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 as well as 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. As Figure 29 shows, 73% of the participants (14 out of 19) expected the heat pumps to maintain their desired heating temperature slightly or much better than their original heating system, with five respondents (26%) expecting it to be about the same. All but three respondents (16%) said that the heat pump system performs at least as well as their previous heating system, and only one respondent (5%) said that the heat pump system performs at least as well as their previous cooling system. The one “much worse” response is a homeowner whose single heat pump installed in the living area was only able to partially displace boiler heat. They may have been expecting the heat pump to serve more areas of their house. This participant was also the only one to say electricity bills are much higher than expected.

Note that one participant did state:

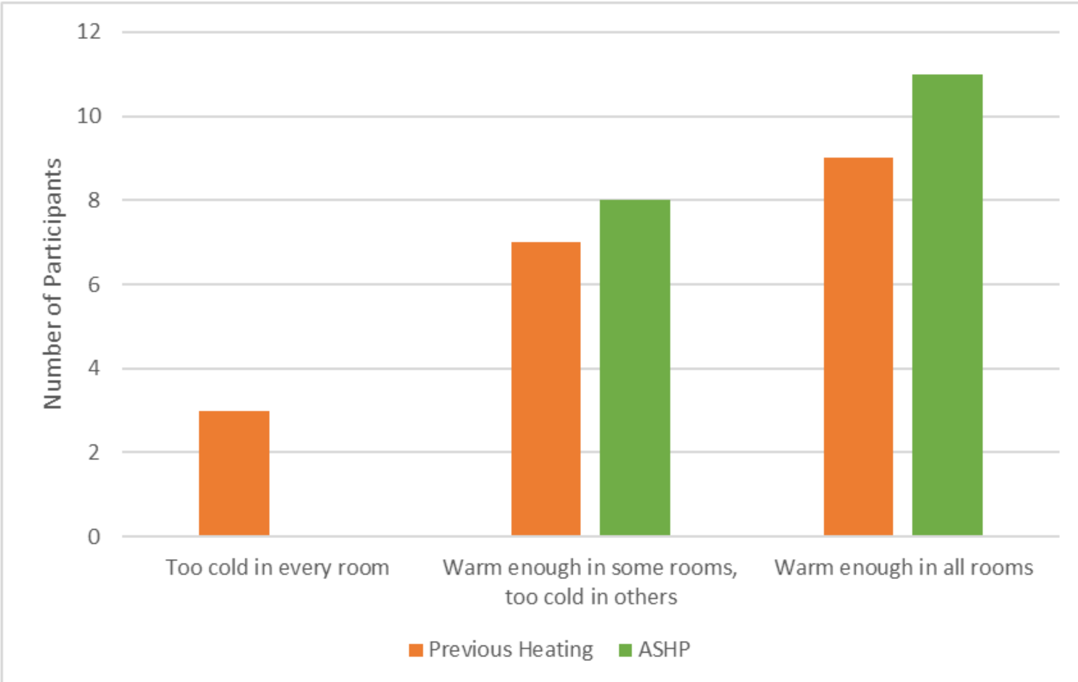
- “Did not own building for entire winter before installing heat pumps, so some of my responses regarding comparison between heating costs/comfort/operation will not make sense.”

Figure 29. Perceived Ability of Heat Pump to Maintain Desired Winter Temperatures Compared to Previous Heating System



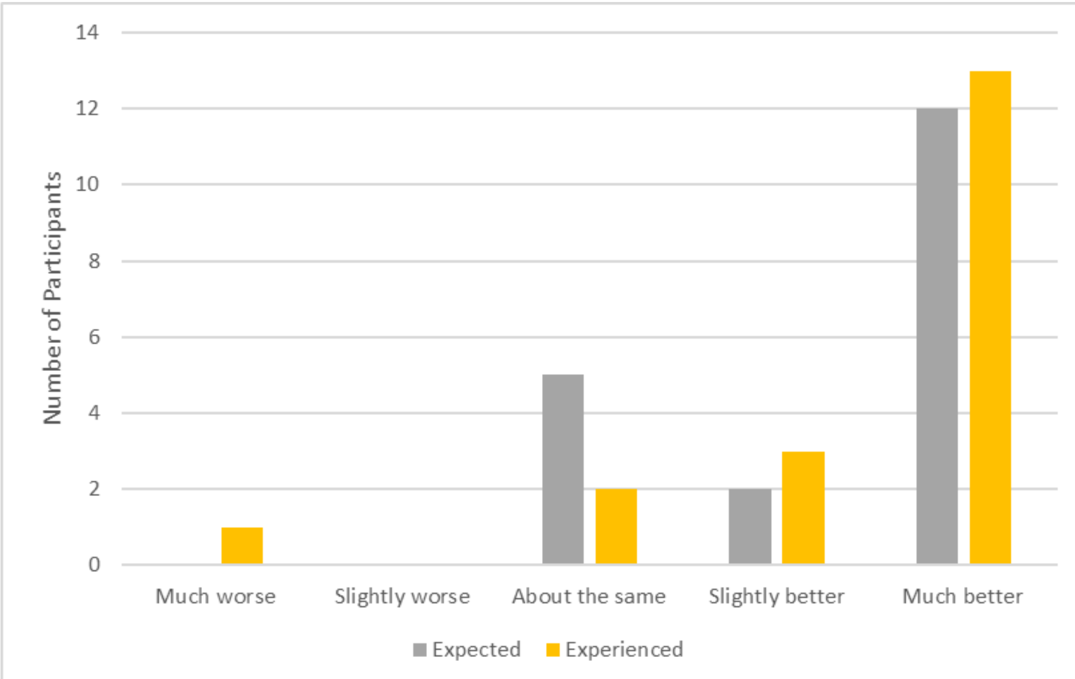
Participants did, however, report an improvement in the distribution of temperatures throughout the home, as seen in Figure 30. Most participants felt that their original heating equipment maintained their desired temperature in all rooms of their home during the heating season, prior to the installation of the heat pump system (47%, or nine out of 19 respondents). Seven of the respondents felt that their desired temperature during the heating season was achieved in some but not all rooms, and three felt that their desired temperature was never achieved. In contrast, no participants reported that all rooms were too cold in winter with the ccASHP system. This is not surprising, as likely cold areas of the home were taken into account when deciding where to place heat pumps.

Figure 30. Perceived Distribution of Comfort Throughout Home During Winter for Previous Heating System and Cold Climate Air Source Heat Pump



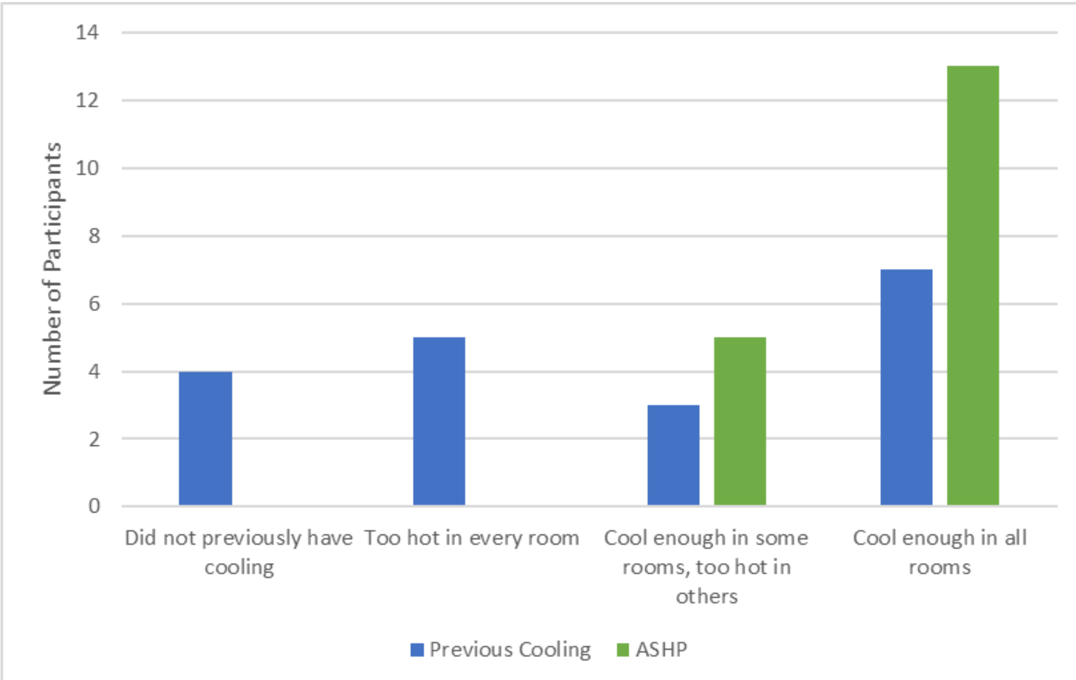
Participant responses for summer temperatures also indicate an improvement in the ability for the heat pump to maintain cool enough temperatures for comfort. Similar to heating, 74% expected their heat pumps to maintain their desired cooling temperature slightly or much better than their original system. Five respondents expected it to be about the same. The remaining four participants answered that they did not have a cooling system (central AC or window units) prior to the heat pump installation, and these questions therefore did not apply to them.

Figure 31. Perceived Ability of Heat Pump to Maintain Desired Summer Temperatures Compared to Previous Cooling System



Seven respondents (37%) felt their original cooling system kept all rooms of their home maintained at their desired temperature throughout the cooling season (Figure 32). Three respondents said some but not all of the rooms maintained their desired cooling temperature and five said nowhere in their home was their desired temperature met. Note: The "much worse" answer is a homeowner who does not use the heat pump for cooling, and instead continues to use pre-existing central air conditioning for space cooling. This participant was also the only one to say electricity bills are much higher than expected. More participants (13 compared to seven) reported that all rooms were able to achieve their desired temperature with the ccASHP; however, five participants still feel that the ccASHP is not able to deliver cooling to all areas of the home. The general trend is toward higher comfort with the ccASHP installation.

Figure 32. Perceived Distribution of Comfort Throughout Home During Summer for Previous Cooling System and Cold-Climate Air Source Heat Pump

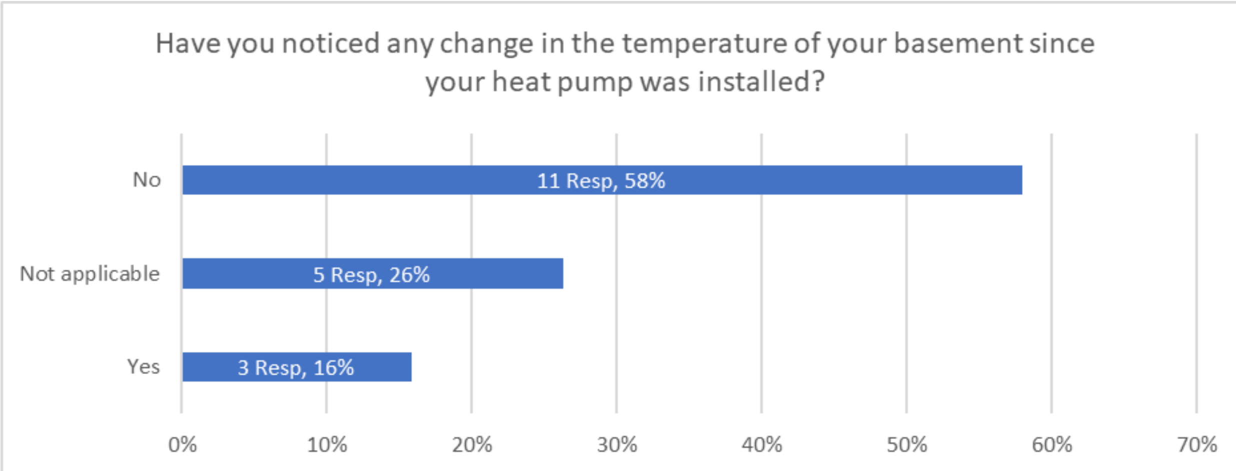


It must be noted that reasons for results are not necessarily explained by the simple survey responses. In the final survey, some participants elaborated:

- "Summer has been great, cooling is excellent compared to prior unit. In the winter, our lower family room is still hard to keep warm, but it was much more of a problem with our old units and mostly due to large, inefficient windows."
- "It is hard to heat and cool side bedrooms and bathrooms, unless you keep the doors open all the time."

With regards to the final question pertaining to comfort, most respondents had not noticed a change in basement temperature, as shown in Figure 33.

Figure 33. Perceived Distribution of Comfort in Basement



4.1.6 Operation

All 19 survey responders noted that they received written instructions on how to operate the heat pump. All but one reported having been trained to use the new system and the information provided was sufficient to operate the heat pump. One person stated that he or she could have used more help to program the thermostat. Of the 19 responders to the final survey to date, 15 reported that it was "very easy" to operate their heat pump, and four reported that it was "easy."

Additional comments from participants regarding operation are as follows:

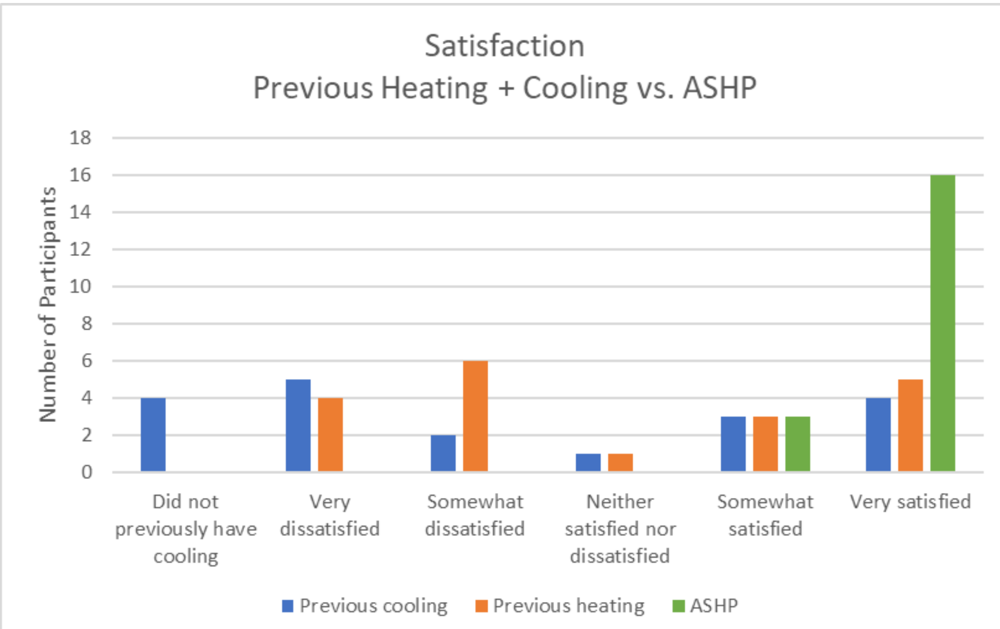
- "More training is needed. A video would be helpful. There are several control variables."
- "Perhaps I will set the heat pump stat at a higher temperature than I did with the gas heater. I am still working out the details and practice."

4.1.7 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 34, satisfaction levels with the previous heating and cooling systems varied. Four answered that they did not have a previous cooling system. In contrast, 16 out of 19 responses to the final survey reported they are "very satisfied" with their air source heat pump 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 expressed dissatisfaction with their air source heat pump system.

Given that more participants indicated high satisfaction than those stating comfort was fully met indicates that comfort is not the only impact on satisfaction. (In the cases where the heat pump only meets part of a home's heating load and existing heating system(s) remain as a backup, the differences may also be explained by respondent's literal interpretation of the question regarding the "ability of [the] *heat pump* to maintain desired winter temperatures compared to previous heating system" (emphasis added). Their satisfaction with the heat pump *includes* the context of having a backup system that can meet some heating needs that the heat pump cannot, but the survey question was only about the heat pump itself.)

Figure 34. Participant Satisfaction with Previous Heat and Cooling Systems in Comparison to Heating and Cooling Provided by the Cold-Climate Air Source System



4.1.8 Other Feedback

Between the various surveys (web and phone, before and after), along with other participant conversations (for example, to obtain fuel records), homeowners provided a number of other comments that did not necessarily fit within a specific survey question. For example, some participants were excitedly anticipating to see how the systems would perform, and some were adjusting setpoints to see if it made a difference:

- "I haven't actually seen much of a decrease in cost since installing the heat pump a month and a half ago. I have raised the temperature by 5 degrees from the baseboard."
- "I look forward to seeing how the heat pump performs and what it costs."

Others expressed concern with noise:

- “The heat pump is definitely louder than baseboard.”
- “In the winter when they are working hard, the heat pumps cause significant noise and vibration.”

Several participants commented on the humidity control as an unexpected benefit:

- "… the dehumidification is a nice plus.”
- “Also, during the winter, the heat pumps did not dry out my lips and nose like my gas heat did. I didn't have to wear Chapstick or use a dehumidifier [presumably the respondent meant a “humidifier”].”
- “The ability to dehumidify is very useful.”

Meanwhile, one participant (a builder of net zero homes) provided an opinion regarding what might help to improve the sizing and design of heat pumps for a given building:

- “One of the main areas for improvement is the lack of a comprehensive heating and cooling energy model to properly size the units. Few (or no) HVAC contractors are required to be trained in Building Science nor are they required to do a blower door test to accurately assess the air infiltration in a building, which is simply not the best way to cost effectively suggest the size of any heating equipment. The survey should include information about what envelope improvements were made and also if the homeowner has solar generation. Some kind of “pro forma” tool should be included to analyze the cost and usage of every load in the home before and after the installation of the equipment.”[11]

When asked if they experienced any unexpected problems, the following responses were given:

- “I didn’t save as much when I had a roommate, because she preferred to keep her door closed for privacy reasons, even when away. So, the heat pump rarely heated her room and the baseboard was used much more. I also don’t know how to turn the vanes.”
- “No problems. However, since my original air conditioning unit has blowers in all rooms of the house and the heat pump only works in the core rooms, I use the original unit when I need to run air conditioning.”

- “The former heating system was hydronic baseboards from boiler. In colder months, the pipes to these baseboards kept other water pipes in kitchen warm and prevented freezing, as well as kept baseboards from freezing. On first cold spell after heat pump installed in January 2019, upstairs baseboards and water pipes froze. After that time, when it was very cold, generally below 20 degrees, I would put on boiler to heat upstairs zones and baseboards to avoid this issue and turn off the heat pump. This winter I have discovered that I could avoid freezing baseboards and water pipes upstairs by heating the baseboards in these upstairs zones for 15 minutes before bed and in the morning to avoid freezing. Then I could keep the heat pump on. Also, the heat pump ran through our ducted system and the forced air led to challenges with low humidity in the home, versus the radiating heat from the baseboards, so I got a whole home humidifier. It also took some experimentation and modulating the duct dampers to find a temperature setting the kept the home temperature reasonably uniform, within 3 degrees or so of 69 degrees, during the heating season, in the upstairs zone that was served by the ducted heat pump.”

And finally, during the final survey period, the following additional comments were given:

- “Overall, we like the new units very much. We especially like the zoned nature of our heating now. We have not yet made a thorough comparison of our savings/costs for electricity vs propane bills before and after the switch to the air heat pump units, but we believe we are saving around $800/year with these units. We also believe this will raise the overall value of our house should we someday choose to sell.”
- “I had electric baseboard which is why I said the install was more invasive than a unit replacement for me. To what end would the replacement have been? A full electrical rewire. Sure, that is more invasive but just replacing a baseboard unit or thermostat controller is probably less invasive than running coolant lines through my exterior walls.”
- “Overall, happy to reduce our oil consumption—last year we calculated that we reduced our oil by 163 gallons. Forced air heat isn't as pleasant as radiant hydronic heat is our experience, so we are also using our wood stove to get some of that radiant heat back.”
- “I am very happy to be reducing my greenhouse gas emissions while also enjoying a comfortable, highly efficient heating/cooling option. Some people still shudder at the thought of electric heat—because it used to be so expensive. Not anymore. Everyone should have a heat pump system!”
- “Comfort levels, indoor air quality, are vastly improved.”

4.1.9 Summary of Customer Survey Findings

It is clear that this set of homeowners were driven to participate, in large part, by a desire to reduce greenhouse gas emissions. Also, that the incentives, potential financial savings, and increased comfort (as well as the recommendation from a trusted friend) all assisted in their deciding to install heat pumps. Customers were generally satisfied with the installation contractor and did not find the installation process to be too inconvenient compared to conventional systems. They found maintenance and operation of the heat pumps to be relatively easy, with no respondent stating it was much more difficult to maintain than their original systems. While all 19 received education about operation and maintenance, some of the anecdotal comments presented above indicate the potential for further follow up and education to address specific customer questions.

Participants had a range of satisfaction levels with their original heating and (if applicable) cooling equipment. They generally all expected to see their desired temperatures improved by the heat pumps, although this wasn't always achieved in the entire home, sometimes only in certain rooms only. The variability in responses to how the heat pumps were performing in individual rooms as compared to the entire home may be reflective of the various individual applications of the heat pumps for each building site. Only two respondents stated their desired heating temperature had slightly worsened when compared to their previous heating system. Nevertheless, 16 responses to the final survey reported they are "very satisfied" with their air source heat pump 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. The fact that participants were generally very satisfied, even though the heat pumps were not necessarily acting as a "whole home" heating or cooling solution, may be indicative of the level of communication with the customer that single-head, one-to-one heat pumps are not central heating and cooling systems, but rather address particular needs for specific spaces. Additionally, many homes retained their pre-existing heating system to use as a backup.

4.2 Contractor Survey

The EFG team developed a survey in SurveyMonkey® to better understand contractors' awareness of residential energy solutions such as efficiency as well as heat pumps, their approach to working with customers, and if (and how) the HVHPP might alter their business approach moving forward. Four of the six contractors responded to the survey, with one of these contractors completing only half.

4.2.1 Awareness of Energy Efficiency and Heat Pumps

The HVHPP did not require air sealing, insulation, and other efficiency measures to be incorporated with each heat pump project. The overarching goal of the original NYSERDA PON was focused on identifying ways "to accelerate the market uptake of commercially available, but underused [HVAC] building technologies … in the existing residential building market" and there was limited budget to incorporate additional requirements and incentives into the overall project. However, the EFG team is critically aware of, and concerned with, the need to ultimately approach existing building stock with a comprehensive approach that includes envelope improvements like air sealing and insulation, more efficient HVAC equipment, and renewables. Therefore, the EFG team did ask customers and contractors about the extent of efficiency measures that had been undertaken and completed a cursory review of the home to ensure that exceedingly inefficient homes were not included in the program. Additionally, the EFG team utilized the contractor survey as an opportunity to better understand whether and how contractors incorporated efficiency into their heat pump sales and installation practices.

Specifically, contractors were asked how familiar they were with and whether participation in the HVHPP increased their familiarity with air sealing and insulation, how familiar they were with specific aspects of heat pumps (installation, operation, maintenance, application, and performance), whether HVHPP participation increased their familiarity (and if "yes," how), and whether they would alter their installation practices as a result of the program.

One of the four contractors stated that they were "not at all familiar" with air sealing and insulation prior to the HVHPP, while the other three stated they were "very familiar." All four of the contractors stated their familiarity was not increased at all by the program, either because they were already very familiar (e.g., they were Building Performance Institute certified) or because they didn't have to learn more as the program did not require these efficiency measures.

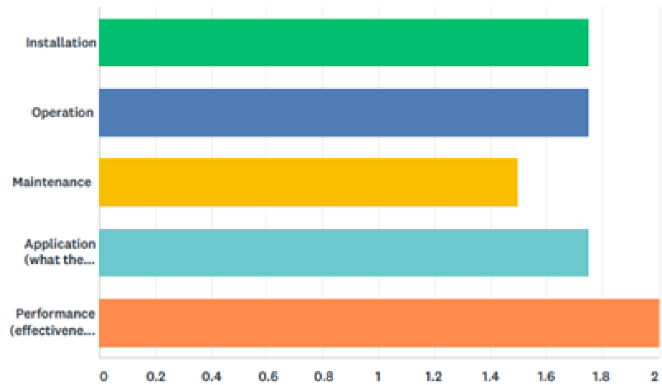
With regards to familiarity of heat pumps, all four stated they were "very familiar" with the installation, operation, and application of heat pumps. Two stated they were "somewhat familiar" and two stated they were "very familiar" with the maintenance of heat pumps. Three stated they were "very familiar" with the performance while one stated he was "somewhat familiar."

As shown in Figure 35, the HVHPP program "somewhat increased" three of the four contractors' familiarity and experience with the installation, operation, and application of heat pumps. All four contractors felt that their familiarity regarding heat pump performance was "somewhat increased." Contractors stated that they learned "performance and application tips form Pasquale Strocchia, while working with him and his team (IBD)," while others stated they believe they will learn more once the results are completed and shared.

Figure 35. Extent to Which Participation in Hudson Valley Heat Pump Pilot Increased Contractor Familiarity with Cold-Climate Air Source Heat Pumps

Q6 Did your involvement in this program increase your familiarity and experience with the following aspects of cold climate ASHPs?

Answered: 4 Skipped: 0



	DID NOT INCREASE	SOMEWHAT INCREASED	INCREASED SIGNIFICANTLY	TOTAL	WEIGHTED AVERAGE
Installation	25.00% 1	75.00% 3	0.00% 0	4	1.75
Operation	25.00% 1	75.00% 3	0.00% 0	4	1.75
Maintenance	50.00% 2	50.00% 2	0.00% 0	4	1.50
Application (what the purpose is: e.g., whole home heat, supplemental heat)	25.00% 1	75.00% 3	0.00% 0	4	1.75
Performance (effectiveness, efficiency)	0.00% 0	100.00% 4	0.00% 0	4	2.00

In response to the question “What do you think you will do differently regarding ccASHP installations as a result of participating in this program?” contractors stated:

- I will slightly undersize BTU capacity of multizone outdoor ccASHP condenser units by sizing total indoor unit BTU demand to ~130% of outdoor unit BTU capacity. This was a helpful time [tip] from Pasquale. He found it increases the overall operating efficiency of the systems. It also reduces our material costs slightly.
- Mount head units lower from ceiling.
- Not much. Once results are out maybe it will change.
- Better information for clients.

Contractors were given a number of published guidance materials through the program; therefore, they were also asked which of the publications they found to be most helpful. These included a Homeowners Operation Checklist, the NEEP Guide to Installing ccASHPs in Cold Climates and the NEEP Guide to Sizing and Selecting ccASHPs in Cold Climates.[12] Two contractors felt that the Homeowners Operation Checklist and NEEP Guide to Installing heat pumps were the most informative and helpful while one contractor felt the NEEP Guide to sizing and selecting heat pumps was the most informative and helpful. Additionally, one contractor stated that “the NEEP/NYSERDA average snow depth and condenser install height map/instructions were helpful. Some of the other guides were a good refresher for me,” while another contractor stated that the materials “help me understand things I should point out to the customer.”

4.2.2 Customer Approach and Perspectives

The “set it and forget it” heat pump operation directions are a change for many customers in comparison to their original, whole home central heating system which frequently made sense to turn down at night or while away. Therefore, contractors were asked if they left educational materials with homeowners prior to the HVHPP and if “yes,” what those were; whether they would continue to provide materials from the HVHPP to customers once the program was completed; and what other materials they wish to be available.

When asked whether they left educational materials with homeowners regarding how best to operate a heat pump prior to participating in the HVHPP, two contractors replied “yes,” and two contractors replied “no.” The two contractors who did leave materials stated they left the manufacturer operation and installation manuals as well as other product brochures provided by the manufacturer. Moving forward, all four contractors stated they would continue to provide the materials from the HVHPP to customers, even once the program was finished. This improvement in how contractors approach customers is further corroborated by the fact that all four contractors replied affirmatively to the question: “Do you think the awareness and education of your customers regarding how to operate ccASHPs has changed as a result of the materials and training you received during this program?” The areas cited as having the greatest improvement is the reinforcement of “set it and forget it” and zoning operation.

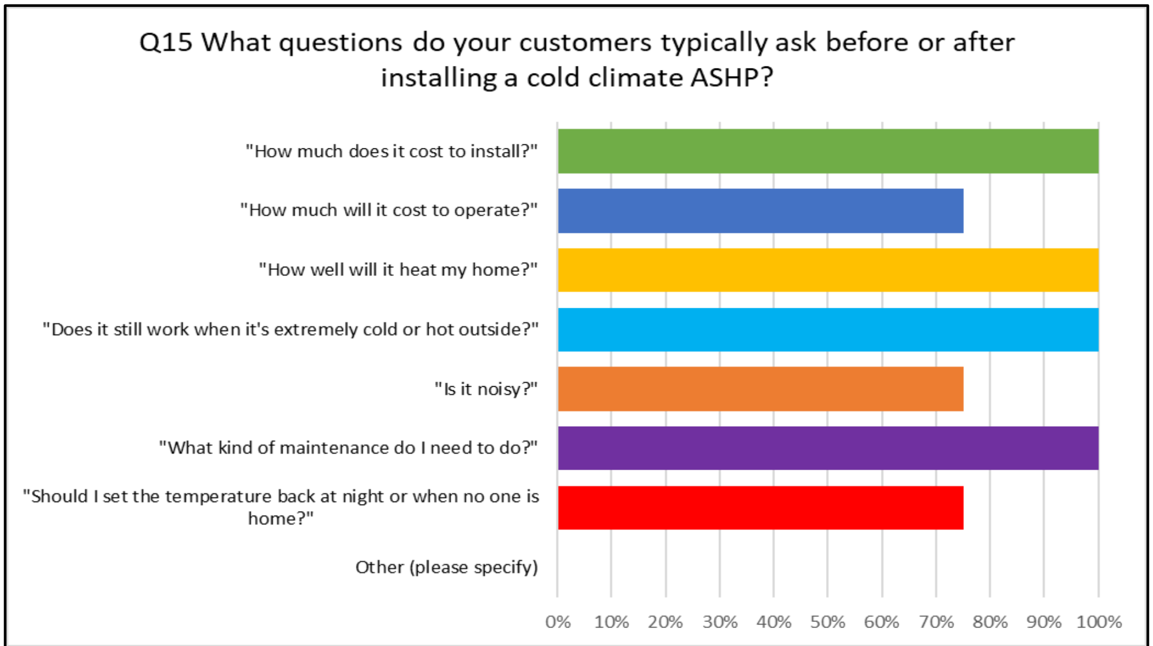
With regard to other materials, handouts, resources, or tools contractors wish they had access to, contractors replied as follows:

- "An annual energy savings calculator that compares heating and cooling operating costs for ccASHP systems versus other common heating and cooling systems. We have modeled these systems in Optimiser and the energy savings estimates seem to be way too bullish. A simple calculator that takes in average annual energy usage, existing HVAC system types, square footage and percentage of home to be conditioned with ccASHPs could be a very effective way to convey the savings to a client without getting lost in the details. These systems use a fraction of the amount of energy that many existing HVAC systems use, but it is currently hard to back that statement up due to a gap in quick energy modeling tools for ccASHPs. If homeowners could see more accurate annual energy savings totals to help cost justify the initial investment in ccASHPs, I believe they would be more widely adopted."
- "Case studies of homes average savings."
- "Research program results. Helpful in educating future clients."

To better understand the contractor's view of the customer's perspective, the EFG team also asked contractors which questions customers typically asked about heat pumps; the reasons why customers chose heat pumps and which reason was the most prevalent; what contractors wished New York State homeowners knew about heat pumps and what type of customer education is needed; and whether the contractor recommends a comprehensive approach to customers that pairs heat pumps with weatherization and/or solar and why or why not.

As shown in Figure 36, customers ask every question the survey listed; however, they focused predominantly on install cost, how well the system would heat the home, whether it would still work when temperatures are extreme, and what kind of maintenance would be needed.

Figure 36. Customer Questions About ccASHPs



ANSWER CHOICES	RESPONSES	
"How much does it cost to install?"	100.00%	4
"How much will it cost to operate?"	75.00%	3
"How well will it heat my home?"	100.00%	4
"Does it still work when it's extremely cold or hot outside?"	100.00%	4
"Is it noisy?"	75.00%	3
"What kind of maintenance do I need to do?"	100.00%	4
"Should I set the temperature back at night or when no one is home?"	75.00%	3
Other (please specify)	0.00%	0

Contractors were also asked what the reasons were for their customers choosing to install heat pumps:

- To improve the comfort of their home.
- To add a cooling solution to their home.
- To be able to have a flexible solution that can both heat and cool.
- To save energy and money.
- To move away from fossil fuels.
- To use a “cleaner” energy source.

Contractors responded that all of these reasons matter; when asked which reason was the most common, the three contractors who responded to this question, differed in their replies. One contractor chose “to add a cooling solution,” one chose “to have a flexible solution that can heat and cool,” and the last chose “to save energy and money.” None of them chose “to move away from fossil fuels,” which was the most common reason amongst the HVHPP participants.

Contractors wish homeowners in New York State "knew that ccASHPs were one of, if not the most cost-effective option for heating and cooling their homes. This applies to both the initial investment as well as lifetime operating costs. The perceptions that they cannot heat in very cold temps and that ductless wall units are too obtrusive both need to be overcome." Another contractor stated that "they need to recognize low-ambient operation and that they are an effective Northeast solution." A third contractor stated that customers needed to see "proven results."

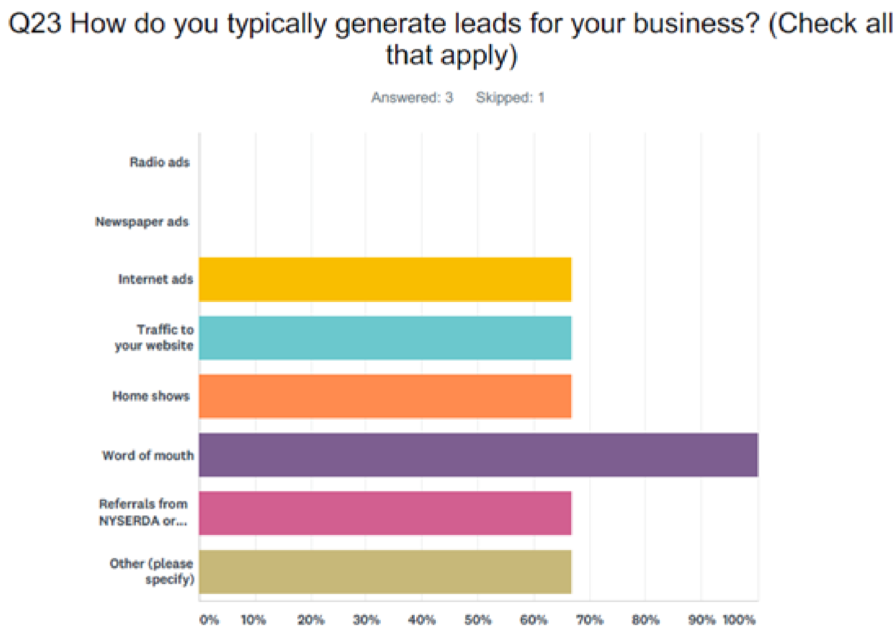
Three out of four of the contractors stated that they recommend customers take a comprehensive approach that pairs heat pumps with weatherization and/or solar. The rationale is to be expected: "The ccASHP system will perform better for heating and cooling while using less energy." For the one contractor who does not recommend this to customers, the rationale is that it is "too much for a person to digest at once."

4.2.3 Business Approach

To assess how contractors develop business and understand their view of the heat pump market in the State, they were asked how they typically generated leads; whether their peers in the residential HVAC space were generally informed about the benefits of heat pumps and interested in selling them; what they think the biggest challenge is in promoting, selling, and installing cold-climate air source heat pumps; whether heat pumps should be promoted broadly to New Yorkers and why/why not; what tools or resources should be provided to customers; and how they would alter their business model if market uptake increased significantly.

As shown in Figure 37, contractors use a variety of methods to generate business leads, but the prevailing method is "word of mouth."

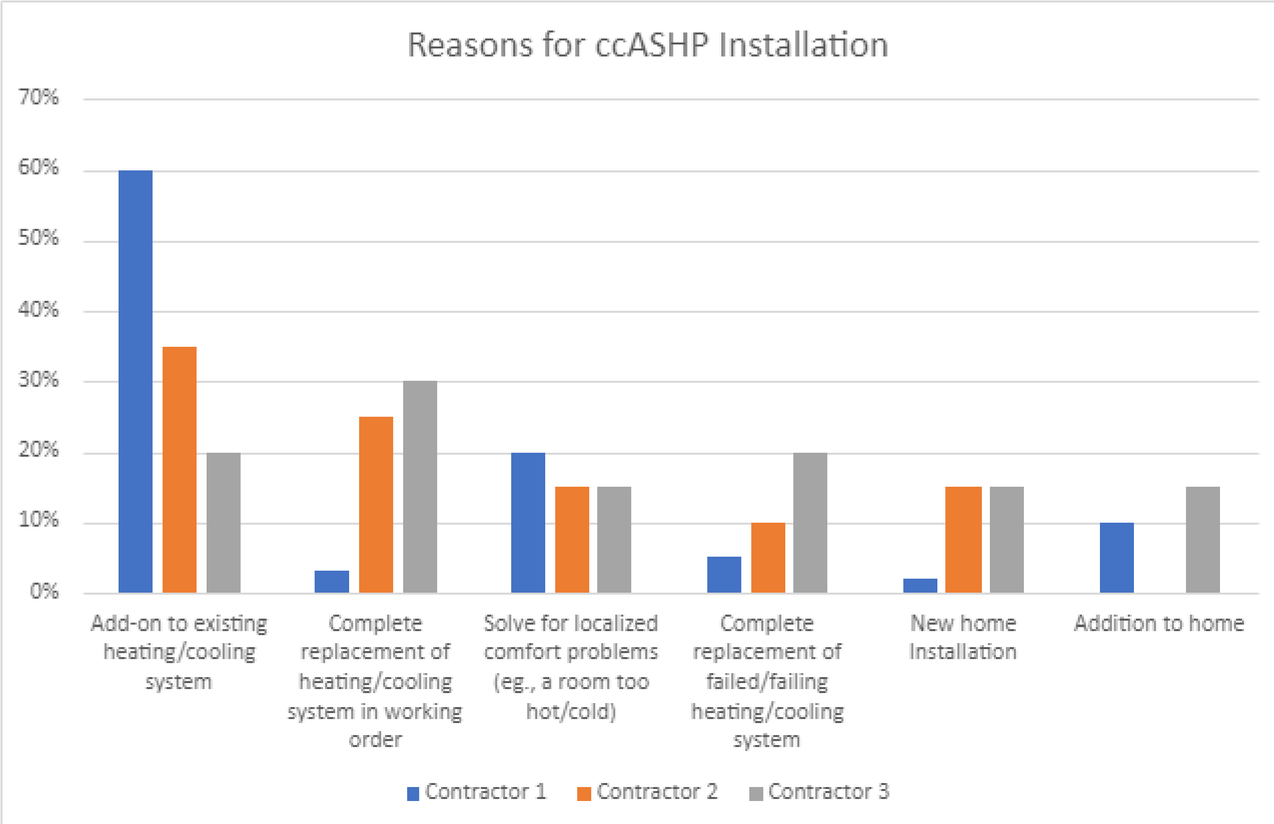
Figure 37. Contractors Approaches to Generating Leads



Two of the three contractors[13] felt their peers and competitors in the residential HVAC space were generally not informed about the benefits of cold-climate heat pumps, and generally not interested in installing them (one contractor felt the opposite). The challenges in promoting and selling heat pumps include "initial investment cost," "aesthetics," and "potential customers' education" as well as "rebates for proven accepted technologies." Contractors agreed that heat pumps should be promoted to New Yorkers because "they work very well and will help to reduce home energy waste," and that a heat pump "saves money, increases comfort." Contractors would appreciate NYSERDA providing support such as additional "homeowner rebates and low-interest financing," "more comprehensive materials demonstrating the advantages and capabilities of heat pumps," and "saving tools."

Finally, contractors were asked to estimate which type of installation they did the most frequently; for example, whether the heat pumps were to completely replace the existing systems or whether the system would be supplemental. As shown in Figure 38,[14] the most frequent response was "Add-on to existing heating/cooling system," which received double the percentage responses than any other type of installation, followed by "complete replacement of heating/cooling system that is in working order," and "solve for localized comfort projects (e.g., a room that is too warm/cold). Trailing farther behind were "complete replacement of failed (or failing) heating/cooling system, then "new home installation," and finally "addition to home."

Figure 38. Reasons for ccASHP Installations



4.2.4 Summary of Contractor Survey Results

The contractors who responded to the HVHPP contractor survey are confident in their awareness of energy efficiency and heat pumps, but still found the published materials and various installation techniques that were part of the HVHPP to be helpful and useful. Their approach to educating customers and explaining how to efficiently operate heat pumps was augmented by the HVHPP, and they plan on continuing to use the resources made available. Their experience indicates that customers are interested in heat pumps for a range of reasons, but that comfort, convenience, and energy and financial savings ultimately drive the customer's decision to install. Their primary business development tool is "word of mouth," and they generally feel that New Yorkers overall, as well as other residential HVAC businesses, are not aware of the potential comfort and savings that cold-climate air source heat pumps can provide. Finally, they would appreciate being able to offer their customers greater rebates, low-cost financing options, and case studies with "proven results."

5 Technology Transfer

There are a number of barriers to the widespread adoption of ccASHPs, as mentioned in sections 1 and 4. These include lack of awareness by customers and contractors, uncertainty in performance, limited performance data, and other issues. Throughout the HVHPP, the EFG Team has implemented various approaches to address some of these barriers. For example, efforts to address "lack of awareness" within the scope of the HVHPP were described earlier, that is, various outreach approaches to customers and contractors. Meanwhile, the HVHPP sought to address "uncertainty in performance" through contractor trainings and QA visits, as well as various contractor- and customer-facing materials that discuss topics including how to size, design, install, maintain, and operate heat pumps. Efforts were also made in setting customer expectations as to how the heat pump application specific to their home would and would not address heating and cooling issues. Finally, performance monitoring was undertaken to collect measured data to validate performance for this new technology.

An additional component of the overall HVHPP was, however, to undertake a broader Technology Transfer process. At the time of the writing of this report, this process was nearing completion. Completed work includes the initial outreach materials developed to identify and secure HVHPP participants (Figures 4 and 5 provide examples), recording "b-roll" during the initial installation process (to be used later when designing videos), receiving approval from NYSERDA for the overall Technology Transfer Workplan, completion of one fact sheet, completion of one case study video, and near completion of a second case study video. Through discussion with NYSERDA, it was determined that the HVHPP Technology Transfer would focus on New York State homeowners as the key audience.[15] This included the development of several key messages, including the following:

- "ccASHPs are an effective, efficient, and sustainable heating and cooling solution proven to deliver high performance in New York State."
- Cold climate: "ccASHPs are effective and efficient when temperatures in the NYS region drops below zero."
- Energy savings:
  - "ccAHPS have saved Hudson Valley area homeowners who use electric heat an average of $900 on annual heating costs."
  - "ccASHPs have saved Hudson Valley area homeowners who use propane heat an average of $850 on annual heating costs."
  - "the average savings of all participants (not including the three with natural gas[16]) was $549/year, with the heat pumps offsetting 89% of the pre-heat pump heating fuel use."
- Environmental benefits: "Hudson Valley homeowners have reduced annual carbon emissions by an average of 3274 lb (equivalent) of CO_2 per year."

- "If you want heating and cooling equipment that results in energy savings, low maintenance, a smaller carbon footprint, and greater control over comfort, then a ccASHP might be right for your home—see what area homeowners have to say!"
- "The lifetime costs of a ccASHP compared to other heating and cooling systems make it a cost-effective solution—see the pros/cons of ccASHP versus other heating/cooling systems and compare costs."
- "Not all heat pumps are created equal—find contractors that specialize in ccASHPs that are appropriate for this region."
- "Proper operation and maintenance ensures that you get the highest performance and savings from a ccASHP—learn how."

As of late winter of 2022, one video case study was completed, with a second underway. The case study videos are testimonial-based, telling the story of a family or homeowner and their positive experience installing a ccASHP, including results and anecdotal benefits.

The first video, featuring homeowner Tina, focused on a homeowner making her home more sustainable by reducing fossil fuel consumption. It highlighted her primary motivation to switch to a heat pump as a personal approach to addressing climate change, and also touched upon her secondary motivation of safety. She has seen multiple benefits from shifting to cold-climate heat pumps, including addressing some of her environmental concerns, increasing control over comfort, reducing heating equipment maintenance, and having only one energy bill.

The second video, slated to be completed in the spring 2022, will highlight homeowner Seth and his young family. The key theme of this video case study will highlight how a fuel switch leads to better comfort. Seth's primary motivation to switch to a heat pump was discomfort in the home during summer and winter months, while his secondary motivation was moving away from fossil fuels for safety and environmental reasons. The video will highlight Seth's financial ability to purchase heat pumps as a result of available incentives, as well as the convenience of a ductless system including the quick and non-intrusive installation process. Benefits the video will feature include zoned-temperature control for year-round comfort, as well as a secondary, surprise benefit of more ideal nap time conditions for young children as a result of quiet operation.

The videos are likely to be featured in the NYSERDA/Utility Statewide Heat Pump marketing campaign and can be found on the NYSERDA website, where they can potentially be distributed by contractors and other outreach partners. Each video is estimated to last roughly five to seven minutes. The videos can be viewed on NYSERDA's YouTube channel, youtube.com/NYSERDAofficial.

Regarding fact sheets, two concepts were discussed.[17] One fact sheet focused on comparing ccASHPs to other heating and cooling systems and was ultimately developed and published on NYSERDA's website. The focus on equipment comparison was suggested by KSV to address inertia with homeowners when they are due to replace their existing heating and cooling equipment, to help them understand that other options are available to them and that these other options may be more cost-effective and, as shown by the customer survey responses, may involve an easier installation process than replacing the pre-existing system. Framing of this fact sheet focused on "Why switching to a ccASHP is a better choice for your home" and spoke to efficiency, life expectancy of different technologies, installation process, noise level, indoor air quality, operating costs, and other factors highlighting when ccASHPs may be a better technology option for the homeowner as compared to other options.

A second fact sheet—a "Cost and Savings Guide"—was also developed, focusing on addressing customer concerns with upfront installation costs. The draft fact sheet outlined the long-term savings potential of ccASHPs through energy cost savings and maintenance cost savings, while also highlighting rebate and incentive opportunities to reduce equipment and installation costs. The fact sheet also included the installation and cost-savings details of four ccASHP installations—two from the Hudson Valley pilot and two from the downstate New York pilot. This fact sheet was sketched out but ultimately not published, as the number of participating projects in the two pilots represented such a wide array of differing rebates, incentives, and unique project specifics that it was challenging to present aggregate overviews of incentives, costs, and savings.

6 Lessons Learned

The HVHPP's primary goal was to assess the performance of ccASHPs in existing homes in NYS. The findings pertaining to this goal are explained in depth in section 3. However, a number of other findings, or "lessons learned" were also obtained throughout the entire project period. This section summarizes the key lessons and findings that resulted from this project.

6.1 Lessons from Program Design: Customer and Contractor Recruitment

Prior to the HVHPP, the EFG Team had designed and implemented a number of energy-related pilot programs. As a result, many of the program design elements within the HVHPP worked smoothly and with few challenges. However, there were lessons learned regarding contractor and customer recruitment, and as a result of the recruitment process, the EFG Team also experienced a different outcome from the initial goal of a mixture of ducted/ductless systems with and without solar.

For example, the EFG Team had thought that customer recruitment would occur primarily through the contractors bringing interested customers into the HVHPP. This did not occur. Contractors are busy and the additional paperwork, monitoring, and QA visits increased the amount of time required to complete a project for both the contractor and the customer, as well as increased the level of intrusion for the customer. To address this additional level of effort and complication, the EFG Team offered a $500 bonus incentive to contractors, as well as additional incentives for the homeowner. Ultimately, it fell to the EFG Team to conduct significantly more outreach through targeted outreach via environmental volunteer groups and utilities as well as attendance at local events to recruit interested homeowners. Additionally, it fell to the EFG Team (predominantly IBD and BHEC) to repeatedly follow up with contractors to ensure paperwork was completed and any identified QA issues were attended to prior to receipt of the $500 bonus incentive. Fortunately, all projects were completed, and customer satisfaction is generally high.

Regarding contractor recruitment, contractor excitement and interest was generally very strong at the start of the project, but then waxed as the program continued. Again, this is likely due to the mixture of contractors being busy, and the program requiring more of both their (and their customers') time and effort. Fortunately, the EFG Teams' modified approach to address customer recruitment (explained above) also brought in new contractors. For example, upon learning about the HVHPP at various environmental events that the EFG Team attended to recruit participants, homeowners already thinking about heat pumps and who had already identified their preferred contractor, ended up asking their contractors to participate in the program.

It is clear that both a “pull” and a “push” is needed to move the market. Incentives and EFG Team support did assist in ensuring projects were completed by contractors (the “pull”), but customers also needed to “push” their contractor, at times, to participate. It appears as though pilots such as the HVHPP, which require more time and a deep interest in detailing energy and cost savings, are a good fit for “early adopter” contractors and homeowners.

Finally, the EFG Team had originally hoped for a relatively even mixture of 10 ducted and 10 ductless systems with and without solar, as shown in Table 1. Given the additional time and effort needed for these projects, and therefore the challenge to find participants because contractors were not necessarily “selling” the HVHPP, this even distribution did not occur. Rather, the final outcome regarding the presence of solar and the mix of ducted versus ductless was determined by who wanted to participate in the program, and what these homeowners had as home characteristics prior to participating in the HVHPP.

6.2 Lessons from Program Quality Assurance

As discussed in section 2.3, installation contractors did not always follow the best practices recommended through the HVHPP, and the NEEP installation guidelines also changed during the project time frame, so the on-site QA was helpful to address issues of concern and/or deficiencies. The primary areas of focus for the QA included the installation of the outdoor and indoor units as well as the line set, ductwork, and setup. When issues of serious concern were found, contractors were asked to return to the site and correct the identified installation issues. Until this was completed, the $500 incentive bonus was not sent to the contractor. The bonus incentive was a helpful mechanism to acknowledge the additional time and effort required by contractors to install HVHPP projects as well as to ensure installation issues were corrected.

The outdoor units were generally installed well. The few identified issues included:

- The lack of a recommended (but not required) NEEP "best practice" to install surge protectors (17 out of 20 sites had this issue).
- Units that were not installed plumb or with missing fasteners (3 out of 20 sites had this issue).
- Units not placed adequately above the expected snow line (3 out of 20).
- Units that were not adequately installed away from walkways or other areas such that refreezing defrost meltwater might cause a hazard (4 out of 20 sites had this issue).

Proper refrigerant charge procedures that could have a critical impact on performance were questionable, including evacuation, pressure testing, and charging. Some of the field QA challenges included the fact that it is impractical to field check proper procedures at time of installation and to field test for proper refrigerant charge post-installation using conventional testing methods. Some recommended QA actions to consider in the future include photo-documentation of actual refrigerant charging procedures for each system and developing, standardizing, and implementing alternate testing and measuring protocols.

Line sets had few issues. A few homes had thermal insulation within walls that was disturbed by the heat pump installation; for these homes it was not possible to return the site to the exact original condition. Finally, one site had issues with the insulation not running all the way to the outdoor unit, but this was corrected.

As mentioned regarding outdoor unit installations, several sites (10 out of 20) were not properly drained to shed condensate away from the foundations of the homes, and in some cases the units drained onto walkways, creating potential slip hazards during freezing weather (4 out of 20). This was addressed as much as possible during the QA process and may be a helpful point to address in future contractor trainings as NYSERDA continues to support the growth of the ccASHP market in NYS.

Indoor unit installations were rarely problematic with the exception of clearance to the ceiling. At the time of the writing of this report, the NEEP recommendation is a minimum of 6 inches when possible. While this was not physically possible at some sites, at the sites where it was possible it was clear that there is a tendency of contractors to install the units as close to the ceiling as they possibly can, typically as close as 3 inches (as allowed by manufacturer recommendations). This reduces heating efficiency by increasing return air temperature, and while it's not a critical requirement it is certainly a lesson to share moving forward as contractors continue to install ccASHPs in the State.

Of the 20 sites, only one was entirely ducted, while the other was a mixture of ductless and ducted. One of these sites performed quite well with no installation issues of concern. However, there were installation issues with the other site, particularly related to the heat pump air-handlers in the existing ductwork.

There may or may not be a lesson to learn regarding the fact that 90% of the participating sites installed ductless systems. The initial group of contractors who participated in the HVHPP training were a mix of contractors: some offered only ducted systems, some specialized in ductless, while others offered both. Ultimately, the contractor that completed the most HVHPP installations (14 out of 20) specializes in and prefers ductless systems. Therefore, one cannot generalize that, at this time, contractors prefer to install ductless systems over ducted. However, the fact that it is relatively easy to install ductless heat pumps as compared to ducted systems does presumably lend itself to be a preferrable technology for some installers.

The two primary issues regarding setup were both recommended “best practices” and not requirements. These pertained to the lack of wall-mounted thermostats/integrated controls and the fact that the “continuous fan operation” setting was not disabled. To address the lack of wall-mounted thermostats/integrated controls, the EFG Team ensured that for all 18 sites where this occurred, the homeowner was made aware of the correct operation. The issue of disabling the continuous fan operation setting appears to be more challenging to address, as the manufacturer designed the ductless units with continuous fan operation and in order to disable that feature, an irreversible modification would need to be made to the indoor unit. Therefore, this recommendation was not favorably received by the installing contractors, and customers were not advised of this option despite the fact that the modification was suggested by the factory representatives, is supported by the manufacturer, and does not void the warranty.

As part of the QA process, many homeowners took time to discuss their experience with the EFG Team. From these conversations, it is clear that customers need greater training and orientation regarding the various controls and features (for example, the use of the “dry” mode) as well as how best to optimize ccASHP efficiency in relation to the pre-existing heating system. Alas, the results of the contractor surveys suggest that contractors believe they are adequately training homeowners in ccASHP operations. Addressing this gap between customers needing more education and contractors believing they are already providing the necessary training overview to homeowners, is critically necessary to ensure both efficient and effective use of ccASHPs, and customer satisfaction with the technology.

Finally, a significant lesson learned is the poor applicability of ccASHPs as a "displacement" strategy in a house with a steam boiler system. Steam-heat systems cannot be zoned, so heat is delivered to the entire house at once; any rooms where the heat pumps are installed are immediately heated and the heat pumps simply don't operate enough to offset a significant amount of heat. S5 (the one in the project with steam heat) added two ductless units to two that were already in place (and ineffective) and based on the customer interview they still were unable to utilize the heat pumps effectively.

6.3 Lessons from Measured Performance Data

The energy cost savings and implied heating efficiency of the heat pump installations were determined for 15 of the 20 sites using measured heat pump electricity use data as well as pre- and post-retrofit utility bills and fuel delivery logs. At the other five sites savings estimates were confounded by behavioral or occupancy changes between pre- and post-retrofit periods as well as other issues with secondary fuels, such as irregular wood stove use. These issues occurred even though the project team carefully screened potential sites up front in an effort to minimize these risks. The findings from this study show that pre- and post-savings analysis methods are still subject to uncertainties and unknowns that cannot always be foreseen—even with careful upfront screening of sites.

The savings analysis from this study point to several key findings and lessons:

- The implied seasonal heating COP of the 15 HPs ranged from 1.7 to 2.6 with an average of 2.1. The seasonal average heating efficiency averaged 63% of the published heating seasonal performance factor (HSPF) for each ccASHP unit. This provides an approximate metric to gauge what heating efficiency (and savings) can be expected in NYS based on the manufacturer's published HSPF values.
- Cost savings were highest when the displaced fuel was electric, propane, or fuel oil. Cost savings were either negative or very small when the displaced fuel was natural gas. The normalized heating savings per installed ton averaged $300 when the displaced fuel was electric and costs increased by $100 when the displace fuel was natural gas. The survey results demonstrated that reducing fossil fuel use and greenhouse gas emissions was a primary motivator for many homeowners in this study. However, it seems that large scale adoption of ccASHPs will depend on homeowners realizing at least positive cost savings to offset higher capital costs. Positive cost savings for natural gas requires a seasonal COP over 2.5, which may be achievable with some equipment but is on the high end of what was measured in this study.

- Most ccASHP systems were designed and installed to displace, but not fully replace, the original heating system. On average the ccASHP systems displaced 85% of the original fuel use. In most cases the fuel reductions at each site were fairly well aligned with the original design intentions. However, three sites that intended to fully replace the original heating system still had significant fuel use (between 30–40% of pre-retrofit fuel use). Better feedback is needed to installers to ensure the ccASHP systems designed to fully displace fossil fuel use can meet this expectation.
- Customer behavior has a significant effect: at one site where the homeowner had intended to fully heat the home with heat pumps, the oil heating only dropped by 33% the first winter. After program staff coached the homeowner about thermostat settings, the fuel reduction for the second winter increased substantially to 62%. This highlights the importance of occupant training.

6.4 Lessons from Homeowner Perceptions and Motivations

The customer surveys revealed some key findings:

- This set of homeowners were driven to install heat pumps, in large part, by a desire to reduce fossil fuel use and greenhouse gas emissions. Energy cost savings and increased comfort was also a factor in their decision to install heat pumps.
- Customers were generally satisfied with the installation contractor and did not find the installation process to be more inconvenient than for conventional heating systems.
- Customers found maintenance and operation of the heat pumps to be relatively easy, and no more difficult to maintain than their original systems.

Participants had a range of satisfaction levels with their original heating systems and generally expected to see their desired temperatures improved by installing the heat pumps. However, desired temperatures were not always achieved in every room of the entire home, most likely due to the distribution limitations of ductless units. Two homeowners stated that their desired heating temperature had slightly worsened when compared to their previous heating system. Nevertheless, 80% of the homeowners in the final survey reported that they are "very satisfied" with their air source heat pump systems, and all were either "somewhat satisfied" or "very satisfied." The disparity between their overall satisfaction and their more mixed reports of comfort suggest that consumers need to be educated to better understand the benefits and limitations of ductless heat pumps that replace central heating systems—especially when converting a baseboard hydronic heating system to a ductless unit.

Generally, homeowners' perception of energy and cost savings were in reasonable alignment with the actual measured savings. One exception was site S14, a homeowner that formerly used propane for heating and had the highest cost savings of any home in the study. Their perception was that their electric bill increased more than they expected. Because heating with propane is more expensive than operating the heat pump, that represents a net *benefit* to the homeowner that they don't seem to fully grasp. This highlights a key issue with heat pumps: emotionally preparing customers for the inevitable increase in wintertime electric bills that will accompany the anticipated decrease in their fuel bills. This is especially critical with delivered fuels, for which the decrease may take months to realize, while electric bills increase rapidly. A clear message for any existing heating fuel other than natural gas should be "the more you use the heat pump the more money you save."

6.5 Lessons Learned on Contractor Perceptions and Motivations

The contractors who initially participated in the HVHPP varied in a number of ways: regarding their previous experience with ccASHPs, their business goals, marketing approach, and customer interactions. While the HVHPP initially established relationships with four installation contractors, ultimately the program interacted with six installation companies.

As discussed previously in section 4.2, the contractors who responded to the HVHPP Contractor Survey are generally confident in their business offerings and their awareness of heat pumps (sizing, installation, application, design, and customer training). Nevertheless, they still found some of the customer-facing published materials and a few key "tricks" they learned through the program to be helpful and useful (e.g., the NEEP guides and suggestions such as sizing adjustments). Their approach to educating customers and explaining how to efficiently operate heat pumps was not significantly altered, but supported and slightly augmented by the HVHPP, and they plan on continuing to use the resources made available.

Their experience indicates that customers are interested in heat pumps for a range of reasons, but that comfort, convenience, and energy and financial savings ultimately drive the customer's decision to install. Their primary business development tool is "word of mouth," although they all undertake other marketing efforts and initiatives such as attendance at home shows and other forms of advertising. While they are fairly confident about their heat pump knowledge and expertise, they generally feel that New Yorkers overall, as well as other residential HVAC contractors who do not currently offer ccASHPs, are not aware of the potential comfort and savings that ccASHPs can provide.

Of the three responses to the question, “Do you recommend a comprehensive approach that pairs a heat pump installation with weatherization and/or solar to your clients?” two said “yes” while one said “no.” The two that replied affirmatively explained that they suggest weatherization because it will improve ccASHP performance (and, by extension, customer satisfaction). The remaining respondent stated he focuses solely on heat pumps because otherwise it is “too much for a person to digest at once.”

Responding contractors mentioned two primary customer barriers (upfront cost and customers’ lack of awareness) and three critical opportunities for NYS support:

To have more case studies showing energy and cost savings, as well as customer experience with the technology that demonstrate the advantages and capabilities of ccASHPs in colder climates, and to have these widely promoted and shared by trusted resources such as NYSERDA and local utilities.

To have greater rebate offers and access to low-interest financing.

To have a savings tool, such as an annual energy savings calculator that would compare heating and cooling operating costs for ccASHPs to other common heating and cooling systems.

In sum, the primary lessons learned from the contractors participating in this program are as follows:

- For contractors already offering ccASHPs, they are generally confident with their business model, offerings, and expertise.
- If NYSERDA is interested in driving market adoption, contractors believe that having actual, proven energy and cost savings results (as well as customer testimonials regarding their overall experience) widely advertised is a critical, key next step. This would build customer confidence in the technology and estimated savings, thereby increasing market uptake.
- If NYSERDA is interested in driving market adoption, assisting in the upfront installation cost via increased rebates and access to low-income financing products were recommended.

7 References and Bibliography

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., 2020. "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.

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

Appendix A. HVHPP Program Documents Used to Identify and Recruit Sites

A.1 Outreach List: List of Entities and Events Utilized to Market Program and Identify Participants and Sites

Abundant Efficiency
Catskill Mountain Keeper
Citizens for Local Power
Energize NY
Hudson Valley Community College
Interfaith Earth Action
Maris College
New Paltz Climate Action Committee
Northeast Chapter of ASHRAE - Albany
Our New Energy Fair - April 2018
Pace University
Rensselaer Polytechnic Institute
Rensselaer Renewable Energy and Sustainable Living Fair - Oct 2017. Sponsors included 350.org/People of Albany United for Safe Energy, Citizen's Climate Lobby, Stop NY Fracked Gas, and Albany Bicycle Coalition and other names presented in this overall list.
Rural Ulster Preservation Company
Siena College
Sierra Club Atlantic Chapter
Skidmore College
Solarize Albany
Solarize Saratoga
Solarize Schenectady
State University of New York - Albany
State University of New York – New Paltz
Sustainable Hudson Valley
Sustainable Saratoga
Vassar

A.2 Program Overview Documents for Customers and Installation Contractors

Hudson Valley Heat Pump Project
Program Overview

Background

Residential customers in New York state now have an opportunity to increase the comfort in their homes while saving energy and money. Through the installation of cold climate heat pumps--optionally combined with additional improvements such as air sealing and insulation and solar photovoltaics--many New York homes can now be more comfortable, efficient and affordable. This program offering involves technical support and design review for each project – before, during, and after the project is completed. The goal is to help you, as a homeowner, improve your comfort and save on operating costs.

Who is offering this program?

This program is a partnership involving several businesses, overseen by the New York State Energy and Research Development Authority (NYSERDA). As a customer, you'll work most closely with your heat pump installation contractor. If your house needs weatherization or you include a solar photovoltaic array in the project, there will be additional contractors to provide those services.

In addition, the NYSERDA team includes technical experts to provide design support to your heat pump installer, and install monitoring equipment to help measure its performance.

One objective of this project is to provide better understanding to the public about the benefits of cold-climate heat pumps. KSV is a marketing firm assisting with this goal; they may interview you or take photos or videos of your home (with your permission) to help tell this story.

Who can participate?

Up to twenty homeowners who live in the Albany and Hudson Valley areas of New York State are eligible.

What is the timeline?

Installation contractor businesses and homeowners will be identified and selected through May 2018 , with installations occurring ideally prior to summer 2018.

What are the benefits to participating?

- Improve comfort of your home, reduce utility bills and operating costs of heating and cooling equipment
- A discount of $350/ton (up to $1,000 per home, usually) is available for the “best in class” cold climate heat pump installation;
- Assistance and coordination in identifying other incentives (e.g. solar federal tax credits, local utility incentives, NYSERDA Home Performance with ENERGY STAR incentives and low-interest loans);
- Experts with 25+ years’ experience in building science will provide technical support for the design of your project to help you save the most energy at the most reasonable cost and accurately track and record the energy savings of your home
- Access to a web-based system that tracks the energy use of your heat pump. If you wish, select monitoring system components may be left in place for your use after the project is completed.

What are the requirements to participate?

- Working with one of the local installation contractor businesses who have been trained to participate in this program
- Allowing data monitoring of your energy savings and usage for at least one year
- Participating in pre-construction and post-construction surveys
- Providing two years of past fuel and electricity bills, and access to future bills for at least one year
- Allowing program-related staff to come visit your home (for example, to develop a project scope of work with specific design requirements, to install monitoring devices, to provide follow-up inspections, and perhaps to interview you for about your experience in your upgraded energy-efficient home)
- Some homeowners will be asked to allow photographs and video during the assessment, installation, and/or interview to be used in promotional materials.

How to Learn More:

Contact Gabrielle Stebbins at gstebbins@energyfuturesgroup.com and 802 825 9515

Hudson Valley Heat Pump Project
Program Overview

Background

Leading HVAC contractors now have the ability to work with Mitsubishi and a team of building science experts in a program to help the New York State Energy and Research Development Authority (NYSERDA) develop a new heat pump program for residential customers in New York state. Through the installation of cold climate heat pumps, optionally combined with additional home improvements such as air sealing and insulation, or solar photovoltaics, many New York homes can now be more comfortable, efficient and affordable. This program offering involves training, technical support and design review for each project – before, during, and after the project is completed. The goal is to help understand homeowner benefits of heat pumps, provide support and market exposure to the installing contractor partners, and to provide resources for NYSERDA to promote better market understanding of the benefits of air source heat pumps.

Who is offering this program?

This program is a partnership involving several businesses, as highlighted below:

Business Name	Description of Role
Energy Futures Group	Lead on overall program implementation
Local Installation Contractor business – you!	Coordinates and installs heat pump with design and evaluation businesses
Bruce Harley Energy Consulting, Integral Building and Design	Technical Design and Review team
CDH Energy	Evaluation and Data Monitoring
KSV	Marketing Project Results
Mitsubishi Electric Cooling & Heating	Manufacturer of Heat Pump and Provider of Incentives

New York State Energy and Research Development Authority (NYSERDA)	Program oversight and funder
Solar and/or home performance contractors	Optionally, depending on home and customer needs, additional contractors may provide key home energy upgrades and solar electric (photovoltaic) installation.

Who can participate?

Up to twenty homeowners who live in the Albany and Hudson Valley areas of New York State.

What is the timeline?

Installation contractor businesses and homeowners will be identified and selected through August 2017, with installations occurring from July 2017 – November 2017.

What are the benefits to participating?

- Getting in as one of the first contractors participating in NYSERDA's new heat pump initiative
- Offering additional equipment discounts to your customers
- Enhancing your understanding of cold climate heat pumps – helping you to increase your value to customers
- Potential marketing exposure of your company through a broad cold climate heat pump campaign
- Real-time monitoring of each heat pump installation with web access to performance data

What are the requirements to participate?

- The participating HVAC installer must utilize Mitsubishi equipment (and preferably be Mitsubishi Diamond qualified)
- Attend a training to understand the program
- Work with the various businesses involved to meet the goals of the program
- Being open, willing, and interested in learning more about more comprehensive home energy savings and cold-climate heat pumps in particular
- Optionally, being willing to participate in on-camera documentation of the installation process and/or case study interviews

What’s in this for your customers?

- A discount of $350/ton (up to $1,000 per home, usually) for the "best-in-class" cold climate heat pump; additional discounts on thermostat controls
- Assistance and coordination in identifying other incentives (e.g. solar federal tax credit, local utility incentives, NYSERDA Home Performance with Energy Star incentives and low-interest loans)
- Experts with 25+ years' experience in building science to provide technical support for the project design to help homeowners save the most energy at the most reasonable cost and data monitoring systems to accurately track savings
- Access to the web-based monitoring system; select system components may be left in place for the customer's use after the project is completed, if they wish

What do your customers need to know about participation?

- They must work with a Mitsubishi installation contractor who has been trained to participate in this program
- They will be asked to participate in two customer surveys (pre- and post-construction)
- A data monitoring company (CDH Energy) will need to install and monitor energy savings for at least one year
- They must be able to provide 24 months of historical fuel usage
- They may be asked to participate in an interview by a marketing firm (KSV), and to allow photographs/filming of their home, to help spread the word about these technologies and potential energy and dollar savings.

How to Find Out More:

Contact Gabrielle Stebbins: gstebbins@energyfuturesgroup.com & 802 825 9515

A.3 Memorandum of Understanding

Memorandum of Understanding

Energy Futures Group and (INSTALLATION CONTRACTOR)

This Memorandum of Understanding (MOU) is entered into by and between:

- Energy Futures Group, an energy consulting company based in Hinesburg, Vermont;
  and
- INSTALLATION CONTRACTOR based in XX.

A. Purpose

This Memorandum of Understanding (MOU) sets forth the terms and understanding (roles, responsibilities, reporting requirements, funding and time frame requirements) between Energy Futures Group and the (INSTALLATION CONTRACTOR) as they pertain to the execution and oversight of energy retrofit activities at one or multiple homes in New York State as part of the “Hudson Valley Heat Pump Project” as part of the New York State Energy Research and Development Authority Program Opportunity Notice #3127.

B. Roles and Responsibilities

Energy Futures Group (EFG) is the prime contractor responsible to NYSERDA for overall program delivery (including program design, implementation and reporting) pertaining to the Hudson Valley Heat Pump Project.

INSTALLATION CONTRACTOR is part of the overall EFG Team delivering the program in New York State. INSTALLATION CONTRACTOR’s role is multi-fold:

- To identify Hudson Valley homeowners who may be interested in participating in the Hudson Valley Heat Pump Project
- To ensure that each participating homeowner is willing to:
    - Provide 18-24 months of fuel use data prior to project start
    - Complete a pre-project and post-project customer survey
    - Sign a Site Agreement Form with EFG
    - Allow for various members of the project team to gain access to their property and/or to interview them for the purposes of the following (every attempt to

coordinate these site visit dates will be made to minimize any inconvenience for the homeowner):

        - Site reconnaissance
        - Technical Problem Solving
        - Installation and Maintenance of Data Monitoring Equipment
        - Follow-up inspections
        - Obtaining footage for marketing initiatives

- To oversee subcontractors, coordinate with other installation contractors, and/or to execute energy retrofit projects directly. Work may include:
    - Installation of cold climate air source heat pumps (working with Mitsubishi Electric)
    - Weatherization (working with Home Performance with ENERGY STAR services)
    - Installation of solar photovoltaics
    - Other energy retrofit project determined with customer and EFG team
    - Completion and signing of relevant forms and documents required to show project execution and advancement
- To attend the Hudson Valley Heat Pump Project training – held in or near Albany, New York (maximum time commitment: 4 hours)
- To be, or to become a Mitsubishi Diamond contractor (or similar, as may be approved by EFG)
- To ensure the Mitsubishi discount is transferred in full to the homeowner
- To assist, as applicable, the homeowner in obtaining other available incentives and discounts that may be applicable
- To work with the EFG team (Bruce Harley Energy Consulting, Integral Building Design, Mitsubishi, KSV) and CDH Energy to ensure that project work scope(s) and data monitoring plans are understood and to adhere to these plans
- To be willing to work in a collaborative fashion with the EFG team (primarily Bruce Harley Energy Consulting and/or Integral Building Design, and subject to approval required by NYSERDA) in the final development of the project work scope including (but not limited) to agreeing to and assisting in coordinating at least one site visit with relevant EFG team members
- To be willing to participate in on-camera documentation of the installation process and/or case study interviews giving all parties full rights and usage to marketing assets (e.g. film, photographs) for use in promoting heat pumps and weatherization in New York state
- To complete the design and installation using best practices as covered in the project training, or as may be communicated by the EFG team from time to time during the program
- To complete the necessary documentation and reporting required for projects
- If needed, to be willing to return to the project after project completion if it appears that a technical issue with the heat pump or other work is interfering with efficient operation (this may be identified, for example, through data obtained from the data monitoring analysis) and to commit to working in good faith to achieve a resolution
- To complete a contractor survey with EFG
- To agree to the following flow-down requirements from EFGs contract with NYSERDA:
    - Indemnification: The Contractor shall protect, indemnify and hold harmless EFG, NYSERDA and the State of New York from and against all liabilities, losses, claims, damages, judgments, penalties, causes of action, costs and expenses

(including, without limitation, attorneys' fees and expenses) imposed upon or incurred by or asserted against EFG, NYSERDA or the State of New York resulting from, arising out of or relating to Contractor's performance under this MOU.

- Maintenance of Insurance; Policy Provisions: The Contractor, at no additional direct cost to EFG, shall maintain or cause to be maintained throughout the term of this Agreement, insurance of the types and in the amounts specified in the Section hereof entitled Types of Insurance, including:
  - Commercial general liability insurance for bodily injury liability, including death, and property damage liability, incurred in connection with the performance of this Agreement, with minimum limits of $1,000,000 in respect of claims arising out of personal injury or sickness or death of any one person, $1,000,000 in respect of claims arising out of personal injury, sickness or death in any one accident or disaster, and $1,000,000 in respect of claims arising out of property damage in any one accident or disaster; and
  - Workers Compensation, Employers Liability, and Disability Benefits as required by New York State.
- Compliance with and adherence to all relevant and applicable local, state and federal laws.

C. Reporting Requirements

EFG is required to provide monthly updates, a draft report, a final report and a Technology Transfer Plan to NYSERDA.

To complete this reporting process, INSTALLATION CONTRACTOR will be required to provide signed project documentation materials as described above, and to assist in providing additional feedback and coordination as necessary.

D. Funding

There shall be no exchange of funds between EFG and the INSTALLATION CONTRACTOR. However, INSTALLATION CONTRACTOR is required to ensure that the Mitsubishi discount is transferred in full to the customer. It is the INSTALLATION CONTRACTOR's responsibility to develop and ensure an appropriate project agreement with the homeowner and to be paid directly by the homeowner.

E. Timeframe

The general timeframe for the entire project is 24 months as provided below. The effective project start month is March 2017. While INSTALLATION CONTRACTOR does not necessarily have a specific task or deliverable assigned entirely and solely to INSTALLATION CONTRACTOR, INSTALLATION CONTRACTOR's support and participation will be important before, during and after the installation work is completed (as defined above). It is expected that the INSTALLATION CONTRACTOR will work as expeditiously and efficiently as possible while meeting the requirements of this program, as defined above.

This Memorandum of Understanding is the complete agreement between Energy Futures Group and INSTALLATION CONTRACTOR and may be amended only by written agreement signed by each of the parties involved.

In witness whereof, Energy Futures Group and INSTALLATION CONTRACTOR have caused this Memorandum of Understanding to be executed.

FOR ENERGY FUTURES GROUP	**FOR INSTALLATION CONTRACTOR**
______________________________	______________________________
Signature	**Signature**
______________________________	______________________________
Printed Name	**Printed Name**
______________________________	______________________________
Title	**Title**
______________________________	______________________________
Organization	**Organization**
______________________________	______________________________
Date	**Date**

A.4 Site Agreement Form

Site Agreement: Hudson Valley Heat Pump Project

(Under NYSERDA Agreement # 104082)

Parties: ________________________________ at (Address ____________________ ___________________________________, City _____________________, New York, Zip ________________) (Site Owner) and Energy Futures Group (Hinesburg, Vermont)

The New York State Energy Research and Development Authority (NYSERDA) is sponsoring an Emerging Technologies Program to demonstrate reducing fossil fuel heat usage with mini-split heat pumps in coordination with other efficiency measures and potentially solar photovoltaics, 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 heating systems and window air conditioners.

Energy Futures Group (EFG) is under contract to NYSERDA to coordinate this project and work with site owners, Installation Contractors, a measurement and verification (M&V) contractor hired by NYSERDA to install monitoring equipment and evaluate system performance, and a marketing firm to help "tell the story" about energy savings and increased comfort in participating homes. This Agreement outlines the responsibilities of the Site Owner and EFG under this project. This obligation commences on the date this Agreement is executed and shall continue for 14 months after the retrofit system(s) become operational.

Effective as of the date of this Agreement, Site Owner and EFG enter into this Agreement agreeing to work jointly as follows:

- **Responsibilities of Energy Futures Group:**

Energy Futures Group, in collaboration with project Installation Contractor ____________________________, and subcontractors Bruce Harley Energy Consulting, Integral Building & Design, and KSV, 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. **Measurement and verification:** Facilitate access to sites for M&V contractor and provide support to M&V contractor. Ensure customer is aware that M&V contractor (Frontier Energy) has installed the monitoring equipment, and conduct a pre- and post-construction survey with the homeowner.
3. **Documentation and promotion of results:** Facilitate access between KSV and Site Owner in the event the project site is chosen for filming and interviews to help "tell the story" regarding the energy and financial savings of these technologies and improvements in home comfort.
4. **Confidentiality.** Site owner's address will not be released in any publicity materials, and site owner will have the opportunity to review and approve any release of their name and/or personal photo in any publicity or related materials.

- **Key EFG contacts:** Richard Faesy: rfaesy@energyfuturesgroup.com 802 482 5001 x 2

- **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 EFG, NYSERDA and/or its agents/guests for inspections, data collection, documentation, and installing and retrieving monitoring equipment.
2. **Operation and maintenance.** Operate the retrofitted heat pump and other equipment (if present) equipment as intended by the design and in keeping with manufacturer's instructions and homeowner operation guide. Maintain equipment in good working order; notify the Installation Contractor should any problems occur with the newly installed equipment or materials and facilitate repair/correction by Installation Contractor or its subcontractor(s) as needed.
3. **Provide energy data.** Provide to EFG energy bills (electricity, natural gas, propane, oil, etc.) for the building for 18-24 months before, and a minimum of 18 months after, the completion of the retrofit work. Allow the temporary installation of sensors and data loggers on heating, cooling, electrical and ventilation equipment. It is understood that aggregated or individual site data will be published in reports produced by EFG, Frontier Energy, and/or NYSERDA, and that individual site data will only be included anonymously.
4. **Facilitate occupant survey.** Facilitate and participate in occupant surveys or interviews to be conducted by Frontier before and after the retrofit work.
5. **Publicity.** If the project site is chosen by the marketing firm, KSV, to illustrate the savings and comfort improvements achievable through these energy retrofit technologies, be willing to participate in an interview conducted by KSV and/or allow KSV to film and photograph the site before, during, and/or after construction.

  - **Key Site Owner contact(s):**

    Name:

    Name:

  - **Site Address(es):**

- **Title to equipment and disposition of data**

Title to all retrofit equipment and materials including heating and cooling equipment, ventilation equipment, insulation and air sealing materials installed under this project shall rest with the Site Owner, however subject to any and all terms and conditions in Site Owner's contract(s) with Installation Contractor, their subcontractors, or other installer entities, as applicable.

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, except as noted below, and shall be removed by the M&V contractor or their designee at the conclusion of the project period. The exception to this is that title to the web-enabled heat pump monitor(s) shall rest with EFG. The web-enabled heat pump monitor(s) and associated equipment may, at the conclusion of the project, be left at the home for the Site Owner's use at which time the title will rest with the Site Owner. In the event that the Site Owner takes title to the web-enabled heat pump monitor at the conclusion of the project under these terms, all liability and responsibility associated with ownership of that equipment shall be transferred to the Site Owner.

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 Energy Futures Group 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 Agreement shall incur any legal obligations under this Agreement. Neither this Agreement nor EFG's actions in the conduct of this project imply responsibility for the work of any project suppliers or contractors.

The above is agreed to and accepted by:

____
Print Name:
Print Title:

Date: __________________________, 2019

____
Richard Faesy
Energy Futures Group

Date: __________________________, 2019

A.5 Customer Fuel Release Authorization Form

Fuel Release Authorization Form

Property Information:

Property Address	City	State	Zip
Designated Representative/Property Owner for Info Release	**Contact Phone**	**Contact E-mail**	

Energy Provider Information:

Electric	**Electric Utility Company**	**Account Number**		
Account Name	**Account Mailing Address (if different from above)**	**City**	**State**	**Zip**
Other account numbers associated with this property (if applicable):				
Natural Gas	**Natural Gas Utility Company**	**Account Number**		
Account Name	**Account Mailing Address (if different from above)**	**City**	**State**	**Zip**
Other account numbers associated with this property (if applicable):				
Oil	**Oil Provider**	**Account Number**		
Account Name	**Account Mailing Address (if different from above)**	**City**	**State**	**Zip**
Other account numbers associated with this property (if applicable):				
Propane	**Propane Provider**	**Account Number**		
Account Name	**Account Mailing Address (if different from above)**	**City**	**State**	**Zip**
Other account numbers associated with this property (if applicable):				
Solar/Other	**Solar/Other Installer**	**Account Number (if applicable)**		
Account Name	**Account Mailing Address (if different from above)**	**City**	**State**	**Zip**
Other account numbers associated with this property (if applicable):				

By signing this form, I hereby authorize Energy Futures Group (EFG) and Frontier Energy or their designated representative, to obtain energy usage, energy production and cost data, on my behalf, regarding my property's past and present energy usage for the purpose of analyzing and assessing energy use and production at my property as part of the Hudson Valley Heat Pump Program. This data shall be kept confidential and shall not be shared with any third parties other than those designated by EFG. The data *may* be published in aggregate form with all individual information removed.

First and Last Name	
Signature	**Date**

A.6 Contractor Training Webinar

Hudson Valley
Heat Pump Project
(HVHPP)
Installer Orientation

Richard Faesy, Energy Futures Group
Bruce Harley, Pasquale Strocchia
06/22/2017

1

Program Overview

Richard Faesy, EFG

2

Welcome & Overview

- Welcome (Scott Smith)
- Overview (Richard Faesy)
  - Program objectives, standards, criteria, benefits, overview details, timeframe
  - Introductions
- Project Process and Documentation(Pasquale Strochia)
  - Project steps, eligibility, customer agreement, site description forms
- Design and Installation Guidelines (Bruce Harley)
  - Sizing and installation guidance, customer education
- Coordination with Home Performance, Solar PV, Utilities (Pasquale)
- Lunch and Wrap-Up

3

Program Objectives

- Install air-source heat pumps in 20 Hudson Valley homes
- Understand and demonstrate viability and cost effective savings opportunity
- In order to:
  - Increase awareness, understanding and confidence in the technology among customers, contractors, and public
  - Support and market exposure for contractors
  - Provide resources for NYSERDA to better promote benefits over time

4

Program Partners

- NYSERDA – (Scott Smith) program sponsor
- Energy Futures Group – Lead (Richard Faesy, Gabrielle Stebbins)
- Bruce Harley Energy Consulting, Integral Building & Design - Tech Team
- CDH Energy - Performance validation
- KSV Communications – Marketing, Technology Transfer
- Mitsubishi Electric Cooling & Heating (Mike Gamberoni) support, incentives
- HVAC Contractors
- Solar PV contractors

5

Contractor Introductions

- Name
- Business
- Service area
- Experience with heat pump installations, weatherization, solar

6

House Participation Criteria

- 20 one- or two-family homes, Hudson Valley and Albany area
- Year-round, owner-occupied only
- Heated primarily with oil, LP gas, or electric resistance (baseboard or electric furnace).
  - Existing wood stove supplement or natural gas will be considered
- Participant homes must either be
  - reasonably weatherized already, or
  - willing to address major thermal/enclosure issues by participating in the Home Performance program

7

Participation and Time Line

- Scope
  - Heating displacement, or full replacement
- Targets:
  - Half with ducts, half ductless
  - Up to half may include solar PV installation
- Installations to occur through approximately November 2017
- ...Parallel project in NYC for additional 20 homes

8

Benefits of Participating

- Be one of the first contractors involved in NYSERDA's new heat pump initiative
- Offer additional equipment discounts to your customers
- Enhance your understanding of cold climate heat pumps – increase your value to customers
- Potential marketing exposure of your company through a broad heat pump campaign
- Real-time monitoring of each heat pump installation with web access to performance data

9

What We Ask of You

- Utilize Mitsubishi equipment (preferably be Mitsubishi Diamond qualified)
- Attend an orientation to understand the program
- Sign Memorandum of Understanding (MOU)
- Work with the partner businesses to meet the goals of the program
- Being open, willing, and interested in learning more about more cold-climate heat pumps and comprehensive home energy savings
- Optionally, being willing to participate in on-camera documentation of the installation process and/or case study interviews

10

Customer Benefits

- A discount of $350/ton; additional discounts on thermostat controls
- Assistance / coordination identifying other incentives (e.g. solar federal tax credit, local utility incentives, NYSERDA Home Performance, etc.)
- Experts with 25+ years' experience in building science provide technical support for the project design - to help save the most energy at the most reasonable cost
- Access to the web-based monitoring system
  - Select system components may be left in place for the customer's use after the project is completed, if they wish

11

What We Ask of the Customer

- Work with a Mitsubishi installation contractor who has agreed to participate in this program
- Participate in two brief customer surveys (pre- and post-construction)
- A data monitoring company (CDH Energy) will need access to the house (1/2 day) to install and monitor energy savings, and after ~1 year to remove
- Provide 18-24 months of historical fuel and electric usage/bills
- They may be asked to be interviewed by a marketing firm (KSV), and to allow photographs/filming of their home for promotional materials

12

Project Process and Documentation

Pasquale Strocchia

13

Overview of Project Steps

- Contractor identifies sites for participation, using:
  - "Site Selection Criteria" to qualify site
  - "Program Description" for customer
- Contractor submits "Contractor Site Proposal Form" to Tech Team
  - Tech team visits first site for each contractor before job is completed
- Tech Team reviews and approves proposal, finalizes workscope and "pre-improvement site description" form
- Customer signs site agreement (EFG coordinates)
- Contractor completes work with Tech Team available as resource
  - Post-improvement site visit (QA) by tech team
- CDH installs monitoring equipment (EFG coordinates)

14

Project Home guidelines

- Residential Homes, 1-2 Family, 3 stories or less in height
- Home has pre-existing year-round occupancy of at least 18 months
  - Owner willing to release fuel and electric bills 18 24 months prior to work
- Oil, LP gas, and/or electric resistance heat preferred
- Reasonably energy-efficient or weatherized construction:
  - (1) Built since 1995
  - (2) 1970 and 1995: with a Home Energy Audit (HPwES) recommended
  - (3) Prior to 1970: Home Energy Audit required
  - Basically, if there are major thermal problems with the home, they should be willing and have resources available to correct: attic, wall insulation, air leaks

15

Not Eligible:

- New homes or additions (not been occupied in use for at least 18 months)
- Multi family buildings, homes greater than 2 units, or higher than 3 stories
- Homes with significant identified thermal problems that cannot be resolved as part of the project work scope
- Significant commercial / non residential use on meter (eg: detached work studios). Home offices OK.
- Identified life safety concerns (unless remidiation is part of the project work scope)
  - Pollutant hazards or other issues (eg: exposed asbestos, etc)
  - Substantial moisture problems including mold/mildew like conditions or active water leaks
  - Structural, combustion safety concerns
- House location beyond the Mid to Upper Hudson Valley, NY
- Seasonal homes or other houses that are not occupied regularly

16

Qualified Products

- NEEP cold-climate heat pump listing. Mitsubishi units for this project that qualify are
- M-series, single zone, ductless*
  - KJ models, all sizes (9, 12, 15, 18)
  - FH models, all sizes (6, 9, 12, 15, 18)
- M-series, multi zone:
  - MXZ C (H2i) most sizes (24, 30, 36, 42) – ductless*
  - MXZ C (H2i) **36 – mixed ducted and ductless**
- P-series: HA model 3-ton (PUZ-HA36NHA5) with multi-position AH

* note: mini-duct or mixed systems may be approved as appropriate

17

Customer Agreement Form

- Utility bill / energy delivery information release
  - Important: past bills / delivery records
- Agreement for access to home
- Parties:
  - Customer
  - EFG
- EFG will follow up with customer if needed to answer questions, complete signing

18

Pre-Improvement Site Description and Proposal Forms

- Site Description
  - Basic dimensions and thermal properties of house
  - Existing HVAC equipment inventory
- Proposal
  - List of specific recommended improvements
  - Equipment models, location
  - Zoning as applicable

19

The picture can't be displayed.

Run through forms on screen...

20

Installation Guidelines

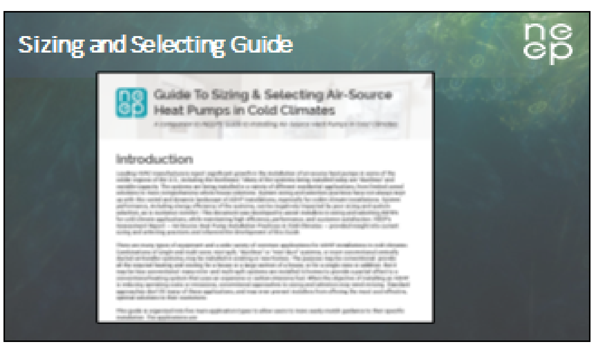
Bruce

21

Installation Guidelines

- Generally follow NEEP installer guidelines
  - We will go over these later
- Emphasis on successful savings
- Homeowner operation checklist
  - To leave with customer to help understand their responsibilities and best operation of their systems
- Post-installation site checklist
  - Tech Team will confirm best practice installation in follow up visit

22



23

24

NEEP Sizing/Selection Guide – key points

- For this program, most (or all) will be heating displacement
- Ensuring it gets utilized:
  - Don't oversell zones; mostly 1-3 depending on house
  - Don't oversize for zone (especially individual bedrooms)
  - Customer education and/or integrated controls
- Strategic location for heating: biggest open area on lower floor
  - Then other major areas: basement living space; family room; master bedroom
- Undersizing somewhat for heating should improve efficiency and reduce overall heating costs – provided the heat pump is *used*

25

Load Calculations

- For this program, only required when heat pump is sole source of heat for the home or zone (e.g. full replacement for a zone)
- Sizing based on performance data for outdoor design temperature
  - NOT nominal capacity

26

Other design condsiderations:

- "Stranded" water pipes in basement
  - If the first/lower floor is entirely served by ASHP, basement may get much colder
  - Address by keeping central heat as cold weather backup (undersizing the heat pump *helps*)
- Also, air sealing basement perimeter (foam at sill!)
- Indoor distribution for optimal heating and utilization

27

Indoor distribution

- Consider floor-mount, especially for larger open spaces on 1st floor

28

Indoor distribution

- Mini-duct system for most bedrooms:
  - Loads are typically much smaller than indoor heads
  - Similar or lower installed cost
  - Reduce size of outdoor unit, or free up capacity for heating on lower floors
- Insulate and seal thoroughly!

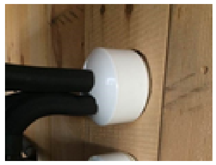
29

Installation Guide

30

NEEP Installation Guide – key points

- Purge/charge procedures – follow manufacturer's guidelines!
- Protection of line set outside the house (physical and UV)
- Rodent-proof line set entry:



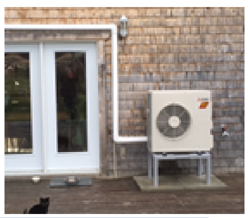
31

NEEP Installation Guide – key points

- Free air flow; protection from snow/ice/drip; elevation and noise

32

Wall mount or stand – aim for 24" minimum:



Beware frost heave w/stands

33

Drip Caps

- Especially where eave drip can't be avoided
- Little need for pan heaters

- Photo: Efficiency Maine

34

Controls (better utilization and comfort)

- Homeowner (checklist)
- Wall-mount for larger spaces (e.g. MHK1)
  - Sense temperature at control, make it relevant to the whole space
- Integrated control
  - Mitsubishi still in prototype stage
  - Maine program has used Honeywell 2 stage heat pump thermostat (at location of existing, wired to central system) – with wireless temperature sensors – for both ASHP & central system. Let us know if you are interested.

35

Other installation – key items

- Surge suppressors (typically at service disconnect)
- Disable continuous fan operation (esp. with wall thermostat)
- Homeowner education:
  - Thermostat settings for utilization
  - Heat / Cool per season (not "auto")
  - Generally avoid temperature setbacks (but OK in mild weather)
  - Fan speed on "auto"
  - Keep ductless supply air vanes wide open (as comfort allows)

36

This... to avoid this:

37

Installation and Homeowner Checklists

38

Coordination with Home Performance, Solar PV, Utilities

Pasquale

39

Lunch and Wrap-up

40

A.7 Site Selection Criteria Form

HVHPP			
Site Selection Criteria Form (Guidance Doc)			
Intro: Project Description			
	20-Site Demonstation Project in the Hudson Valley		
	Use of Air-Source Heat Pumps (ASHP) to displace use of fossil-fuel or electric resistance heating systems while increasing air conditioning efficiency		
	Demonstration of best practice HVAC installations		
	Homeowner / customer education on the use and operation of ASHP systems		
	Monitoring of energy efficiency and energy savings		
	This project is sponsored by NYSERDA		
	Mitsubishi Electric is a co-sponsoring project partner that will be providing technical support and homeowner discounts		
Project Site Selection Criteria			
	Exisiting buildings with an existing year-round occupancy of at least 18 months		
	Residential Homes, 1-2 Family Bldgs, 3 stories or less in height		
	Energy-efficient or weatherized construction:		
		1- Built since 1995 OR	
		2- Built between 1970 and 1995 with a Home Energy Audit recommended, or Contractor Assessment required.	
			Weatherization improvements may be required based on results of the Audit or Contractor Assessment.
		3- Older homes built prior to 1970, Home Energy Audit required.	
			Weatherization improvements may be required based on results of the Audit.
	House location: Mid-to-Upper Hudson Valley, NY roughly between Saratoga Springs and Newburgh), and Albany/Schenectady/Troy		
	Preferred: Homes that are heated with oil, LP gas, and/or electric resistance heat.		
		Homes with significant wood heat, or natural gas heating systems, will be considered on a case-by-case basis	
Homes that are not eligible:			
	Newly constructed homes or additions (that have not been occupied and heated/cooled for a minimum of 18 months)		
	Multi-family buildings or homes greater than 2 units, or higher than 3 stories		
	Homes that have significant identified thermal problems that cannot be resolved as part of the project work scope		
	Commerical or non-residential spaces in homes (eg: garages or detached work studios). This does not include home offices		
	Identified life-safety concerns (unless remidiation is part of the project work scope)		
		Pollutant hazards or other issues (eg: exposed asbestos, etc)	
		Substantial moisture problems including mold/mildew like conditions or active water leaks	
		Structural concerns	
		Combustion safety concerns	
	House location ouside the target region		
	Seasonal Homes or other houses that are not occupied regularly		
Project Proposal Process: Initial Steps			
	Contractor to complete and submit the Pre-Improvement Site Description and Site Proposal Forms		
		Contractor encouraged to contact tech team to review any concerns about qualification or proposed work scope, prior to submission of forms	
	Collection of energy use history for past 18 - 24 months		
	REMINDER: Projects must be approved by tech team and NYSERDA before committing to participation		

A.8 Pre-Improvement Site Description Form

Pre-Improvement Site Description Form					
Contractor:					
	Company Name				
	Representative Name / Title				
	Date				
Proposed Project Site:					
	Owner / Customer Name				
	Street Address				
	City/State/Zip				
	Phone				
	House type	SF Detached or Attached			
	Approx year built				
	# of stories				
	Finished floor area (not incl basement)				
	# bedrooms				
	# of occupants				
	Approx year most recent major rehab				
		Describe			
Home Energy Audit					
	attach Energy Audit Report, if applicable				
Photos & Sketches					
	Exterior				
		one per each exterior side			
	HVAC & DHW Equipment				
		space heating			
		space cooling (indoor & outdoor units)			
		Hot water heater/equipment			
	Other relavant features				
		as necessary			
	Sketch floor layouts				
		one per floor			
Thermal Enclosure					
	Foundation type (check all that apply)				
		Slab on Grade			
			% of house if multiple		
		Basement	Finished or unfinished		
			Conditioned or unconditioned		
			walk-out?		
			% of house if multiple		
		Crawlspace	location of insulation		
			vapor Barrier or slab on floor?		
			% of house if multiple		
		Location / type of insulation and R-Value (predominant)			
		Condition of exposed insulation (Good, Fair, Poor)			

	Above Grade Walls		
		Area (sf)	
		2x4 or 2x6 Framing	
		rigid foam?	
		Panelized or SIP Construction	
		Type of Insulation / R-Value	
	Windows		
		Area (sf)	
		Single, double, double/low-e, or triple/low-e	
		Storm windows	
		Window area: low, average, high, "mostly glass"	
		Condition of windows (good, fair, poor)	
	Attic / Roof		
		Area (sf)	
		Vented/unvented/sealed attic	
		Cathedralized, insulated roof?	
		Insulated kneewalls	
		Location / type of insulation and R-Value (predominant)	
		Condition of exposed insulation (good, fair, poor)	
	Significant Air By-Passes		
HVAC Equipment			
	Space Htg	Equipment Type	
		Fuel Type	
		Location	
		Manufacturer / Model Number (photo of nameplate)	
		Approx year of manufacture	
		Condition (eg: good, fair, poor)	
		Efficiency rating if known	
		Distribution systems / location	
		Number of zones	
	Space Cooling		
		Equipment Type	
		Location	
		Manufacturer / Model Number (photo of nameplate)	
		Approx year of manufacture	
		Condition (eg: good, fair, poor)	
		Efficiency Rating	
		Distribution systems / location	
		Number of zones	
	Duct System(s)		
		Locations	
		For Ducts located in Attics, Garages, Vented Crawlspaces:	
			Duct Insulation
			Duct Leakage / Sealing
	Active Fireplace / Woodstoves / Gas-fired Stoves		
		Equipment Type	
		Location	
		Fuel Type (eg: Wood, Pellet, Gas)	
			If gas, is it direct-vented?
Water Heater			
		Equipment Type	
		Fuel Type	
		Location	
		Manufacturer / Model Number (photo of nameplate)	
		Approx year of manufacture	
		Condition (eg: good, fair, poor)	

Other Conditions					
	Any hazardous condition that requires remediation as part of this workscope				
Solar PV					
	Array size / location / orientation				
Energy / Fuel Types and Usage History: 24-month					
	Fuel Type	Vendor / Utility			
	LP Gas				
	Fuel Oil				
	Wood / Pellets				
	Electricity				

A.9 Contractor Site Proposal Form

Contractor Site Proposal Form			
NOTE: This following forms and docs must be attached with this application:			
		HVHP Project Pre-improvement Site Selection Form	
		Proposed Workscope	
		Load Calculations Report	
Contractor:			
		Company Name	
		Representative Name / Title	
		Date	
Proposed Project Site:			
		Owner / Customer Name	
		Street Address	
Proposed Purpose of Heat Pump System Installation			
		Space Heating	
			Full Replacement or Primary (with Existing Equip as Supplemental)
		Space Cooling	
			Full Replacement or Primary (with Existing Equip as Supplemental)
Duct Systems			
	Existing Ducts		
		Intent to use existing system	
		Will workscope include duct sealing and/or duct insulation?	
		Other duct modifications required	
	New Ducts		
		Will any new ducting be installed?	
Non-HVAC Improvement Recommendations (specify by whom)			
		Insulation (where?)	
		Air sealing	
		Solar Electric	
		Other (eg: Combustion Safety, specify)	

Proposed Heat Pump Equipment and Zones

Outdoor Units - Equipment Info

Unit #	Unit Model	Nominal Size (tons)	Single- or Multi-zone	Location (outdoor unit)
1			Choose One	
2			Choose One	
3			Choose One	
4			Choose One	
5			Choose One	
6			Choose One	
7			Choose One	
8			Choose One	
9			Choose One	
10			Choose One	
11			Choose One	
12			Choose One	

Indoor Units - Equipment and zone info

Zone #	Type of System	Indoor Unit Model	Size nom kbtu/h	Location	Floor	Heating load kbtu/h	Cooling total load kbtu/h	Thermostat/ controls
1	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one
	Choose one							Choose one

Key	IndoorList		Key	ThermostatList
	(Choose one)			(Choose one)
WALL	Ductless Wall		HH	Hand-held Remote
CL	Ductless Ceiling		WM	Wall-mount: Wired
FL	Ductless Floor		MHK1	Wall-mount: MHK1
MD	Mini-duct		KC	Kumo cloud
FD	Central-Fully Ducted		HWI	Honeywell - Integrated Thermostat
			OT	Other (specify)

Questions or Concerns
Please list any issues you'd like assistance with related to the system design and equipment selection

A.10 Post-Improvement Site Form – QA

Post-Improvement Site Form - QA						
Category	Item	Y	N	N/A	D/K	Comment/Notes
Line Set						
	Note any unusual situations regarding lineset length or height change.					
	Insulation covers entire line set length.	Y	N			
	Exterior line set length is protected with a rigid cover with UV tape at unavoidable exposed areas.	Y	N			
	Line set penetration through the building enclosure is rodent-proof (e.g., PVC sleeve and cap drilled to the size of the refrigerant lines).	Y	N		D/K	
	All penetrations through the shell of the home are sealed with insulating sealant/spray foam.	Y	N		D/K	
	Any insulation disturbed by installed line set must be returned to original (or better) condition.	Y	N		D/K	
Condensate Drain						
	Drain is sloped downhill. Drain is terminated away from crawl spaces, walkways and outdoor equipment.	Y	N			
	External condensate pump is used if needed	Y	N	N/A		
Outdoor Unit						
	Unit placement allows for free air flow, following manufacturers instructions. Outdoor unit does not interfere with view through or operation of any windows or doors.	Y	N			
	Outdoor unit is located in an appropriate place regarding aesthetic and noise considerations, in accordance with customer's wishes.	Y	N			
	Outdoor unit is securely mounted and level.	Y	N			
	If multiple outdoor units, they are not stacked above each other, or installed too closely.	Y	N	N/A		
	Unit has adequate clearance above expected snow line (generally >24 inches, higher in snow country).	Y	N			
	Wall mount brackets secure and stable	Y	N	N/A		
	Alternate: outdoor units that are mounted to a pad, risers and/or the surface on which they are set--secure using bolts and/or adhesive.	Y	N	N/A		
	Risers if used are tall enough to avoid snow.	Y	N	N/A		
	Customer has no outdoor-unit noise issues based on actual operation.	Y	N			
	Unit is adequately away from walkways or other areas where re-freezing defrost meltwater might cause a hazard.	Y	N			
	Outdoor unit is out of the way of any drip line from the roof or other overhang.	Y	N			
	Alternately, outdoor unit has drip caps or shield to protect from rain/ice/drips	Y	N	N/A		
	Surge suppressors are installed at service disconnect	Y	N	N/A		
	Alternatively, approved surge suppressors are installed at circuit breaker box	Y	N	N/A		
	Drain pan heater is disabled or not present	Y	N			

Indoor Unit						
	Indoor wall mounted units have adequate clearance from the ceiling (a minimum of 12-18") for ceiling heights up to 8 feet.	Y	N	N/A		
	In rooms with tall or vaulted ceilings, indoor unit is mounted at about 8 feet.	Y	N	N/A		
	Other indoor distribution is used: floor mount	Y	N	N/A		
	Other indoor distribution is used: ducted	Y	N	N/A		
Ducting						
	Mini duct systems are adequately sized / minimizes fittings, air flow seems adequate from all registers.	Y	N	N/A	D/K	
	Any ducts and/or air handlers in unconditioned space are thorougly sealed with duct mastic and all components insulated to a minimum of R-8.	Y	N	N/A	D/K	
Setup						
	In spaces > 150 sq ft, wall-mounted thermostat is installed in a representative location.	Y	N	N/A		
	Controls are set so that the temperature is sensed at the wall thermostat.	Y	N	N/A		
	Unit(s) with standard return-air sensing controls are small (< 150 SF) or cohesive with no significantt comfort issues.	Y	N	N/A		
	For retrofit situations, the main zone ASHP thermostat is mounted near the central system thermostat	Y	N	N/A		
	Temperature sensing /response has been adjusted to customer's satisfaction	Y	N	N/A	D/K	
	For home with remaining central heat, is Integrated multi-stage control installed?	Y	N	N/A		
	Customer is aware of correct operation of two thermostats.	Y	N	N/A	D/K	
	Continuous fan operation is disabled.	Y	N	N/A	D/K	

A.11 Homeowners Operation Checklist

Step	Reasons/comments
Review the manufacturer's Owners Manual for basic (and specific) guidance on operation modes, settings, and general maintenance.	It's important to be familiar with the operation and controls of the equipment.
Be sure to keep snow away from the outdoor unit. This is especially important during heavy snowfall or drifting conditions.	Snow build-up around the outdoor unit can reduce its effiicency or even cause it to shut down temporarily.
Set the heat pump heating temperature approximately 4 degrees higher than any central heating (or electric baseboard) that serves the same area as the heat pump (or an adjacent area of the house).	This ensures that the heat pump produces as much heat as possible, and the backup heat is only used when the heat pump has trouble keeping up.
Use the "heat" or "cool" setting on the thermostat or control. Generally set the unit at "off" when neither is needed.	Using "Auto" settings that allow either heating or cooling to maintain a specific comfort setting can use significantly more energy.
Set the thermostat for comfort rather than basing your setting on a number. It may be necessary to set the heating temperature higher in colder weather than in milder heating temperatures, especially if your heat pump(s) use hand-held remote controls. (For example, see table below).*	This is because the temperature the unit senses in its own air stream may be warmer than the average room temperature. The difference tends to be larger when outdoor conditions are colder.

*Examples: If the outdoor temperature is between:	You may find consistent levels of indoor comfort by setting the control temperature at:
40-60 F	68 degrees
25-40 F	70 degrees
10-25 F	72 degrees
Below 10F	74 degrees
For illustrative purposes only; your comfort settings may be higher or lower	

If central heating systems are the only heat source in your basement, try to make sure it runs adequately in very cold weather to keep pipes from freezing.	This may create an exception to the item above--you may need to run the central heat more in very cold weather to be safe. Of course, that's also when the central heat is most likely to be needed for comfort.

Remember that a handheld remote is not the thermostat. Unless you have a wall-mounted thermostat for the heat pump, the air temperature is sensed by the indoor fan unit. The temperature setting for comfort may be higher or lower than the actual room temperature desired.	Even wall-mounted controls may not be the default temperature sensing location; check with you installer to make sure it's configured to properly sense the temperature of the whole space.

In efficient homes (or heat pump zones with small loads), set indoor temperatures at a steady level with modest or no daily “setbacks"; basically, set it and forget it (within the parameters of the above items).	This will help to reduce inefficient “ramp-up” periods that can actually use more energy with a variable-speed heat pump.
In inefficient homes (e.g., a home where the indoor temperature drops faster than 2 degrees per hour when the thermostat is set back, in freezing temperatures), turn the thermostat back at night and when away to save energy.	The heat pump may run less efficiently but you can still save energy if the house is 8ooler when the heat is not needed. It’s important to set any central backup heat down, at the same time, to maintain the 4 degree differential and let the heat pump continue to provide most of the heat.
Note that for any type of home, during periods when the outdoor temperature is mild (e.g. heating is only needed at night) it's OK to turn the heat pump down, or off, when it's not needed.	Some heat pumps do tend to over-heat a bit when temperatures are mild, so it can actually be an advantage to adjust the controls to a lower temperature - or "off".
If you have an integrated thermostat that controls both the heat pump and the existing central heating system, be sure to familiarize yourself with the control's operation and use in order to accomplish your desired objective.	If integrated controls include an intelligent “ramped recovery” option, be sure to use that so that the heat pump can provide as much of the heating during recovery from setback as possible.
Generally set the indoor fan speed to "auto" or automatic so the fan only runs during heating or cooling operation. If possible, avoid setting indoor fan(s) to run continuously, OR to run only in low speed.	Low fan speeds reduce efficiency, especially in cold weather. Any user selectable continuously-on fan setting (other than may occur on very low speed to sense room temperature) also reduces efficiency. If the fan runs all the time and can't be stopped with user controls, contact your installer for help in changing the settings.
Try to set the supply air vanes generally so that they are open wide, to avoid reducing air flow. Generally avoid vane settings for "automatic" sweeping or auto- adjustment.	The high-efficiency fans in cold-climate heat pumps are very sensitive to restrictions that can reduce air flow; both heating and cooling delivery and efficiency are affected. However, sometimes high-wall mounted units need vanes to point downward at an angle (not as steeply as possible) to deliver heat effectively into a room.

Clean air filters regularly: every 2-6 weeks depending on need.	Air flow is important to cold-climate heat pumps. It's not necessary to keep the filter spotless, but if it's caked with dust when you check it, come back sooner next time. If the dust is barely noticable, you can probably wait a bit longer.
Be careful regarding any construction intended to “hide” outdoor units. Be sure to follow manufacturer's recommended clearances at all times.	Air flow in outdoor units is also critical to efficient operation. Don’t build or install anything that will restrict or recirculate air flowing through the outdoor unit.

Appendix B. Monitoring Installation at Each Site

The following pages in this appendix describe the monitoring equipment installed at each site and also provide details and pictures of the original equipment at each house as well as the newly installed heat pumps.

Monitoring Installation Notes – EFG Site 1

Monitoring Installation Date: December 12, 2017

Installers: Hugh Henderson, Nick Genzel, Carina Paton

Site Overview: Single-story residence with full unfinished basement.

Appliances

- Electric dryer (not used)
- Gas DHW
- Gas hot water boiler
    - Input gas 105,000 Btu/h
    - DOE heating capacity 86,000 Btu/h
    - Net I=B=R Ouput, water, 75 Mbh
    - Single zone for entire house
- Solar array
    - Installed in 2011
- Heat pump
    - Mitsubishi split-system heat pump
    - Model MSZ-FH18NA2
    - 2 ton
    - One outdoor and one indoor unit in open living area
- Thermostat
    - Thermostat in main living area hooked to boiler during installation visit
    - Next day, plan to install thermostat for heat pump and then move boiler thermostat to end of hallway or bedroom (to confirm)

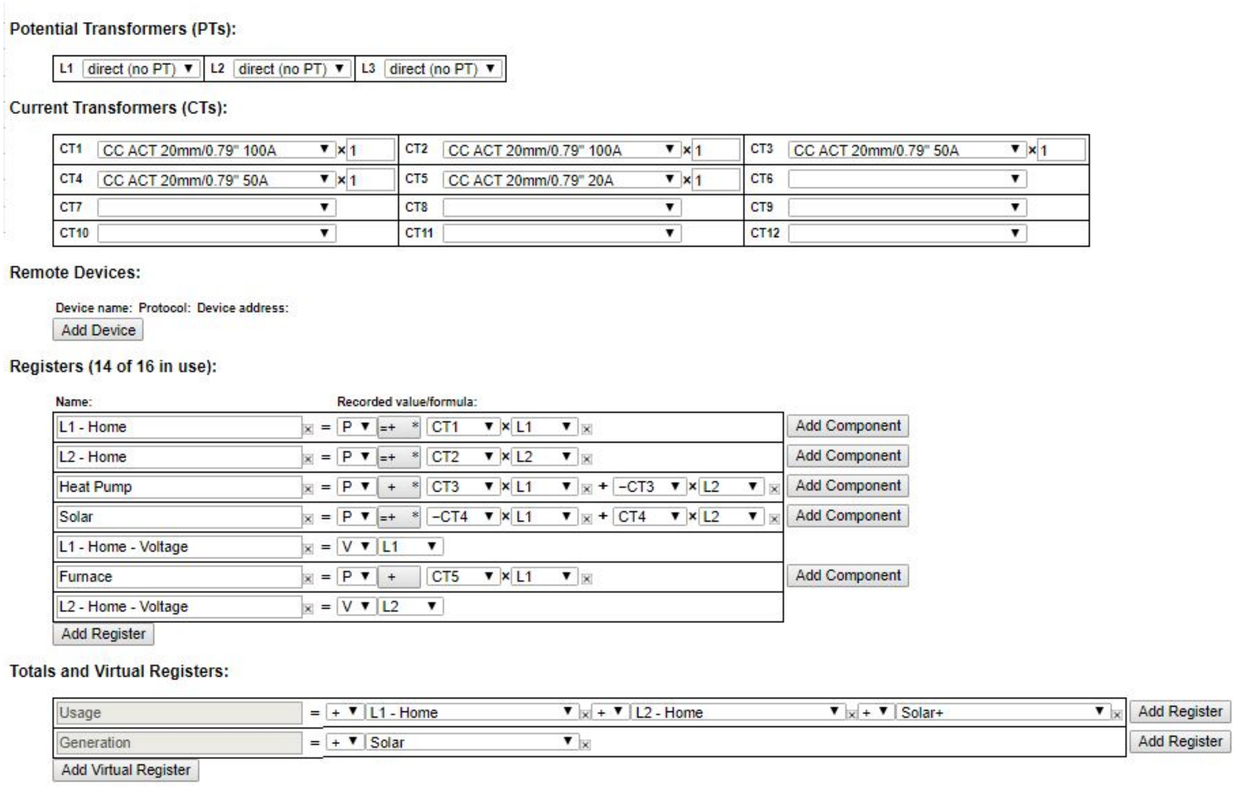
Monitoring Summary

- eGauge:
    - Heat pump power
    - Utility power (L1 & L2, directional)
    - Solar generation (directional)
    - Boiler power
- Battery-powered loggers:
    - Heat pump conditioned space (on piano in living room): temperature, relative humidity
        - Serial: 20263932
    - Unconditioned space (on shelf in master bedroom): temperature
        - Serial: 20244168

eGauge Setup

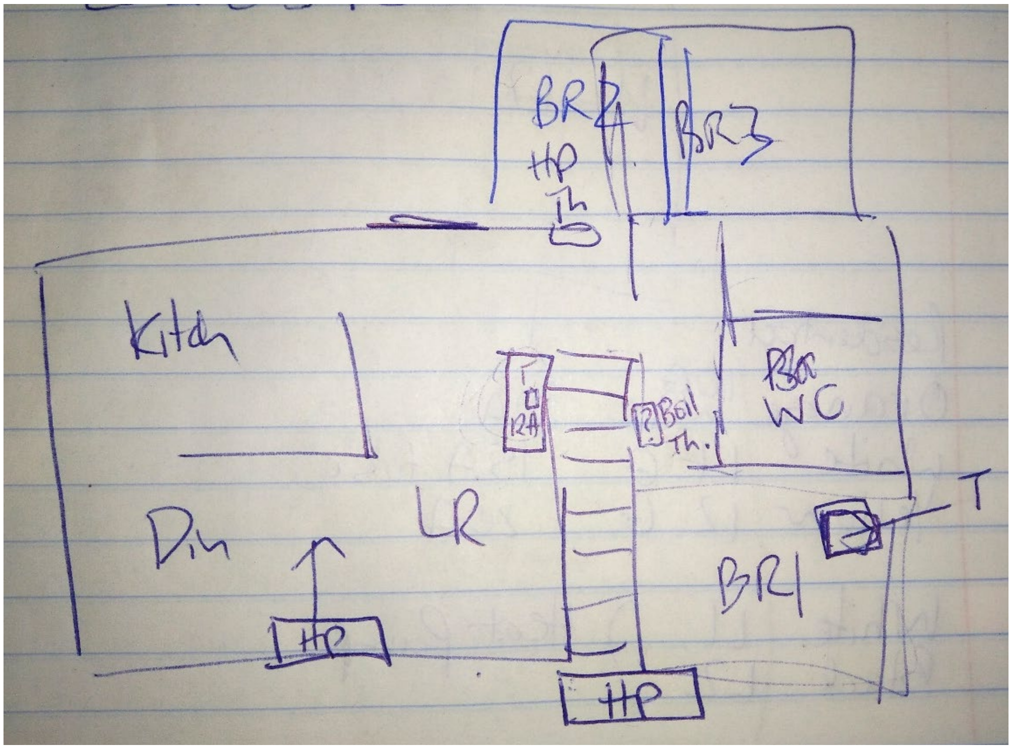
Adjustments:

- Dec 12th – Adjusted the "Usage" virtual register and the "Generation" virtual register to accurately calculate "Usage" and "Generation"
- January 5th – Removed the "Furnace Elec Use" and "Heat Pump Elec Use" virtual registers to avoid duplicates with the non-virtual registers.



Physical Label	CT	Rating	Data Point	Logging
0	CT1	100 A	Utility Phase 1	Net, +, -, apparent
2	CT2	100 A	Utility Phase 2	Net, +, -, apparent
3	CT3	50 A	Heat Pump	+, apparent
4	CT4	50 A	Solar Array	Net, +, -, apparent
5	CT5	20 A	Boiler ("Furnace")	+

Layout Sketch

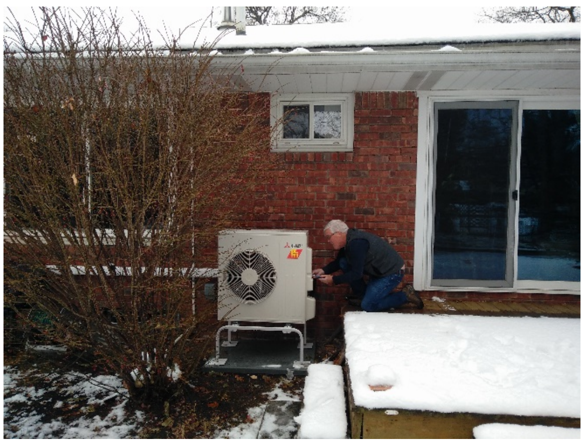


Other Notes

- Owner is surprised at how much electricity they are using now. Was told to leave on by the installer, but are turning it off. They have not looked at the gas bill yet.
- Currently operating by remote, set to 66 degrees.
- The boiler doesn't turn on much – and owner wants it to – so hoping to move boiler thermostat to further away. It's across the room, diagonal from the heat pump in between the living area and the bedrooms It was reading 63 degrees, and the set point was 63. It wasn't on during our visit, but had been on that day. [Update: a few days after our installation, the boiler thermostat was moved to the master bedroom, and the heat pump wall thermostat was installed where the boiler thermostat was.]
- Solar array is old. They do have excess credit they can use in the spring to offset heat pump use. It hasn't paid itself off yet.
- With rebate, the heat pump cost "thousands of dollars".

Photos

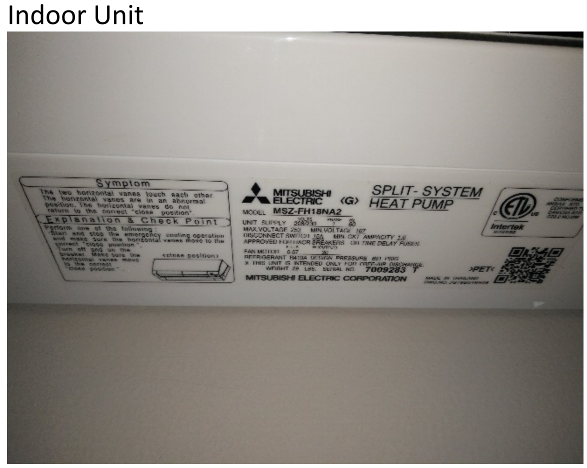
Solar inverter and generation meter



Outdoor Unit

Indoor Unit

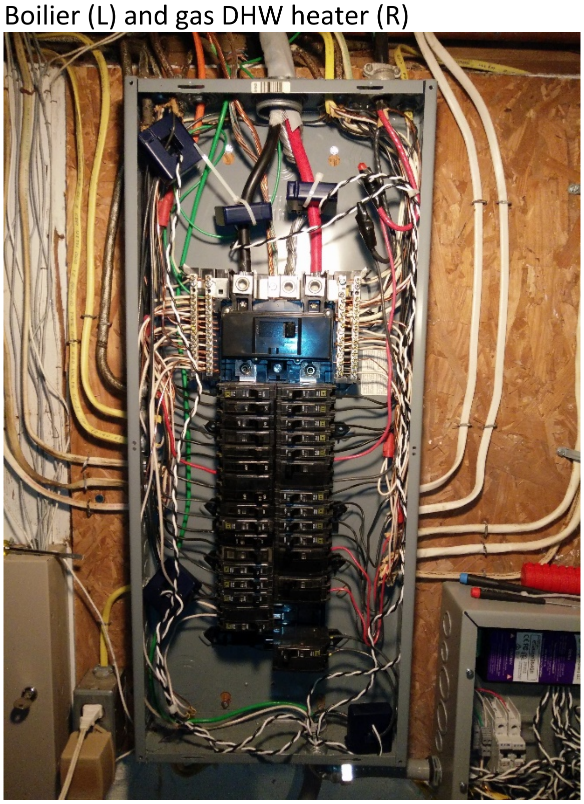
Outdoor Unit Nameplate



Indoor Unit Nameplate

Boilier (L) and gas DHW heater (R)

Boiler nameplate



CTs installed in panel

eGauge monitoring box

Monitoring Installation Notes – EFG Site 2

Monitoring Installation Date: January 11, 2018

Installers: Nick Genzel, Carina Paton

Site Overview: Two-story, four-bedroom residence with dirt basement

Appliances

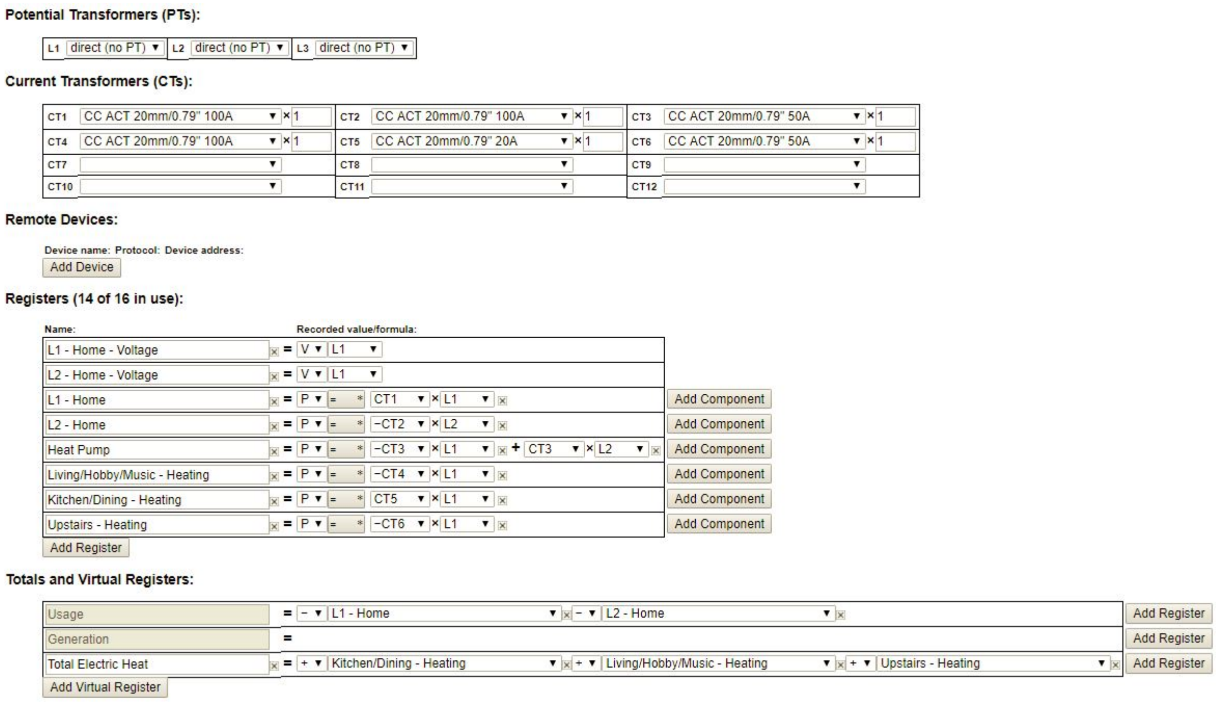
- Electric DHW
- Electric baseboards (single thermostat for each bullet)
    - Kitchen and dining (ground floor)
    - Living room (ground floor)
    - Music room (back bedroom on ground floor)
    - Hobby room (front bedroom on ground floor)
    - Master bedroom (upstairs)
    - Bedroom (upstairs)
    - Thermostats all off at time of installation
- Heat pump
    - Mitsubishi split-system heat pump
    - Outdoor unit: Model MXZ-3C30NAHZ2 (30 kBtu capacity, max 3 zones)
    - Master bedroom indoor unit: MSZ-FH09NA
    - Living room indoor unit: MSZ-FH18NA2
    - Both indoor units have remote controls

Monitoring Summary

- eGauge:
    - Total home L1 (voltage, power)
    - Total home L2 (voltage, power)
    - Heat pump power (one phase)
    - Living/Hobby/Music electric heat
    - Kitchen/Dining electric heat
    - Upstairs electric heat
    - Total electric heat (virtual register)
- Battery-powered loggers:
    - Heat pump conditioned space (on mantelpiece in living room): temperature, relative humidity
        - Serial: 20263933
    - Unconditioned space (on dresser in master bedroom upstairs): temperature
        - Serial: 20244173

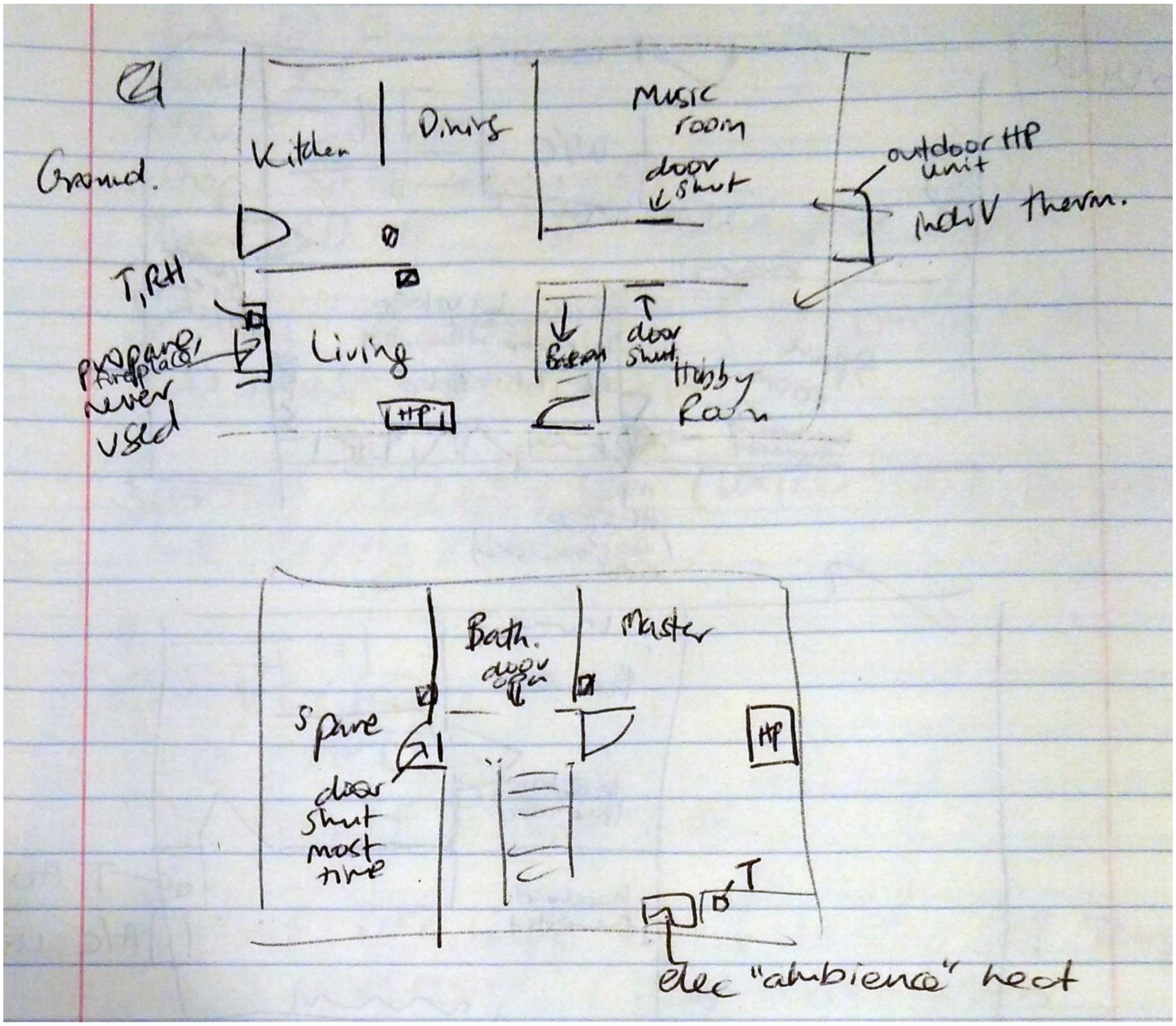
eGauge Setup

Adjustments:



Physical Label	CT	Rating	Data Point	Logging
0	CT1	100 A	Utility Phase 1	Net, volt, apparent
2	CT2	100 A	Utility Phase 2	Net, volt, apparent
3	CT3	50 A	Heat Pump	Net, apparent
4	CT4	100 A	Electric Htg 1	Net, apparent
5	CT5	20 A	Electric Htg 2	Net, apparent
6	CT6	50 A	Electric Htg 3	Net, apparent

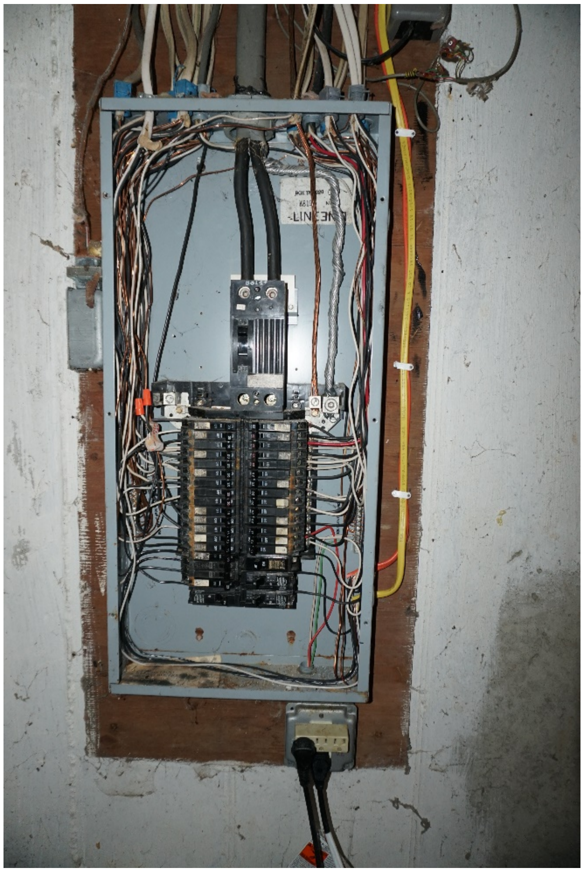
Layout Sketch



Other Notes

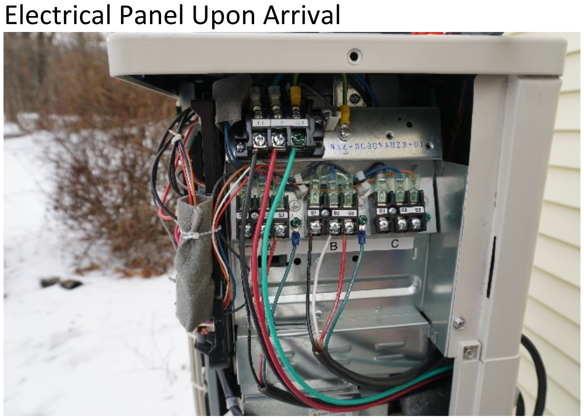
- Dual occupant household, retired.
- Four bedroom. Uses master bedroom daily. Other bedroom upstairs used when son home in summer. Hobby room and music room used occasionally. Doors generally closed to the three bedrooms in occasional only use.
- Propane fireplace in living room is never used.
- Master bedroom has electric heater "for ambience"
- They turn baseboards off completely in master bedroom and living areas when heat pumps are sufficient.

Photos

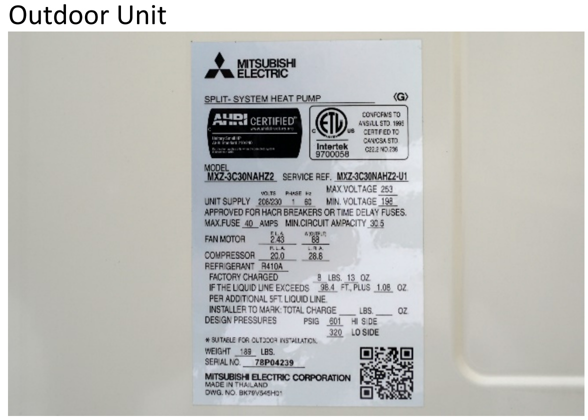


Electrical Panel Upon Arrival

Outdoor Unit



Outdoor Unit Wiring

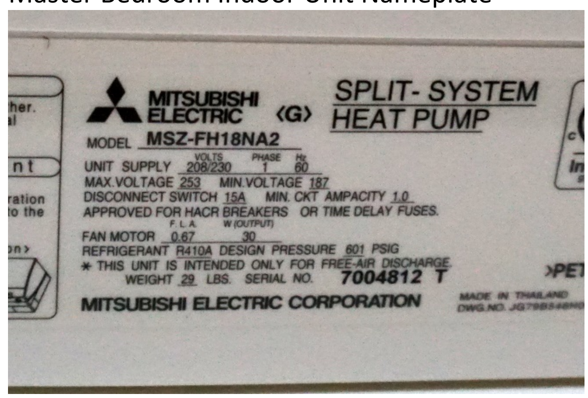


Outdoor Unit Nameplate


Master Bedroom Indoor Unit

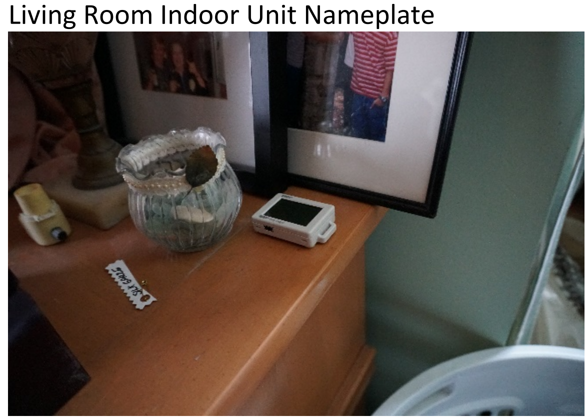
Master Bedroom Indoor Unit Nameplate

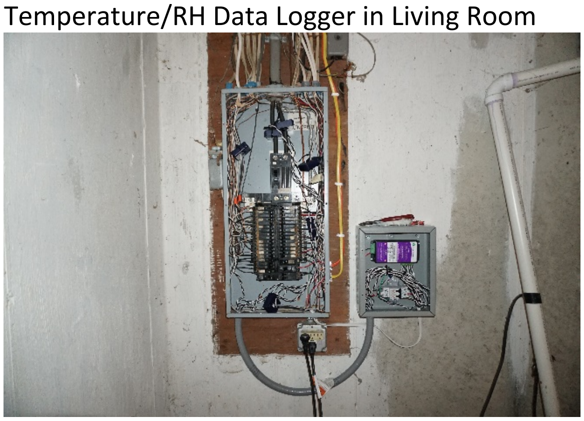

Living Room Indoor Unit

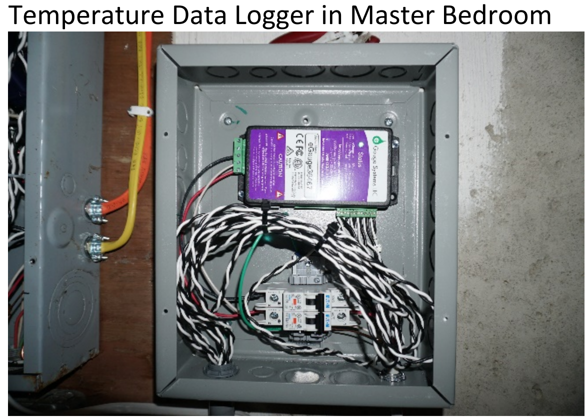


Living Room Indoor Unit Nameplate


Temperature/RH Data Logger in Living Room


Temperature Data Logger in Master Bedroom


Installed CTs and eGauge Panel


eGauge monitoring box

Monitoring Installation Notes – EFG Site 3

Monitoring Installation Date: March 27, 2018

Installers: Nick Genzel, Jeremy Wade

Site Overview: Two-story, three-bedroom residence with concrete floor basement

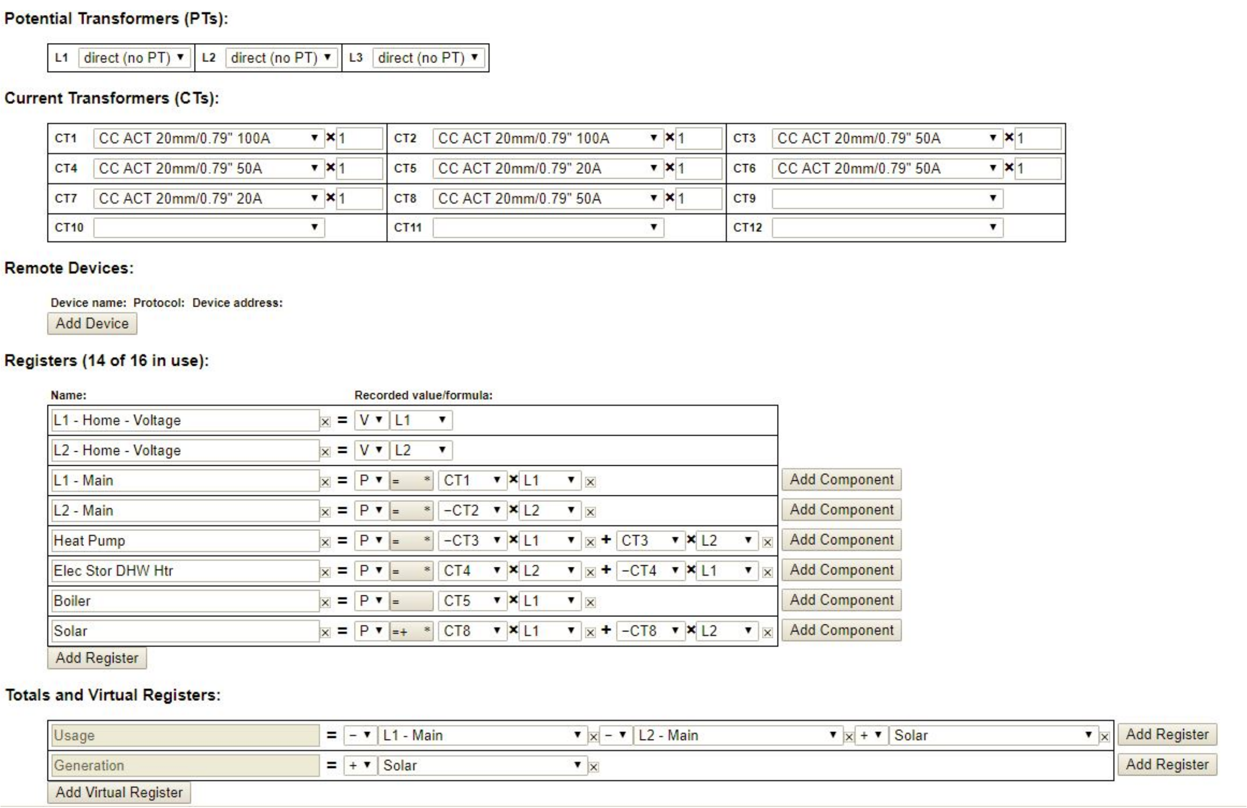
Appliances

- Electric DHW *Note: Pre-Improvement Site Description says Fuel Oil for DHW*
- Fuel Oil Boiler
  - Thermostat in first floor hallway
- Heat pump
  - Mitsubishi split-system heat pump
  - Outdoor unit: Model MXZ-4C36NAHZ (3 zones)
  - Master bedroom indoor unit
  - Living room / kitchen indoor unit
  - Upstairs indoor unit
  - All indoor units have remote controls

Monitoring Summary

- eGauge:
  - Total home L1 (voltage, power)
  - Total home L2 (voltage, power)
  - Heat pump power (one phase)
  - Electric DHW (one phase)
  - Boiler
  - Solar *Note: Left a CT for future solar monitoring – Not hooked to electrical panel yet*
- Battery-powered loggers:
  - Heat pump conditioned space (on wooden display cabinet in living room): temperature, relative humidity
    - Serial: 20263936
  - Conditioned space (on window frame in master bedroom): temperature
    - Serial: 20244172
  - Conditioned space (on wooden display bookshelf in upstairs sitting area): temperature
    - Serial: 20244164

eGauge Setup



Potential Transformers (PTs):

L1 direct (no PT) | L2 direct (no PT) | L3 direct (no PT)

Current Transformers (CTs):

CT1	CC ACT 20mm/0.79" 100A ×1	CT2	CC ACT 20mm/0.79" 100A ×1	CT3	CC ACT 20mm/0.79" 50A ×1
CT4	CC ACT 20mm/0.79" 50A ×1	CT5	CC ACT 20mm/0.79" 20A ×1	CT6	CC ACT 20mm/0.79" 50A ×1
CT7	CC ACT 20mm/0.79" 20A ×1	CT8	CC ACT 20mm/0.79" 50A ×1	CT9	
CT10		CT11		CT12	

Remote Devices:

Device name: Protocol: Device address:
Add Device

Registers (14 of 16 in use):

Name:	Recorded value/formula:
L1 - Home - Voltage	= V L1
L2 - Home - Voltage	= V L2
L1 - Main	= P = CT1 × L1
L2 - Main	= P = -CT2 × L2
Heat Pump	= P = -CT3 × L1 + CT3 × L2
Elec Stor DHW Htr	= P = CT4 × L2 + -CT4 × L1
Boiler	= P = CT5 × L1
Solar	= P =+ CT8 × L1 + -CT8 × L2

Add Register

Totals and Virtual Registers:

Usage	= - L1 - Main - L2 - Main + Solar
Generation	= + Solar

Add Virtual Register

Physical Label	CT	Rating	Data Point	Logging
N	CT1	100 A	Utility Phase 1	Net, volt, apparent
I	CT2	100 A	Utility Phase 2	Net, volt, apparent
S	CT3	50 A	Heat Pump (Outdoor)	Net, apparent
Q	CT4	50 A	Elec Storage DHW	Net, apparent
R	CT5	20 A	Boiler	Net
S	CT8	50 A	Solar	Net, pos, apparent

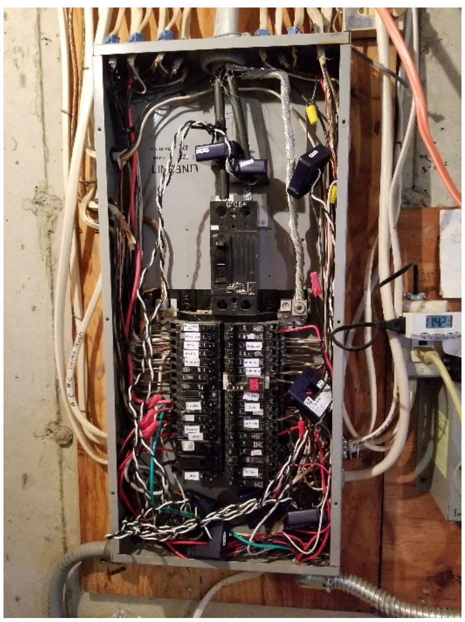
Other Notes

- Dual occupant household.
- Three bedroom. Uses master bedroom daily.
- The old outdoor unit for the retired heat pump system was being removed during install.
- Electrical panel was still hooked up as if old system was still in place.

Photos

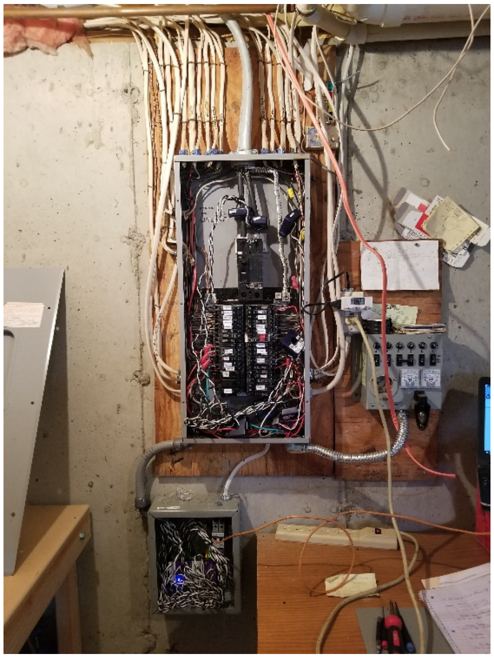
eGauge Monitoring Box

Outdoor Unit



Installed CTs

Outdoor Unit Nameplate



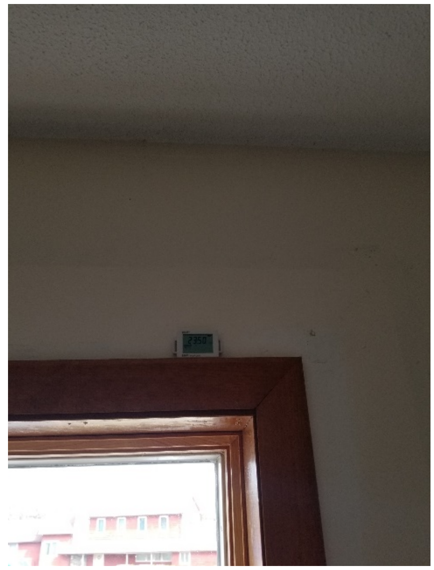
Electrical Panel and eGauge Monitoring Box

Livingroom Indoor Unit

Upstairs Indoor Unit

Temperature Data Logger in Upstairs Sitting Area


Temperature/RH Data Logger in Living Room


Temperature Data Logger in Master Bedroom

Electric Storage DHW


Fuel Oil Boiler

Monitoring Installation Notes – EFG Site 4

Monitoring Installation Date: January 11, 2018

Installers: Nick Genzel, Carina Paton

Site Overview: Two-story, two-bedroom residence with dirt basement

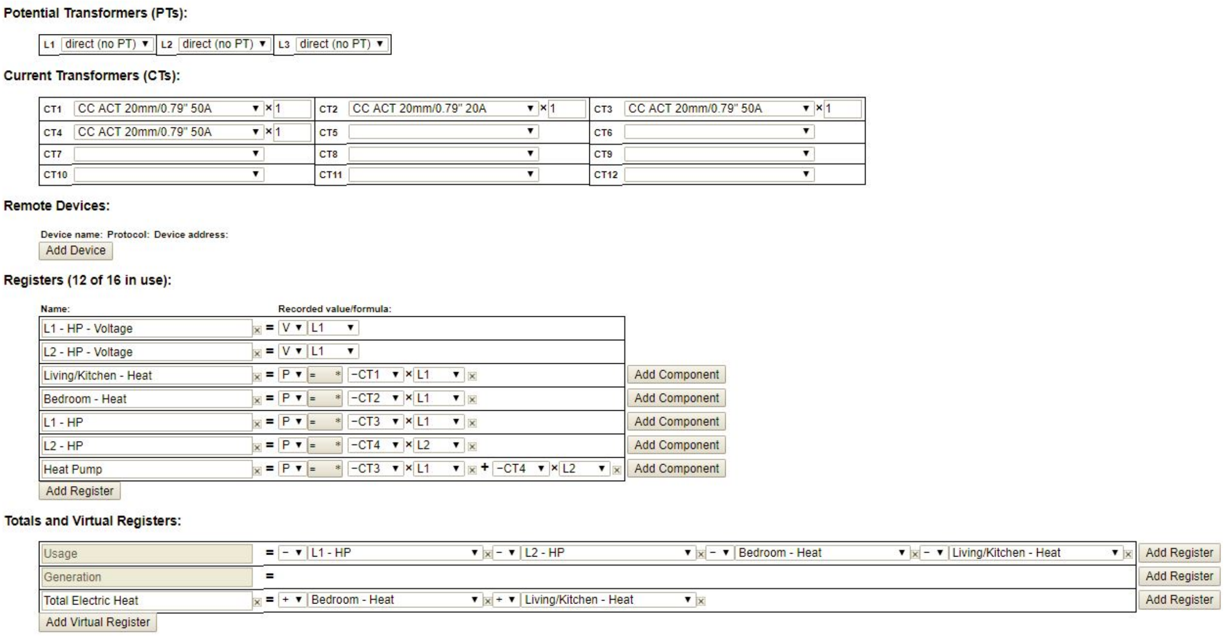
Appliances

- Electric DHW
- Electric baseboards
    - Kitchen and dining, single thermostat in living room tied to a relay
    - Spare room (ground floor), own thermostat
    - Master bedroom, own thermostat
    - Upstairs bathroom, own thermostat
    - Thermostats all set to 50 F at time of installation
    - Only kitchen, dining, and one bedroom heat labeled in the electrical panel
- Heat pump
    - Mitsubishi split-system heat pump
    - Model MSZ-FH15NAH
    - 1.5 ton
    - One outdoor and one indoor unit in open living area on ground floor
    - Thermostat on wall in living room, next to baseboard thermostat
- Window air conditioner
    - In master bedroom (upstairs)
    - Uses ~3 days/year
    - Kenmore 580.74053300
    - 5,250 Btu/h, 540 W, 9.7 Btu/Wh

Monitoring Summary

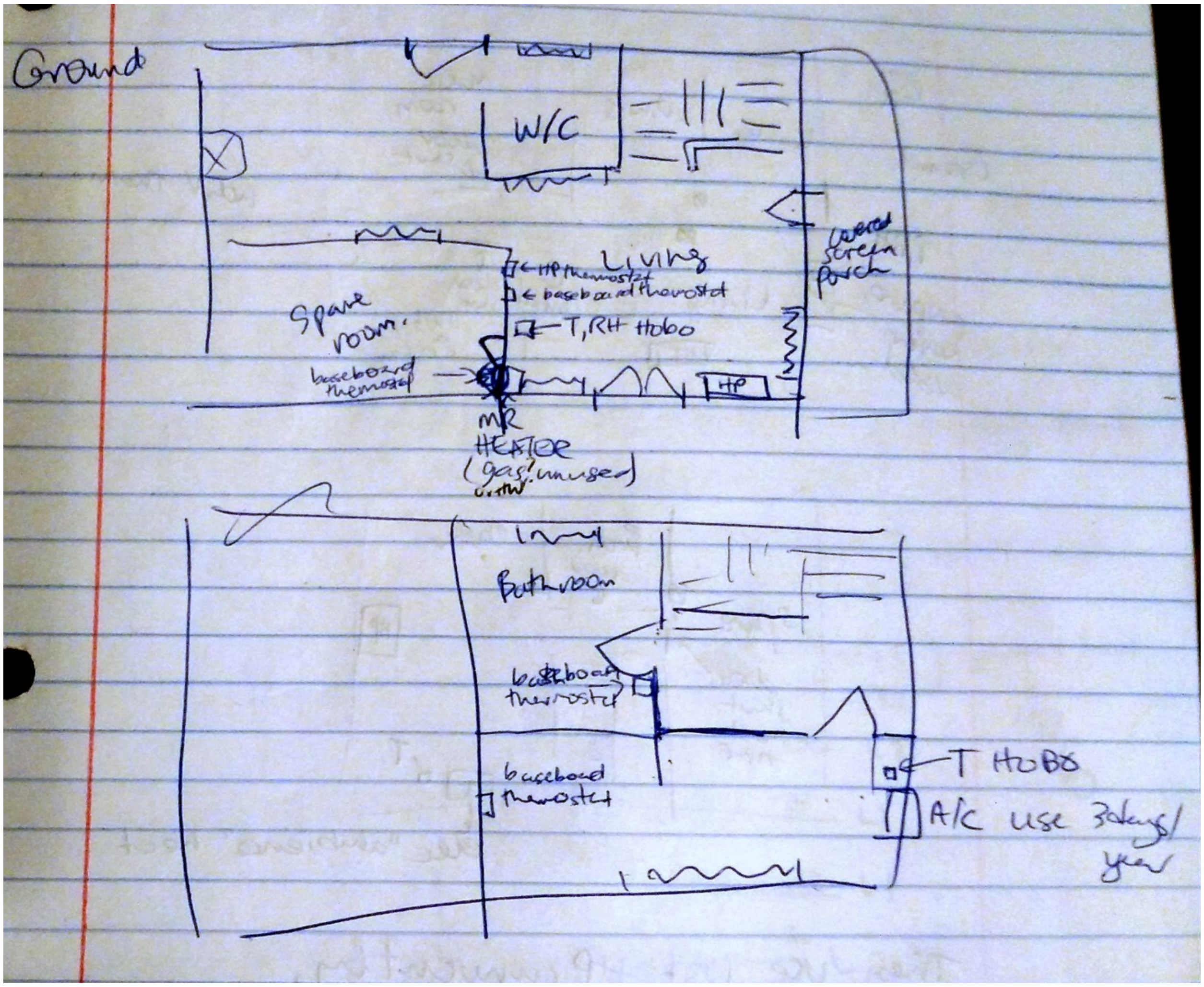
- eGauge:
    - Heat pump power (phase 1 & phase 2)
    - Living room electric heat
    - Kitchen electric heat
    - Bedroom electric heat (not clear which bedroom)
- Battery-powered loggers:
    - Heat pump conditioned space (near thermostat in living room): temperature, relative humidity
        - Serial: 20263934
    - Unconditioned space (on shelf in master bedroom upstairs): temperature
        - Serial: 2044163
    - Basement (temporary, requested by owner): temperature
        - Serial: 20244176

eGauge Setup



Physical Label	CT	Rating	Data Point	Logging
0	CT1	50 A	Electric Htg 1	Net, apparent
2	CT2	20 A	Electric Htg 2	Net, apparent
3	CT3	50 A	Heat Pump Phase 1	Net, volt, apparent
4	CT4	50 A	Heat Pump Phase 2	Net, volt, apparent

Layout Sketch



Other Notes

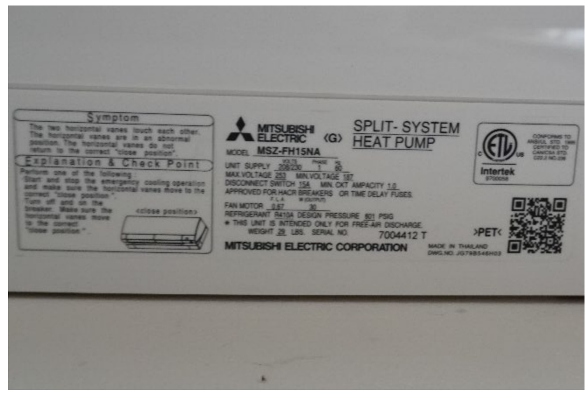
- Single occupant household. Two bedroom, uses downstairs bedroom as spare room and laundry room.
- Doors generally left open, except for door to spare room.
- There is a wall-mount heater in the living room (natural gas or propane) that is disconnected.
- We were not able to fit CTs around the whole house power.
- It is not clear which bedroom we are monitoring.
- There are two panels, an original main panel and a subpanel. The main panel has an animal nest in the bottom of it with fiberglass batt insulation, and wires have been stripped.

Photos


Outdoor Unit

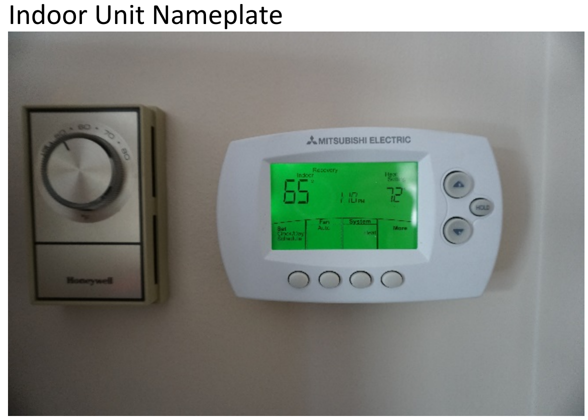

Indoor Unit

Outdoor Unit Wiring and Nameplate

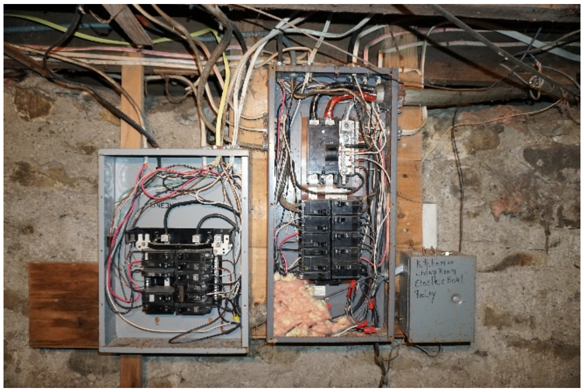


Indoor Unit Nameplate

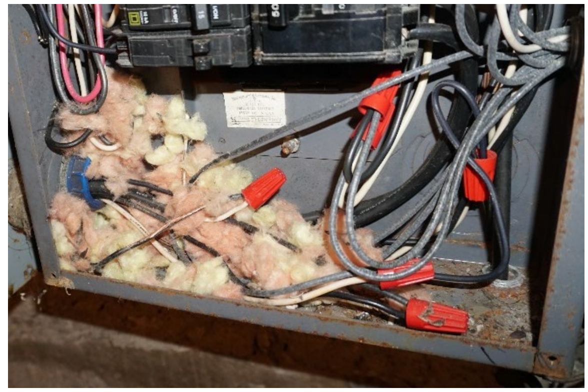

Window Air Conditioner, Master Bedroom



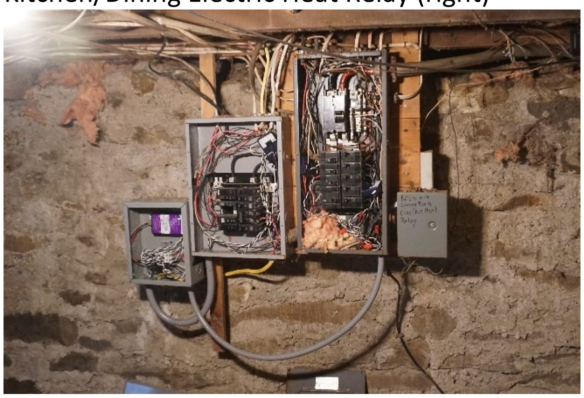
Baseboard and Heat Pump Thermostats



Main Electric Panel (center), Sub Panel (left) and Kitchen/Dining Electric Heat Relay (right)



Exposed Wires Under Insulation Nest



Installed CTs and eGauge Panel

eGauge monitoring box

Monitoring Installation Notes – EFG Site 5

Monitoring Installation Date: March 27, 2018

Installers: Nick Genzel, Jeremy Wade

Site Overview: Two-story residence with dirt floor basement

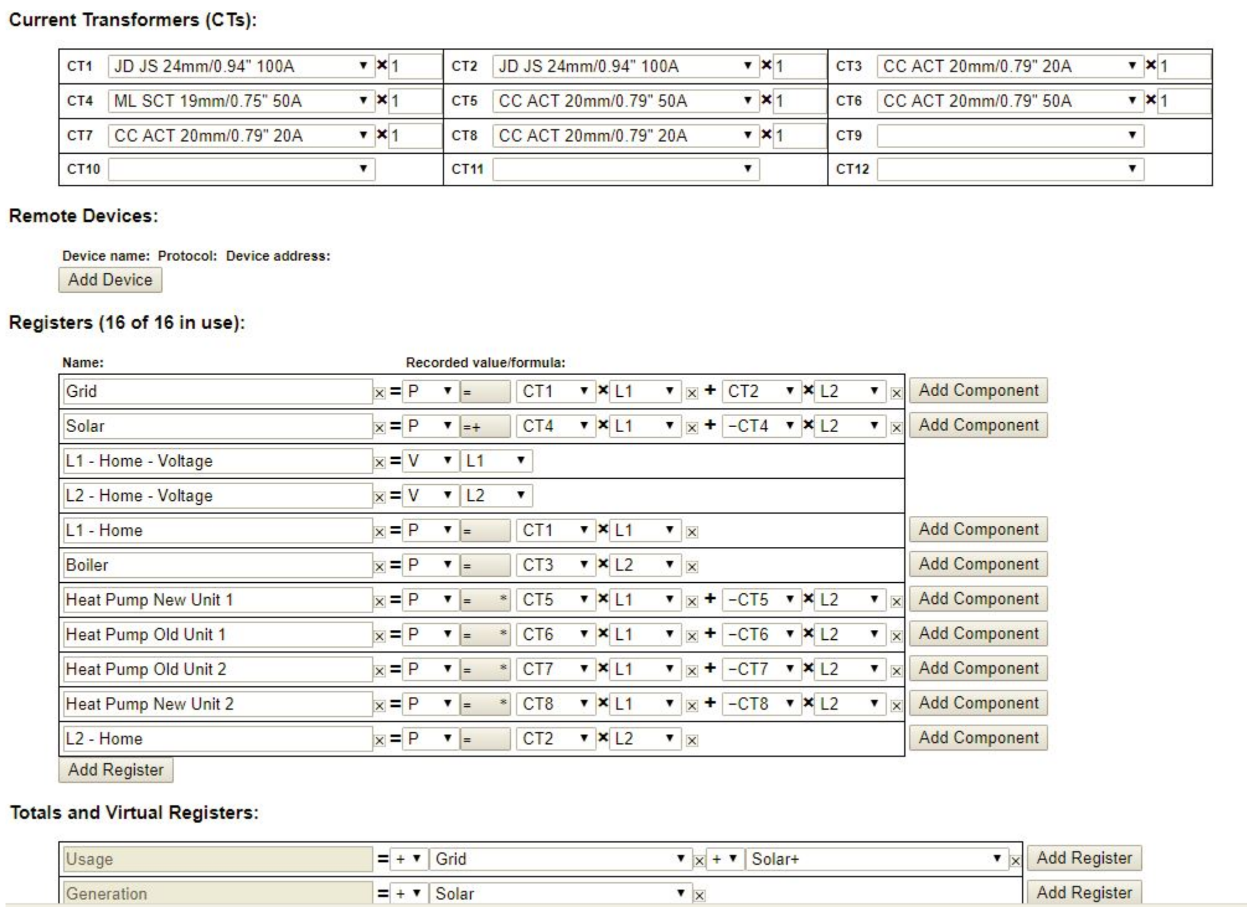
Appliances

- Natural Gas Storage DHW
- Natural Gas Boiler
    - Thermostat in first floor hallway by entrance
- Heat pump
    - Mitsubishi heat pump
    - 4 Outdoor Units (one for each indoor unit)
    - First Floor Master Bedroom Indoor Unit
    - First Floor Living Room Indoor Unit
    - Two Indoor Units Upstairs (did not have access upstairs)

Monitoring Summary

- eGauge:
    - Total home L1 (voltage, power)
    - Total home L2 (voltage, power)
    - Old Unit 1 Heat pump power (one phase)
    - Old Unit 2 Heat pump power (one phase)
    - New Unit 1 Heat pump power (one phase)
    - New Unit 2 Heat pump power (one phase)
    - Boiler (one phase)
    - Solar
- Battery-powered loggers:
    - Conditioned space (door frame in living room): temperature, relative humidity
        - Serial: 20263930
    - Conditioned space (No access - Homeowner moved upstairs): temperature
        - Serial: 20244166
    - Conditioned space (first floor bedroom on TV shelf): temperature
        - Serial: 20244165

eGauge Setup



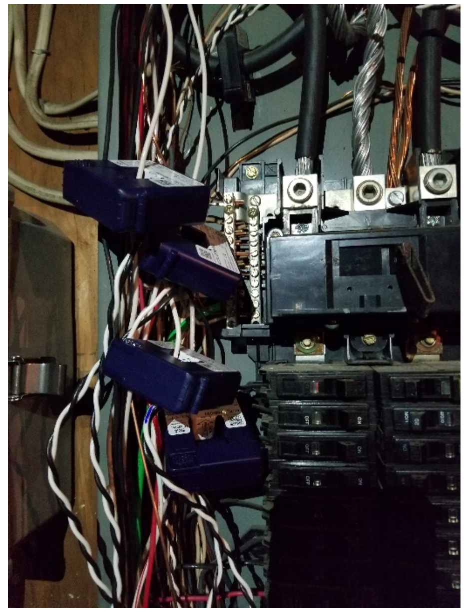
Physical Label	CT	Rating	Data Point	Logging
In-Place	CT1	100 A	Utility Phase 1	Net, volt, apparent
In-Place	CT2	100 A	Utility Phase 2	Net, volt, apparent
E	CT3	20 A	Boiler	Net
In-Place	CT4	50 A	Solar	Net, Pos
X	CT5	50 A	HP New Unit 1	Net, apparent
U	CT6	50 A	HP Old Unit 1	Net, apparent
Blue Marker	CT7	20 A	HP Old Unit 2	Net, apparent
Unmarked	CT8	20 A	HP New Unit 2	Net, apparent

Other Notes

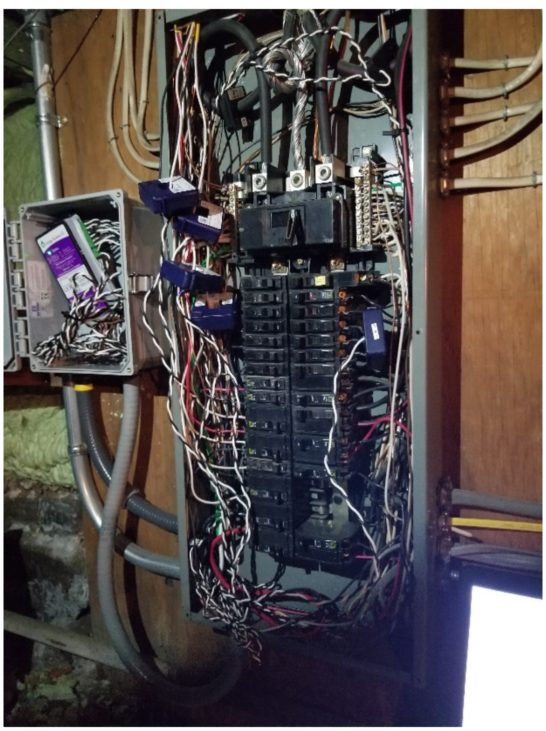
- Two separate living areas.
- Site had eGauge in place to monitor grid and solar.

Photos

eGauge Monitoring Box

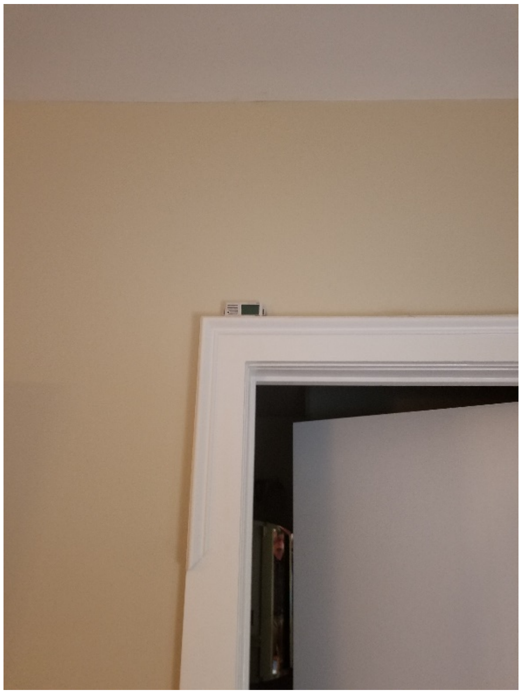


CTs on Each of the Four Outdoor Units



Electrical Panel and eGauge Monitoring Box

Outdoor Units



Temperature/RH Logger in 1st Fl Living Room

Temperature Logger in 1st Fl Master Bedroom

Natural Gas Storage DHW

Natural Gas Boiler

Monitoring Installation Notes – EFG Site 6

Monitoring Installation Date: May 21st, 2018

Installers: Nick Genzel, Carina Paton

Site Overview: Two-story, three-bedroom residence with finished Basement

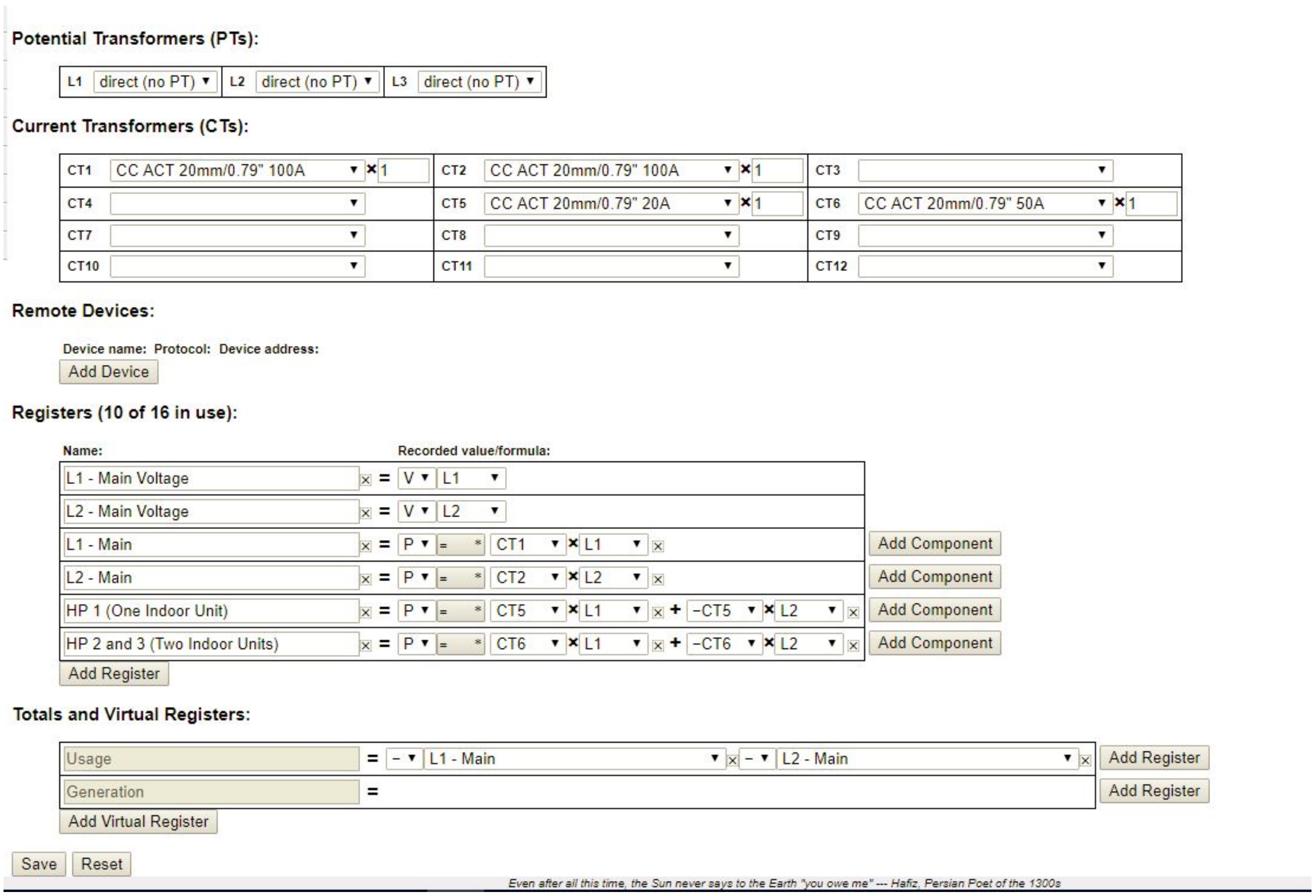
Appliances

- Natural Gas DHW
- Natural Gas Furnace
- Heat pump
  - Mitsubishi split-system heat pump
  - Outdoor units:
    - One Model MUZ-FH06NA (1 zone - Basement Room)
    - One Model MUZ-FH18NA2 (1 zone – Living Room)
    - One Model MUZ-FH12NA (1 zone – Master Bedroom)
  - All indoor units have remote controls

Monitoring Summary

- eGauge:
  - Total home L1 (voltage, power)
  - Total home L2 (voltage, power)
  - Heat pump 1 power (one phase)
  - Heat pump 2 and 3 power (one phase) *Note: One MUZ-FH06NA and one MUZ-FH18NA2 where wired together outside, so only one double-pole 50 AMP breaker was utilized in the main electrical panel. This then does not allow us to measure the two outdoor units separately.*
- Battery-powered loggers:
  - Conditioned space (on wooden china cabinet in living room): temperature, relative humidity
    - Serial: 20263928
  - Conditioned space (bedside table in master bedroom): temperature
    - Serial: 20244169
  - Conditioned space (basement bedroom - resident placed): temperature
    - Serial: 20244170

eGauge Setup

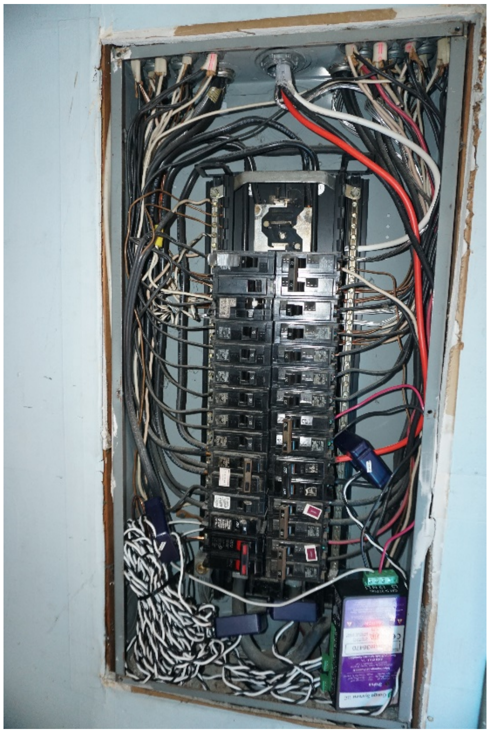


Physical Label	CT	Rating	Data Point	Logging
1	CT1	100 A	Utility Phase 1	Net, volt, apparent
2	CT2	100 A	Utility Phase 2	Net, volt, apparent
5	CT5	20 A	Heat Pump 1	Net, apparent
6	CT6	50 A	Heat Pump 2 and 3	Net, apparent

Other Notes

- Electrical panel was flush with drywall in garage, so we were not able to mount M&V enclosure. The eGauge is being powered from an open 30 AMP double-pole breaker.

Photos



eGauge and CTs

Smaller Outdoor Unit (Model #MUZ-FH06NA)

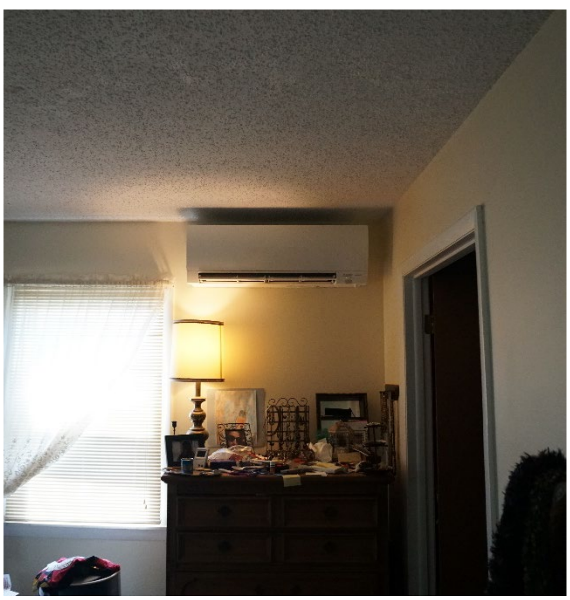
Separate Breaker Box/Subpanel by Outdoor Units

Two of Three Outdoor Units

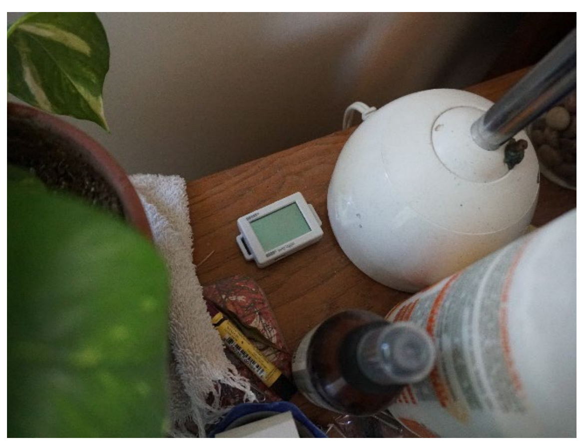
Larger Outdoor Unit (Model # MUZ-FH18NA2)

Living Room Indoor Unit

Temperature/RH Data Logger in Living Room



Master Bedroom Indoor Unit



Temperature Data Logger in Master Bedroom

Monitoring Installation Notes – EFG Site 7

Monitoring Installation Date: August 22nd, 2018

Installers: Nick Genzel, Dan Robb

Site Overview: Two-story, three-bedroom residence with finished Basement

Appliances

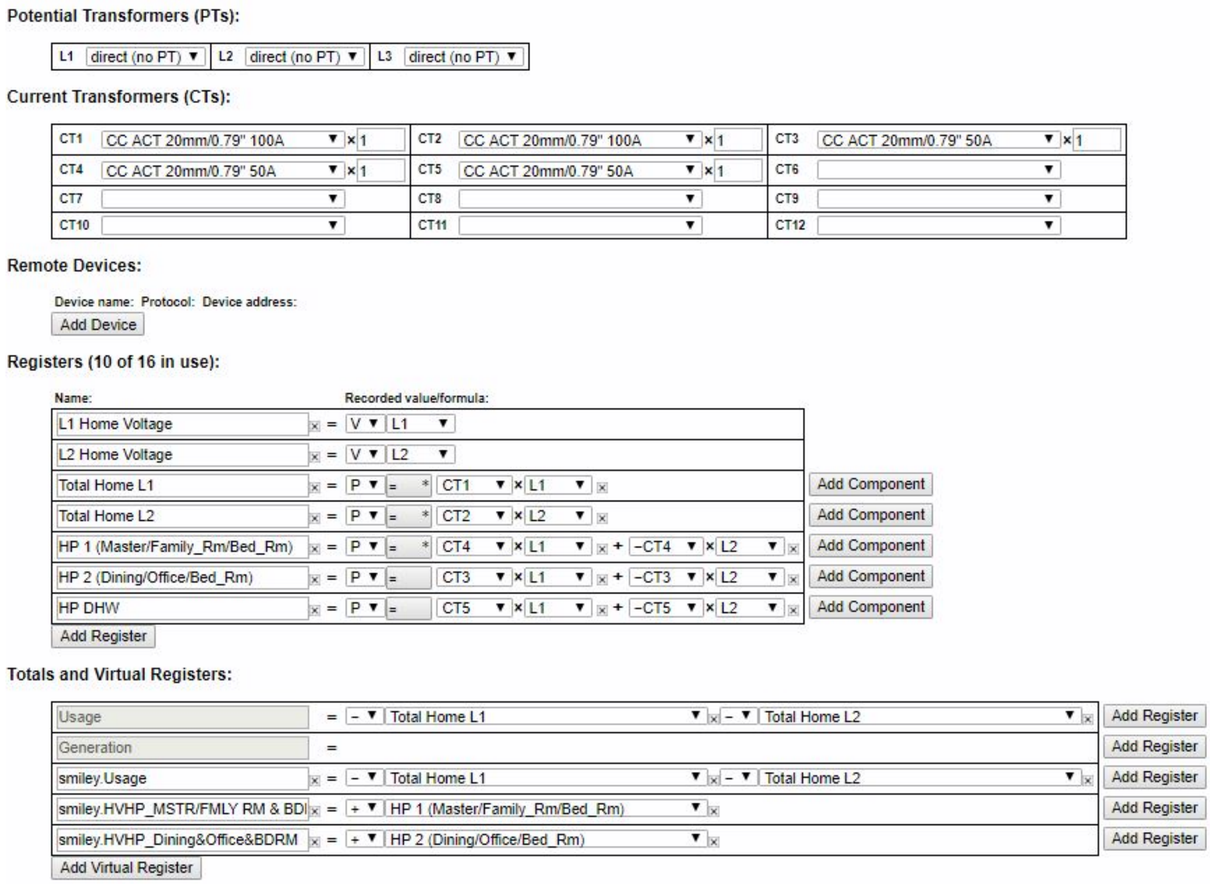
- Electric Heat Pump DHW
- Natural Gas Boiler
- Heat pump
    - Mitsubishi split-system heat pump
    - Outdoor units:
        - One Model MXZ-3C24NAHZ2 (HP1: 3 - Master Bedroom, Family Room, Bedroom)
        - One Model MXZ-3C24NAHZ2 (HP2: 3 zone – Kitchen/Dining Area, Office, Bedroom)
    - All indoor units have remote controls

Monitoring Summary

- eGauge:
    - Total home L1 (voltage, power)
    - Total home L2 (voltage, power)
    - Heat pump 1 power (one phase)
    - Heat pump 2 power (one phase)
    - Electric Heat Pump Water Heater (one phase)

- Battery-powered loggers:
    - Conditioned space (window molding in living room): temperature, relative humidity
        - Serial: 20391245
    - Conditioned space (window molding in family room): temperature
        - Serial: 20404173
    - Conditioned space (window molding in master bedroom): temperature
        - Serial: 20404172

eGauge Setup

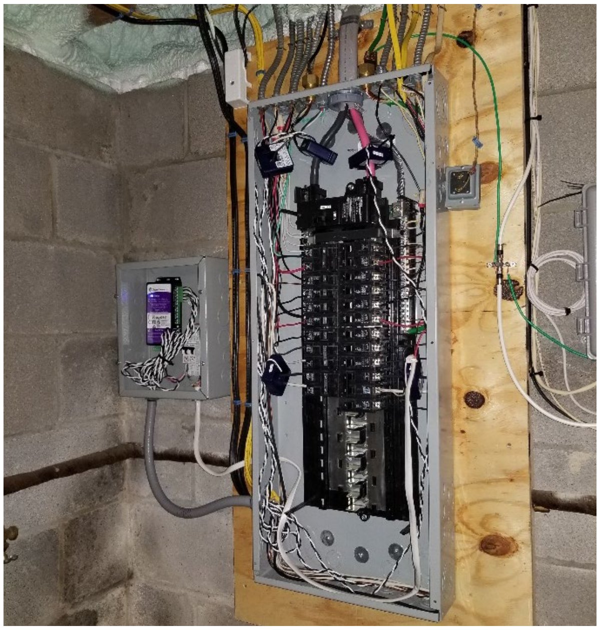


CT	CT Rating	Data Point	Logging
CT1	100 A	Utility Phase 1	Net, volt, apparent
CT2	100 A	Utility Phase 2	Net, volt, apparent
CT3	50 A	Heat Pump 1 (Master Bedroom, Family Room, Bedroom)	Net, apparent
CT4	50 A	Heat Pump 2 (Kitchen/Dining Area, Office, Bedroom)	Net, apparent
CT5	50 A	Heat Pump DHW	Net, apparent

Other Notes

- Data collection for ASHPs to begin on 9/4/2018 due to sign orientation error on eGauge.

Photos



eGauge Enclosure with CTs in Electrical Panel

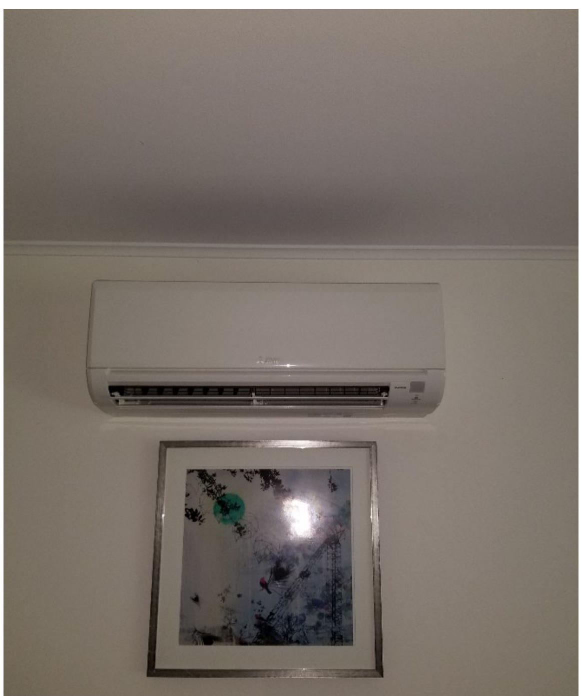
Electric Heat Pump DHW Tank

Master Bdrm, Family Rm, Kids Bdrm - Outdoor Unit
Model #MXZ-3C24NAHZ2

Kitchen/Dining/Living Rm, Office, Bdrm
Model #MXZ-3C24NAHZ2

1 of 2 Outdoor Units - Nameplate
Model #MXZ-3C24NAHZ2

1 of 2 Outdoor Units - Nameplate
Model #MXZ-3C24NAHZ2



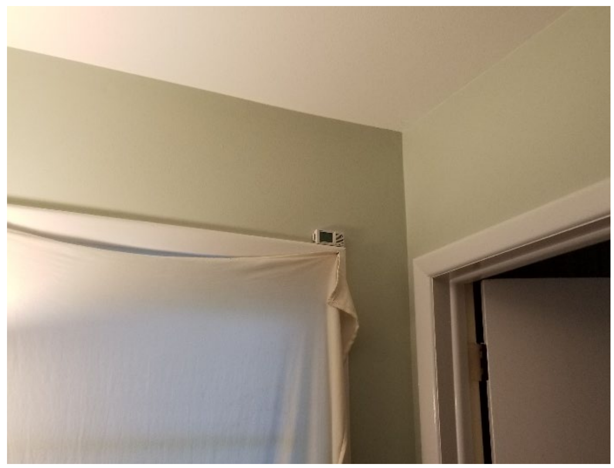
Family Room Indoor Unit

Temperature Data Logger in Family Room

Kitchen/Dining/Living Room Indoor Unit

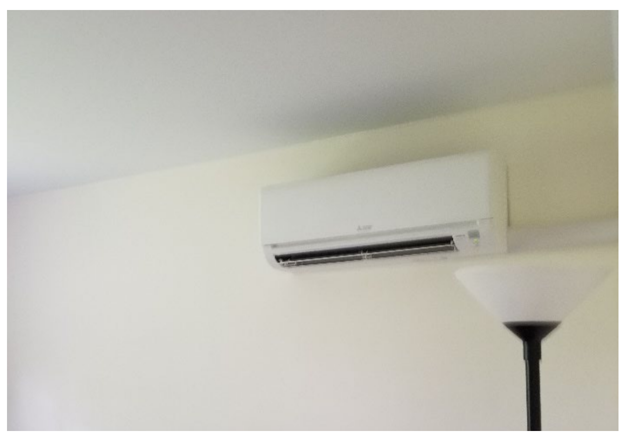
Temperature Data Logger in Living Room

Master Bedroom Indoor Unit

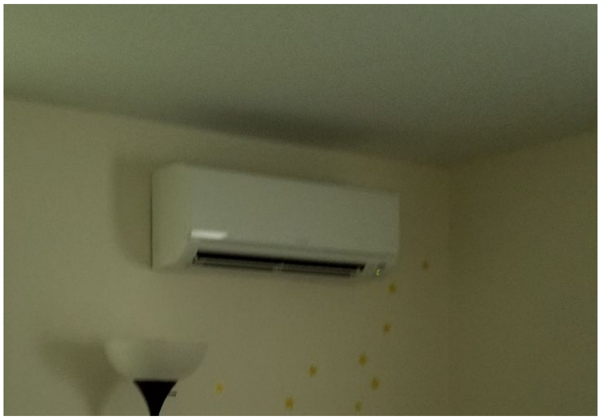


Temperature/RH Data Logger in Master Bedroom

Office Indoor Unit



Kids Bedroom Indoor Unit



Kids Bedroom Indoor Unit

Monitoring Installation Notes – EFG Site 8

Monitoring Installation Date: June 19th, 2018

Installers: Nick Genzel, Jeremy Wade

Site Overview: Two-story, three-bedroom residence with unfinished Basement

Appliances

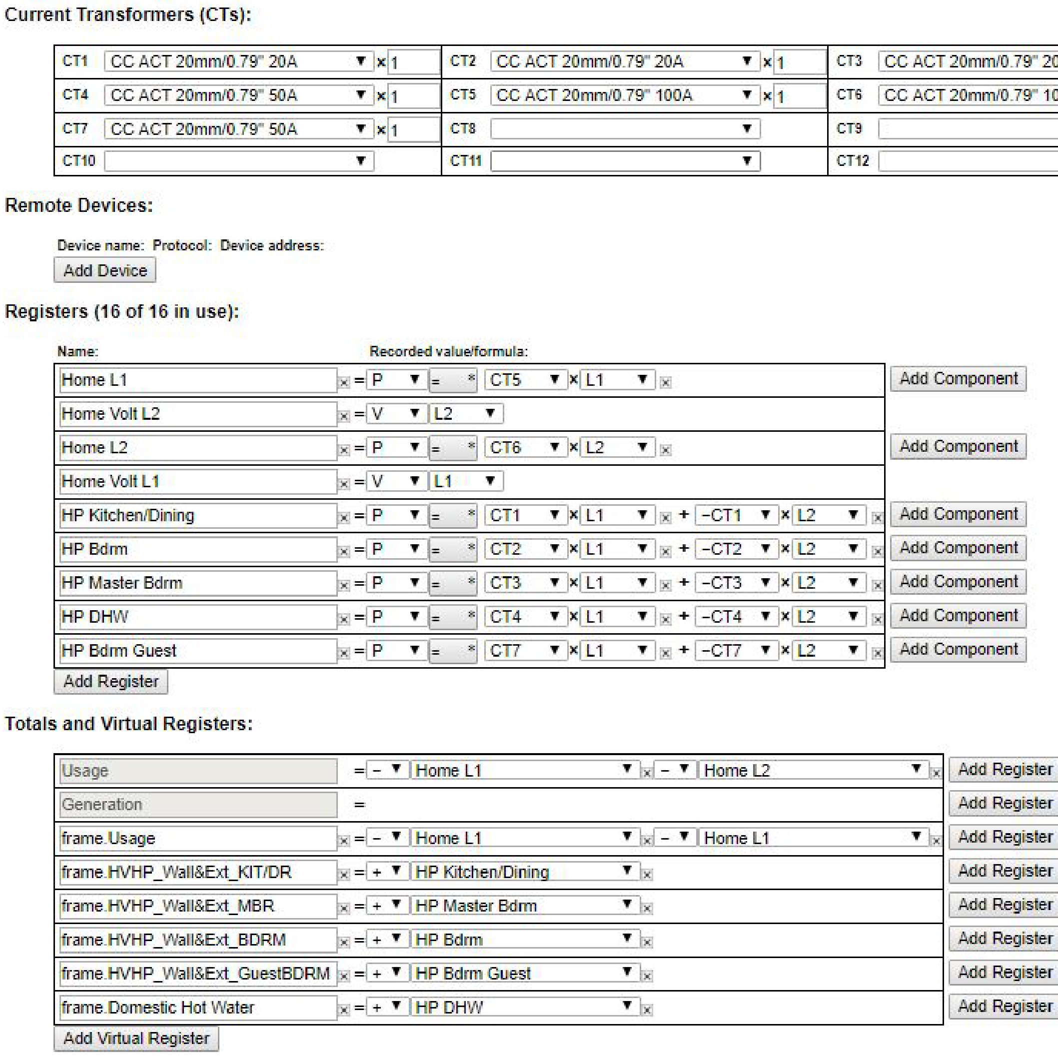
- Electric Heat Pump DHW
- Oil Boiler
- Heat pump
  - Mitsubishi split-system heat pump
  - Outdoor units:
    - One Model MUZ-FH18NA2 (HP1: 1 zone – Kitchen/Dining Area)
    - One Model MUZ-FH06NA (HP2: 1 zone - Bedroom (Nursery))
    - One Model MUZ-FH06NA (HP3: 1 zone – Master Bedroom)
    - One Model MUZ-FH06NA (HP4: 1 zone – Guest Bedroom)
  - All indoor units have remote controls

Monitoring Summary

- eGauge:
  - Total home L1 (voltage, power)
  - Total home L2 (voltage, power)
  - Heat pump 1 power (one phase)
  - Heat pump 2 power (one phase)
  - Heat pump 3 power (one phase)
  - Heat pump 4 power (one phase)
  - Electric Heat Pump Water Heater (one phase)

- Battery-powered loggers:
  - Conditioned space (on built-ins by refrigerator): temperature, relative humidity
    - Serial: 20391247
  - Conditioned space (nightstand master bedroom): temperature
    - Serial: 20244174
  - Conditioned space (nightstand in guest bedroom): temperature
    - Serial: 20404176

eGauge Setup



Current Transformers (CTs):

CT1	CC ACT 20mm/0.79" 20A	×1	CT2	CC ACT 20mm/0.79" 20A	×1	CT3	CC ACT 20mm/0.79" 20A	×1
CT4	CC ACT 20mm/0.79" 50A	×1	CT5	CC ACT 20mm/0.79" 100A	×1	CT6	CC ACT 20mm/0.79" 100A	×1
CT7	CC ACT 20mm/0.79" 50A	×1	CT8			CT9		
CT10			CT11			CT12		

Remote Devices:

Device name: Protocol: Device address:

Add Device

Registers (16 of 16 in use):

Name:	Recorded value/formula:
Home L1	= P = CT5 × L1
Home Volt L2	= V L2
Home L2	= P = CT6 × L2
Home Volt L1	= V L1
HP Kitchen/Dining	= P = CT1 × L1 + -CT1 × L2
HP Bdrm	= P = CT2 × L1 + -CT2 × L2
HP Master Bdrm	= P = CT3 × L1 + -CT3 × L2
HP DHW	= P = CT4 × L1 + -CT4 × L2
HP Bdrm Guest	= P = CT7 × L1 + -CT7 × L2

Add Register

Totals and Virtual Registers:

Usage	= - Home L1 - Home L2
Generation	=
frame.Usage	= - Home L1 - Home L1
frame.HVHP_Wall&Ext_KIT/DR	= + HP Kitchen/Dining
frame.HVHP_Wall&Ext_MBR	= + HP Master Bdrm
frame.HVHP_Wall&Ext_BDRM	= + HP Bdrm
frame.HVHP_Wall&Ext_GuestBDRM	= + HP Bdrm Guest
frame.Domestic Hot Water	= + HP DHW

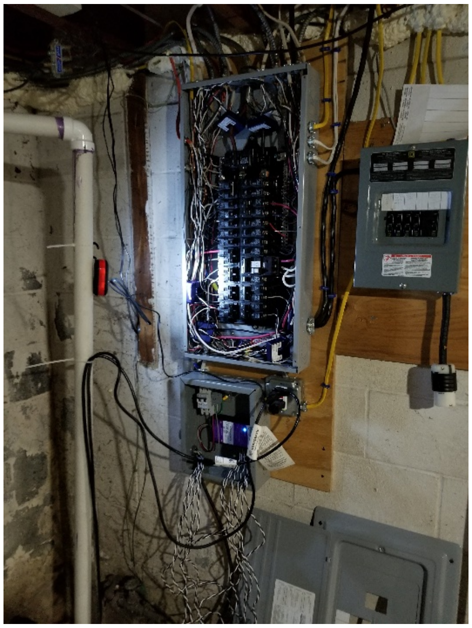
Add Virtual Register

Physical Label	CT	CT Rating	Data Point	Logging
7	CT5	100 A	Utility Phase 1	Net, volt, apparent
8	CT6	100 A	Utility Phase 2	Net, volt, apparent
3	CT1	20 A	Heat Pump 1 (Kitchen/Dining)	Net, apparent
4	CT2	20 A	Heat Pump 2 (Bedroom (Nursery))	Net, apparent
5	CT3	20 A	Heat Pump 3 (Master Bedroom)	Net, apparent
9	CT7	20 A	Heat Pump 4 (Guest Bedroom)	Net, apparent
6	CT4	50 A	Heat Pump DHW	Net, apparent

Other Notes

- None

Photos



eGauge Enclosure with CTs in Electrical Panel

Electric Heat Pump DHW

Kitchen/Dining and Master Bedroom Outdoor Units

1 of 3 Smaller Outdoor Units
(Nursery - Model #MUZ-FH06NA)

1 of 3 Smaller Outdoor Units
(Guest Bedroom - Model #MUZ-FH06NA)

1 of 3 Smaller Outdoor Units
(Guest Bedroom - Model #MUZ-FH06NA)

Larger Outdoor Unit (Model # MUZ-FH18NA2*)*

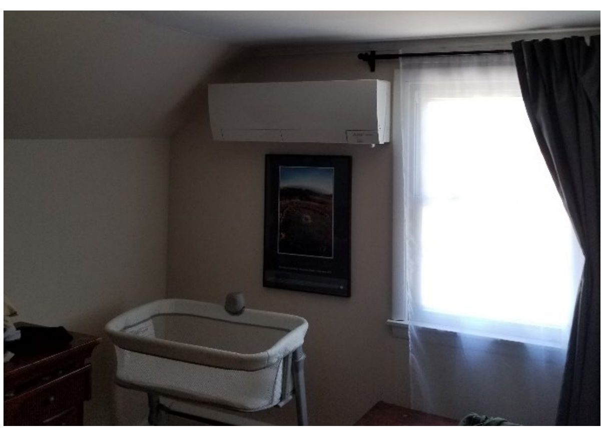
Larger Outdoor Unit (Model # MUZ-FH18NA2*)*

Kitchen/Dining Area Indoor Unit

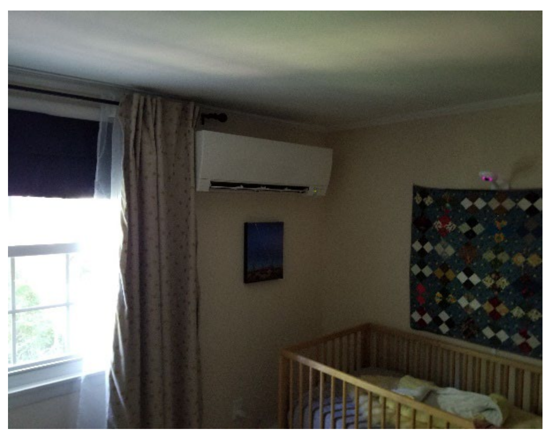
Temperature/RH Data Logger in Kitchen/Dining Area

Guest Bedroom Indoor Unit

Temperature Data Logger in Guest Bedroom



Master Bedroom Indoor Unit



Nursery Indoor Unit

Monitoring Installation Notes – EFG Site 9

Monitoring Installation Date: July 19th, 2018

Installers: Nick Genzel, Jeremy Wade

Site Overview: Two-story + Basement, two-bedroom residence with finished Basement

Appliances

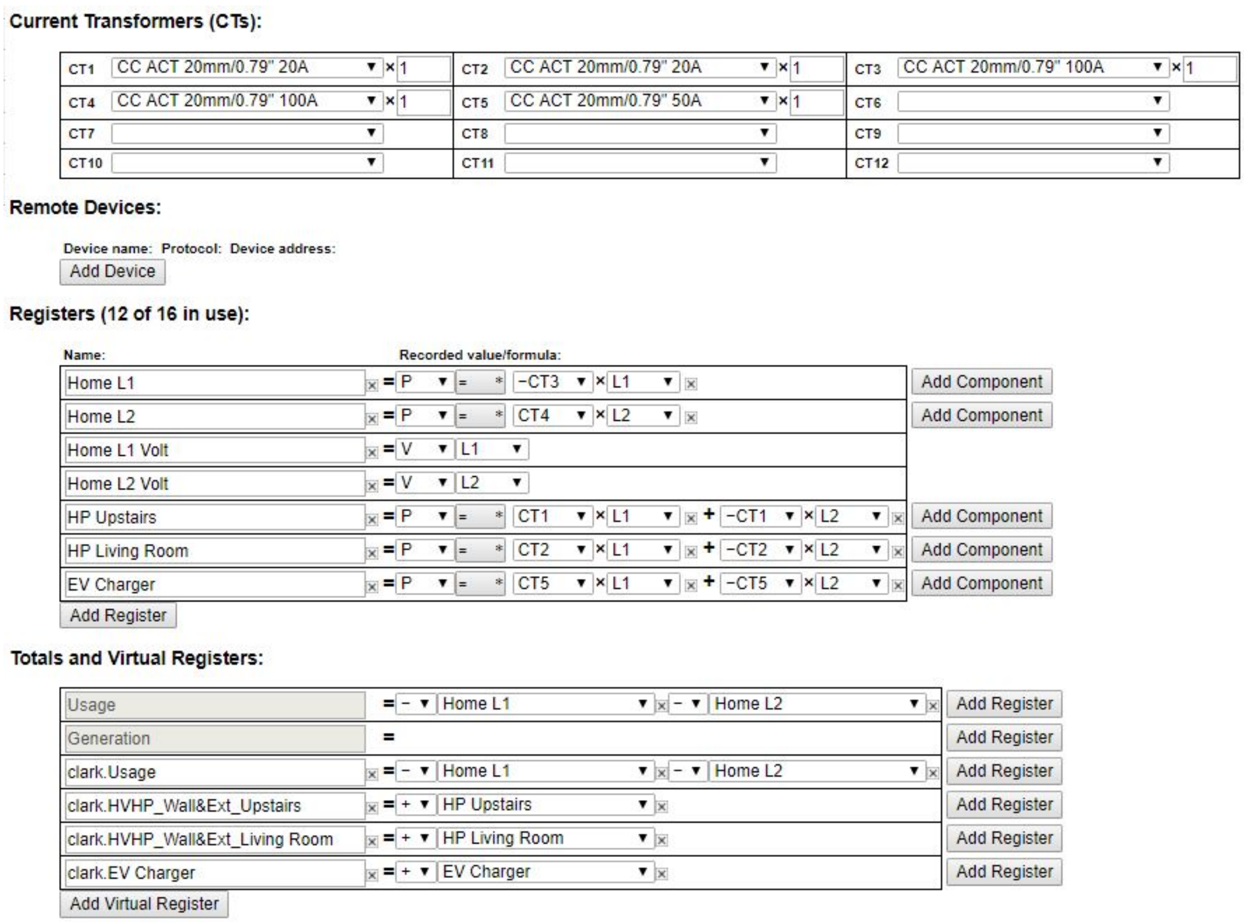
- Propane DHW
- Propane Furnace
- Heat pump
  - Mitsubishi split-system heat pump
  - Outdoor units:
    - One Model MUZ-FH12NA (HP1: 1 zone – Upstairs)
    - One Model MUZ-FH18NA2 (HP2: 1 zone – Living Room)
  - All indoor units have remote controls

Monitoring Summary

- eGauge:
  - Total home L1 (voltage, power)
  - Total home L2 (voltage, power)
  - Heat pump 1 power (one phase)
  - Heat pump 2 power (one phase)
  - EV Charger – Under construction when at site. Left a CT in the electrical panel for the electrician to add to the breaker powering the charging station.

- Battery-powered loggers:
  - Conditioned space (by chimney in living room): temperature, relative humidity
    - Serial: 20263929
  - Conditioned space (behind small table in the kitchen/dining area): temperature
    - Serial: 20404177
  - Conditioned space (upstairs office on top of bookshelf): temperature
    - Serial: 20244167

eGauge Setup

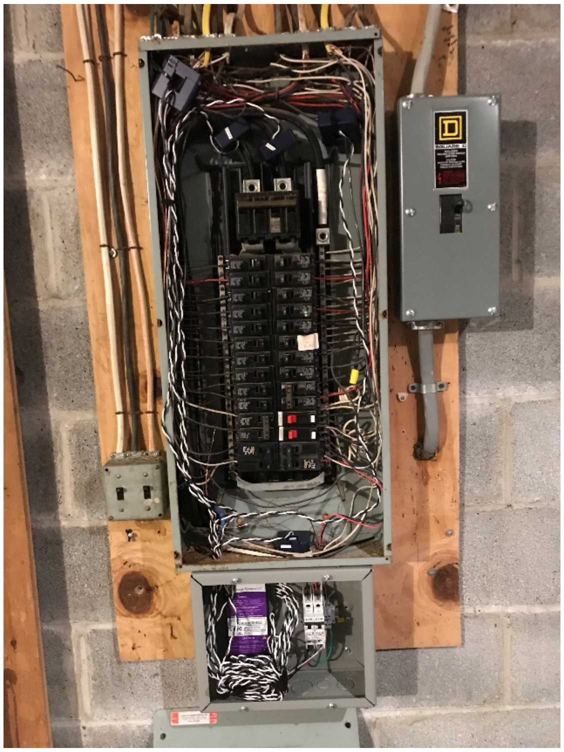


Physical Label	CT	Rating	Data Point	Logging
5	CT3	100 A	Utility Phase 1	Net, volt, apparent
6	CT4	100 A	Utility Phase 2	Net, volt, apparent
3	CT1	20 A	Heat Pump 1 (Upstairs)	Net, apparent
4	CT2	20 A	Heat Pump 2 (Living Room)	Net, apparent
7	CT5	50 A	EV Charger	Net, apparent

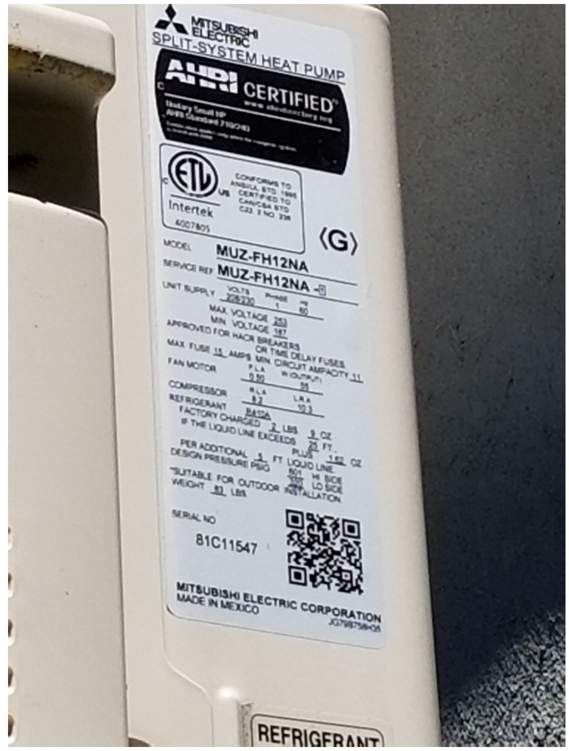
Other Notes

- EV Charging Station not Installed.

Photos



eGauge and CTs



Smaller Outdoor Unit (Model #MUZ-FH06NA)

Larger Outdoor Unit (Model # MUZ-FH18NA2)

Both Outdoor Units

Upstairs Indoor Unit

Temperature/RH Data Logger in Living Room

Temperature Data Logger in Kitchen/Dining Area

Temperature Data Logger Upstairs

Living Room Indoor Unit

Monitoring Installation Notes – EFG Site 10

Monitoring Installation Date: September 27th, 2018 and Mid-October

Installers: Nick Genzel, Juravell

Site Overview: Two-story + Basement, three-bedroom home with unfinished Basement

Appliances

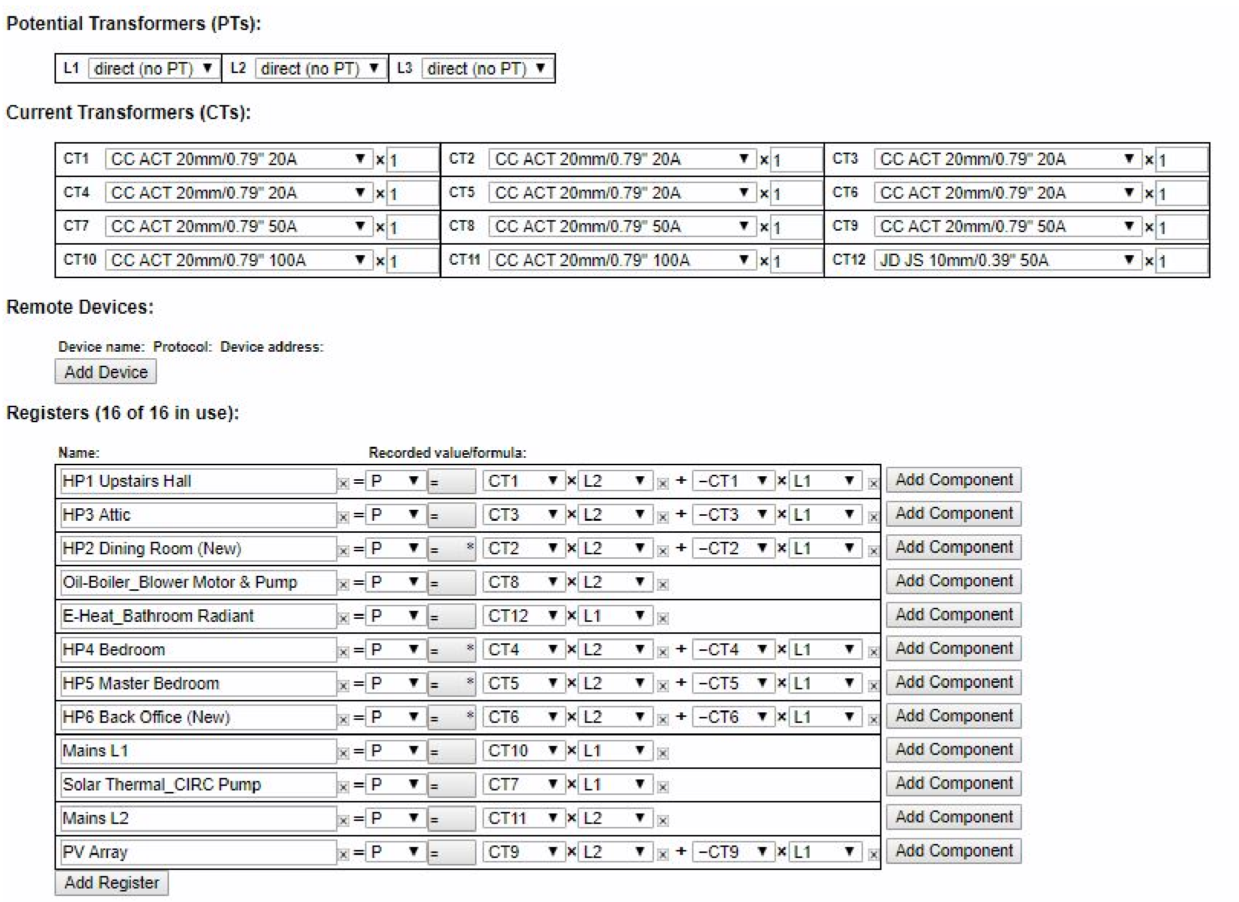
- Oil DHW
- Oil Boiler
- Heat pump
  - Mitsubishi split-system heat pump
  - New Outdoor units:
    - One Model MUZ-FH06NA (HP6: 1 zone – First Floor Office)
    - One Model MUZ-FH18NA2 (HP2: 1 zone – Dinning Room)
  - Old Outdoor units:
    - One Model (HP1: 1 zone – Upstairs Hall)
    - One Model (HP3: 1 zone – Attic)
    - One Model (HP4: 1 zone – Upstairs Bedroom / Office)
    - One Model (HP5: 1 zone – Master Bedroom)
  - All indoor units have remote controls

Monitoring Summary

- eGauge:
  - Total home L1 (voltage, power)
  - Total home L2 (voltage, power)
  - Heat pump 1 power (one phase)
  - Heat pump 2 power (one phase)
  - Heat pump 3 power (one phase)
  - Heat pump 4 power (one phase)
  - Heat pump 5 power (one phase)
  - Heat pump 6 power (one phase)
  - PV Array (one phase) *Note: Sperate larger array from garage*
  - Solar Thermal Circulator Pump
  - Boiler Blower and Motor

- Battery-powered loggers:
  - Conditioned space (Master Bedroom on Thermostat): temperature, relative humidity
    - Serial: 20391246
  - Conditioned space (Upstairs Bedroom / Office on Thermostat): temperature
    - Serial: 20404179
  - Conditioned space (Living Room on Thermostat): temperature
    - Serial: 20404171

eGauge Setup

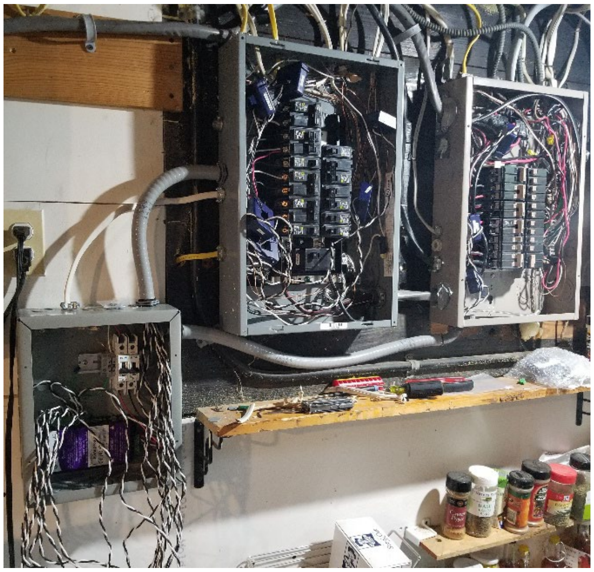


Physical Label	CT	Rating	Data Point	Logging
None	CT10	100 A	Utility Phase 1	Net
None	CT11	100 A	Utility Phase 2	Net
0	CT1	20 A	Heat Pump 1 (Upstairs Hall)	Net
4	CT2	20 A	Heat Pump 2 (Dining Room)	Net, apparent
5	CT3	20 A	Heat Pump 3 (Attic)	Net
6	CT4	20 A	Heat Pump 4 (Bedroom / Office)	Net, apparent
7	CT5	20 A	Heat Pump 5 (Master Bedroom)	Net, apparent
8	CT6	20 A	Heat Pump 6 (First Floor Office)	Net, apparent
9	CT7	50 A	Solar Thermal Circ Pump	Net
55	CT8	50 A	Oil Boiler Blower and Motor	Net
45	CT9	50 A	PV Array	Net

Other Notes

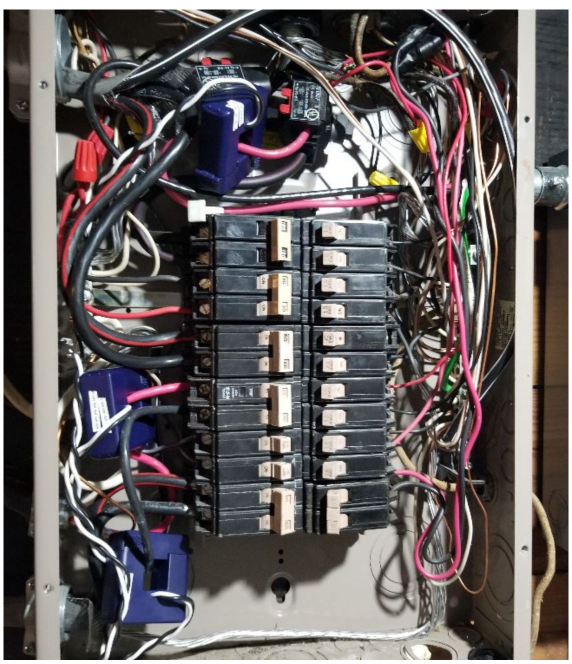
- Total home CTs installed by Juravell with Integral Building & Design Inc.

Photos

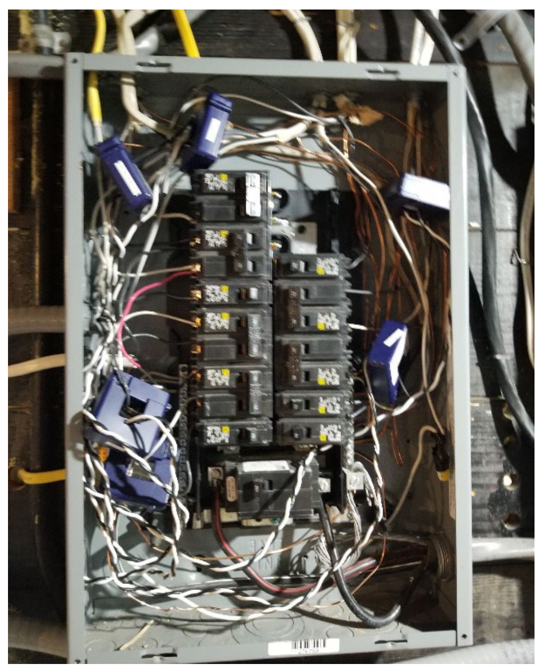


eGauge monitoring enclosure (Left) with CTs in a subpanel monitoring all six heat pumps (Middle) and CTs in a main electrical panel (Right) monitoring both mains, a garage subpanel, and a PV array on the roof of the home

eGauge monitoring enclosure



CTs in a main electrical panel monitoring both mains (not shown), a garage subpanel, and a PV array on the roof of the home



CTs in a subpanel monitoring all six heat pumps

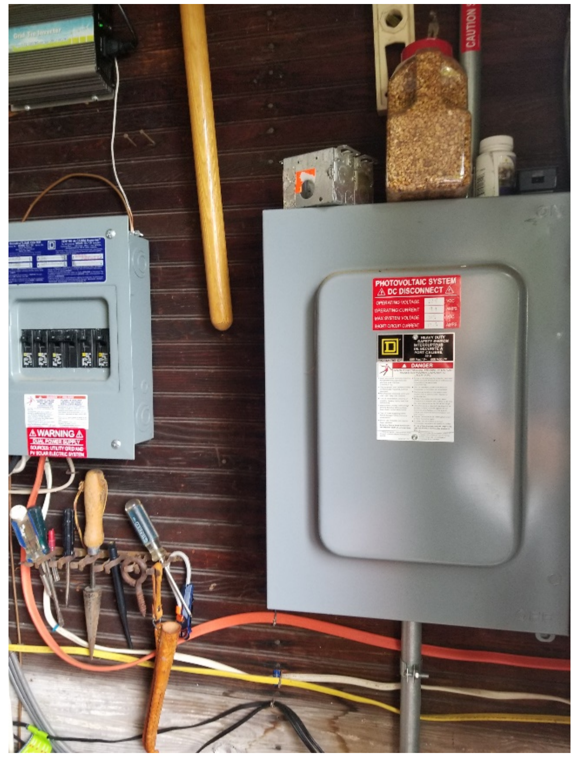
Larger Outdoor Unit (Model # MUZ-FH18NA2)

Smaller Outdoor Unit (Model # MUZ-FH06NA)

Two Old Outdoor Units and PV Array

Two Old Outdoor Units behind Solar Thermal Array (Bottom) and PV Arrray (Top)

Level 2 EV Charger Located in the Garage



Garage Subpael, PV Load Center, and Inverter

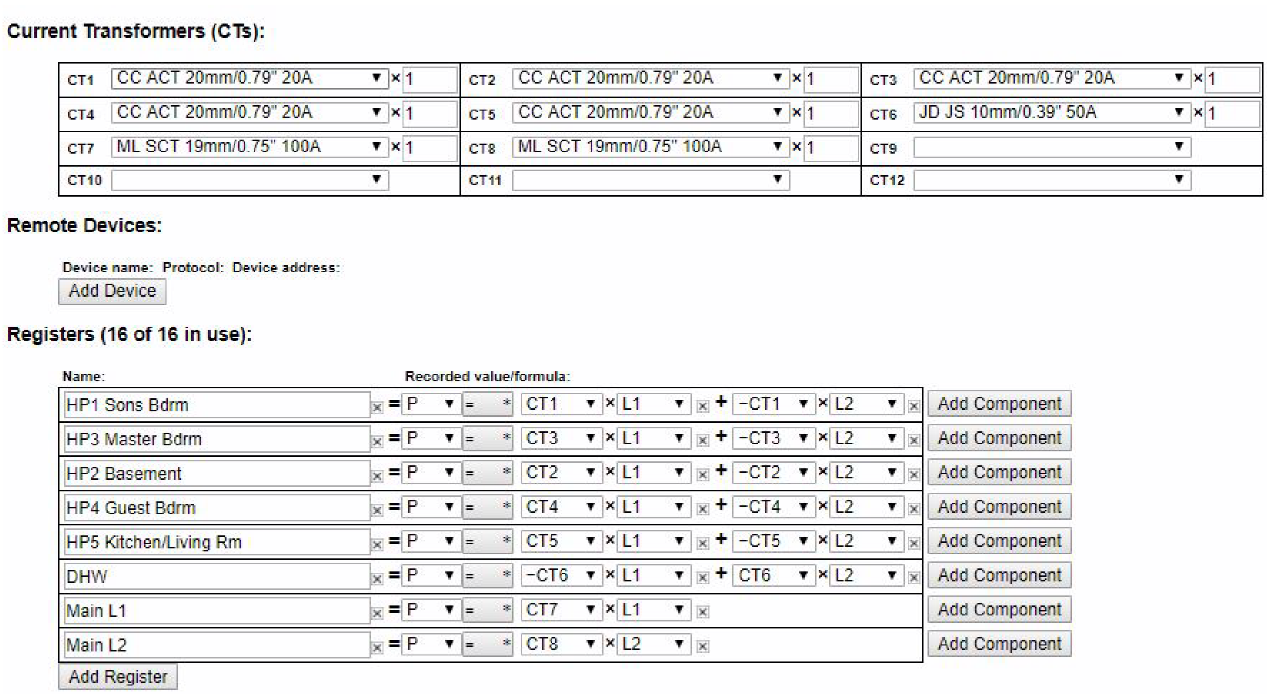
Monitoring Installation Notes – EFG Site 11

Monitoring Installation Date: February 2nd, 2019

Installers: Nick Genzel

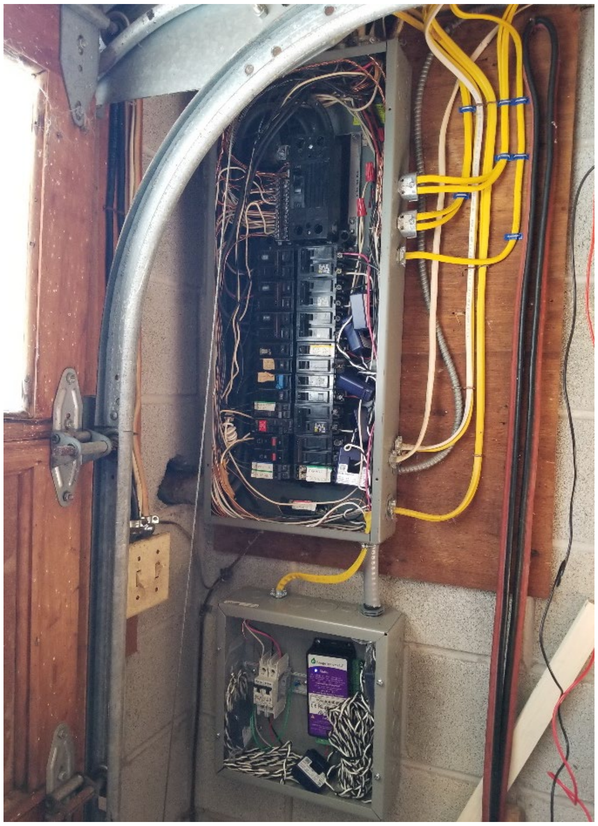
Site Overview: Two-story residence with partially finished basement

eGauge Setup



CT	Rating	Data Point	Logging
CT1	20 A	Heat Pump 1 – Son's Bedroom	Net, apparent
CT2	20 A	Heat Pump 2 – Finished Basement	Net, apparent
CT3	20 A	Heat Pump 3 – Master Bedroom	Net, apparent
CT4	20 A	Heat Pump 4 – Guest Bedroom	Net, apparent
CT5	20 A	Heat Pump 5 - Living Room / Kitchen	Net, apparent
CT6	50 A	Domestic Hot Water Heater	Net, apparent
CT7	100 A	Utility Phase 1	Net, apparent
CT8	100 A	Utility Phase 2	Net, apparent

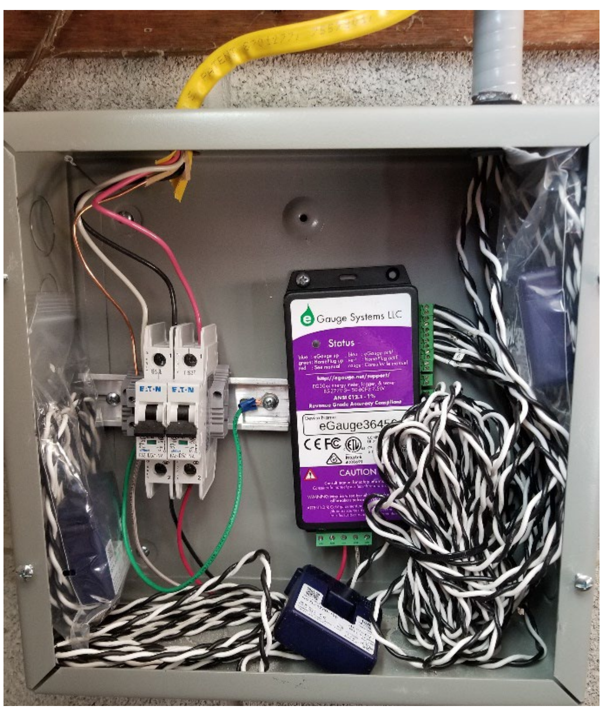
Photos



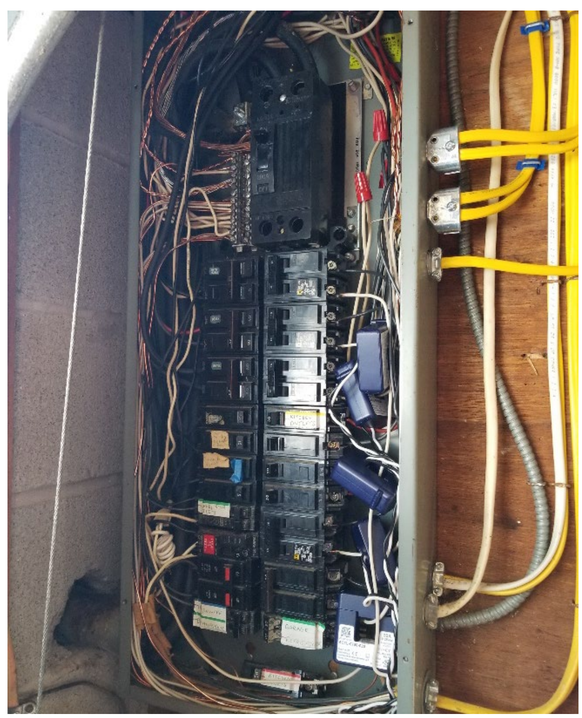
Main Electrical Panel with eGauge and CTs

One of Five Indoor Sections (Bedroom)

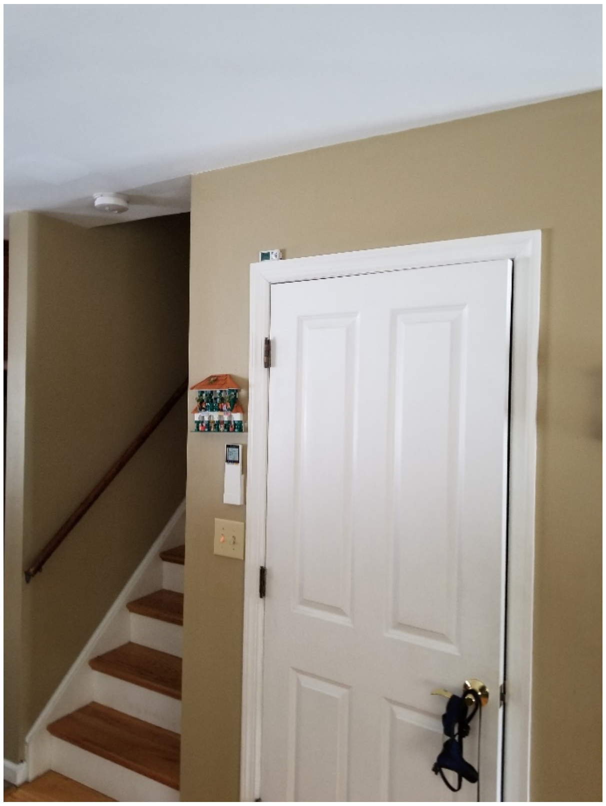
One of Five Indoor Sections

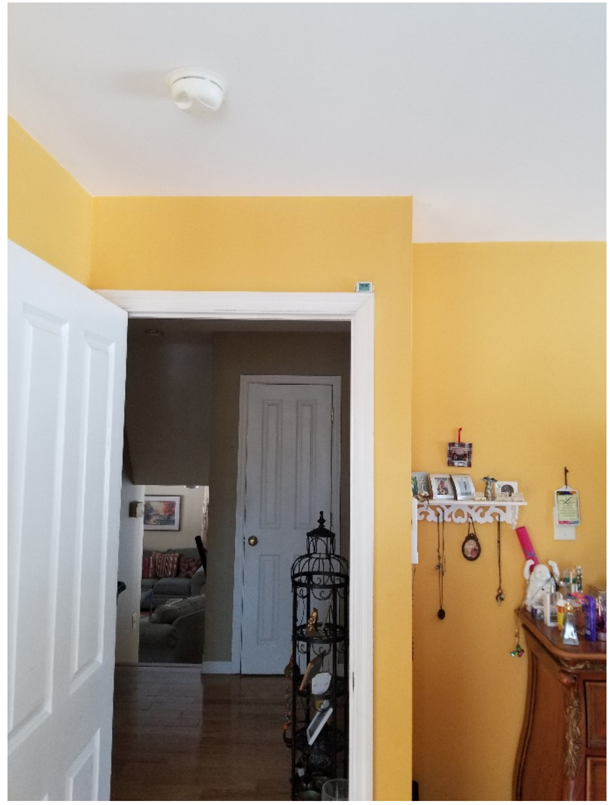


Data Logger Enclosure with eGauge



One of Five Outdoor Sections


Temperature/RH Data Logger in Kitchen


Temperature Data Logger in Master Bedroom

Monitoring Installation Notes – EFG Site 12

Monitoring Installation Date: November 1st, 2018

Installers: Nick Genzel

Site Overview: Two-story + Basement, three-bedroom home with unfinished Basement

Appliances

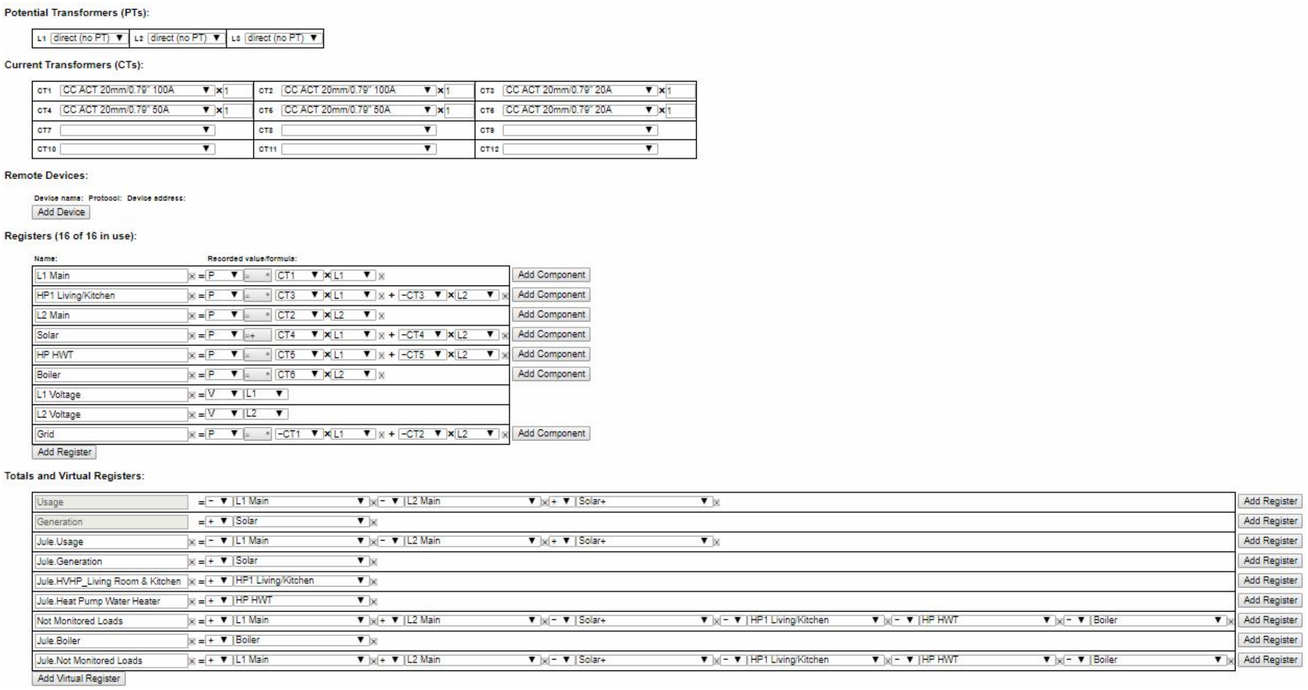
- Heat Pump HWT
- Oil Boiler with Indirect Tank (no longer used for DHW)
- Wood Stove
- Heat pump
  - Mitsubishi split-system heat pump
  - Outdoor units:
    - One Model MUZ-FH09NA (HP1: 1 zone – First Floor Living Rm / Kitchen)
  - All indoor units have remote controls

Monitoring Summary

- eGauge:
  - Total home L1 (voltage, power)
  - Total home L2 (voltage, power)
  - Heat pump 1 power (one phase power)
  - Heat pump HWT (one phase power)
  - PV Array (one phase power)
  - Boiler (power)

- Battery-powered loggers:
  - Un-Conditioned space (Second Floor Hallway): temperature
    - Serial: 20452662
  - Conditioned space (First Floor Hallway): temperature, relative humidity
    - Serial: 20483036
  - Conditioned space (Kitchen): temperature
    - Serial: 20452649

eGauge Setup

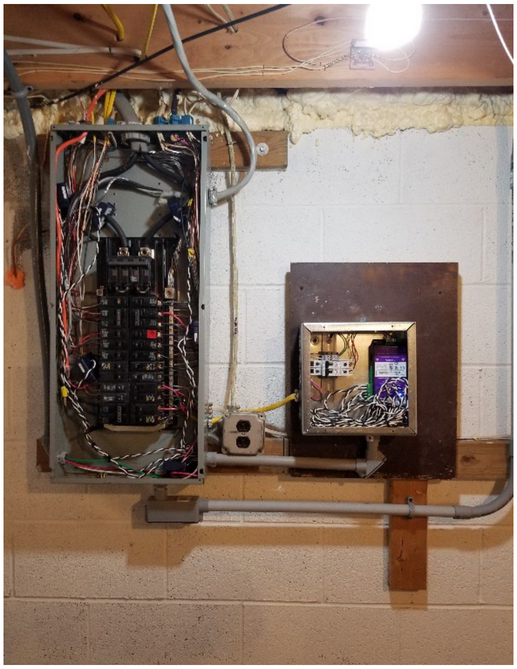


Physical Label	CT	Rating	Data Point	Logging
0	CT1	100 A	Phase 1 Main	Net, apparent, volt
4	CT2	100 A	Phase 2 Main	Net, apparent, volt
5	CT3	20 A	Heat Pump 1 (Living Rm / Kitchen)	Net, apparent
6	CT4	50 A	PV Array	Net
7	CT5	50 A	Heat Pump HWT	Net, apparent
8	CT6	20 A	Boiler	Net, apparent

Other Notes

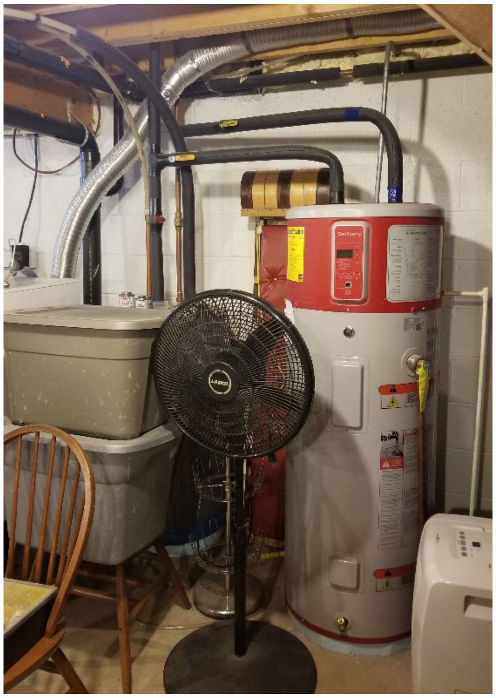
- PV Array 2.5 kW

Photos

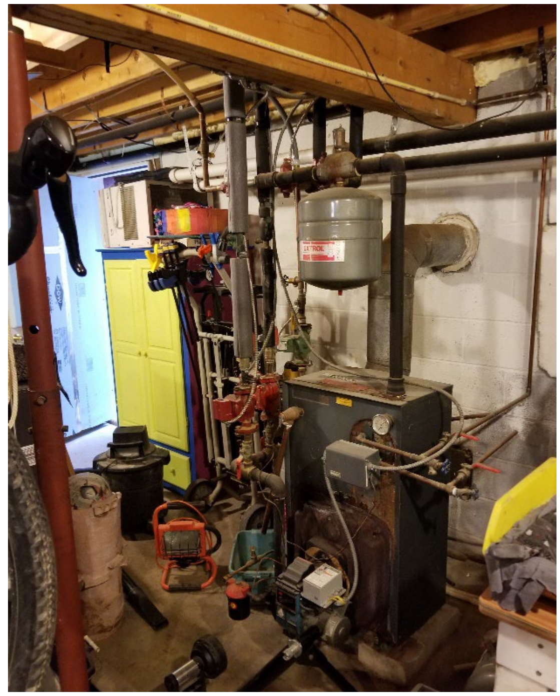


eGauge Monitoring Enclosure (Right) with CTs in Electrical Panel (Left)

eGauge Information



General Electric 50 Gallon Heat Pump HWT



Weil-McLain 109 Btu/hr Oil Boiler

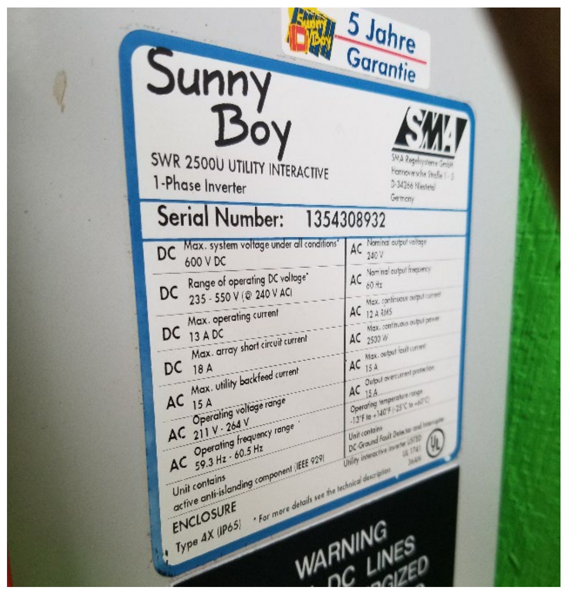
Outdoor Unit (Model #MUZ-FH09NA) Back of Home

Heat Pump Specs

2.5 kW PV Array on Garage

"Sunny Boy" Inverter on Garage

Utility Clean Energy Meter Located on Garage



"Sunny Boy" Inverter Specs on Garage

Temp Sensor in Kitchen / Living Room

Temp/RH Sensor in First Floor Hallway

Monitoring Installation Notes – EFG Site 13

Monitoring Installation Date: October 30th, 2018

Installers: Nick Genzel

Site Overview: Two-story, three-bedroom home

Appliances

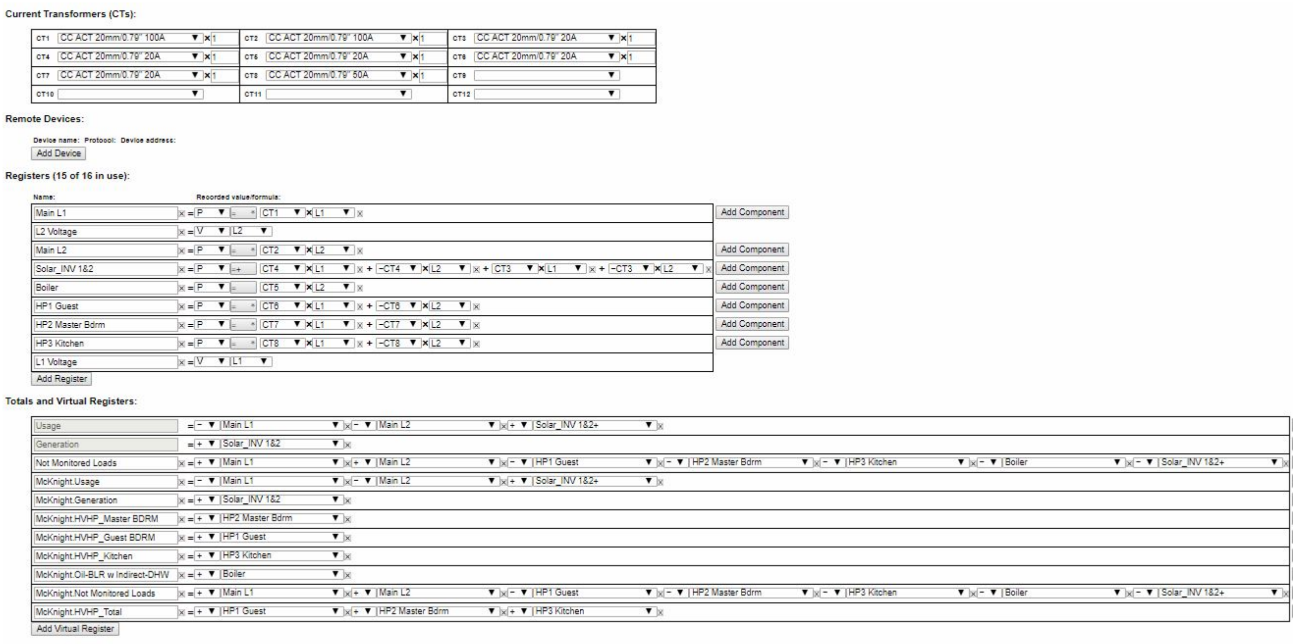
- Oil Boiler with Indirect Tank
- Heat pump
    - Mitsubishi split-system heat pump
    - Outdoor units:
        - One Model MUZ-FH12NA (HP1: 1 zone – Guest Bdrm)
        - One Model MUZ-FH12NA (HP2: 1 zone – Master Bdrm)
        - One Model MUZ-FH18NA (HP3: 1 zone – First Floor Dining Rm/Kitchen)
    - All indoor units have remote controls

Monitoring Summary

- eGauge:
    - Total home L1 (voltage, power)
    - Total home L2 (voltage, power)
    - Heat pump 1 power (one phase, power)
    - Heat pump 2 power (one phase, power)
    - Heat pump 3 power (one phase, power)
    - PV Array Inv 1 (one phase, power)
    - PV Array Inv 2 (one phase, power)
    - Boiler (power)

- Battery-powered loggers:
    - Conditioned space (Guest Bdrm): temperature
        - Serial: 20452650
    - Conditioned space (Master Bdrm): temperature, relative humidity
        - Serial: 20483031
    - Conditioned space (Kitchen): temperature
        - Serial: 20452651

eGauge Setup

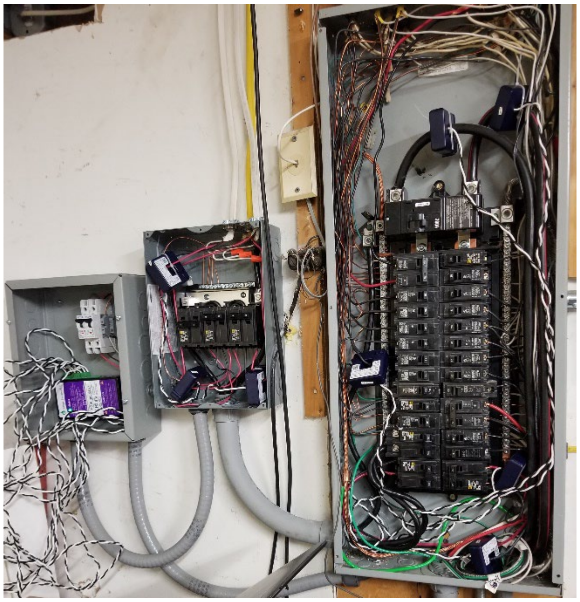


Physical Label	CT	Rating	Data Point	Logging
0	CT1	100 A	Phase 1 Main	Net, apparent, volt
4	CT2	100 A	Phase 2 Main	Net, apparent, volt
5	CT3	20 A	PV Inv 1	Net
6	CT4	20 A	PV Inv 2	Net
7	CT5	20 A	Boiler	Net
8	CT6	20 A	HP1 Guest Bdrm	Net, apparent
9	CT7	20 A	HP2 Master Bdrm	Net, apparent
99	CT8	50 A	HP3 Kitchen / Dining Rm	Net, apparent

Other Notes

- PV Array 7.0 kW

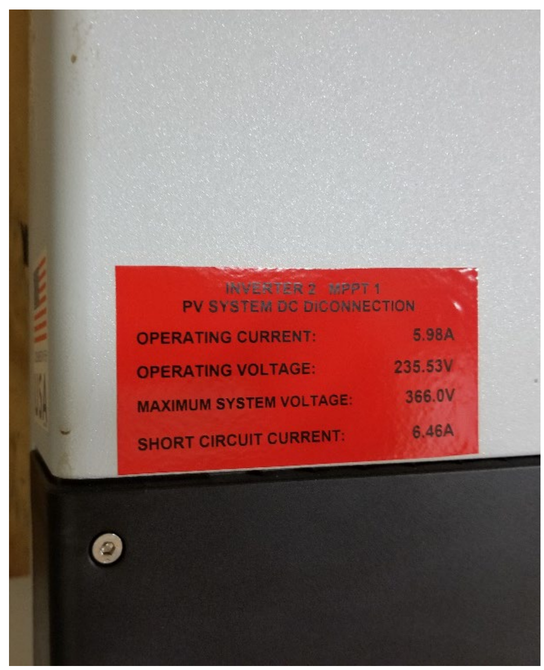
Photos



eGauge Monitoring Enclosure (Left), Heat Pump Panel with CTs (Middle), and Electrical Panel with CTs (Left)

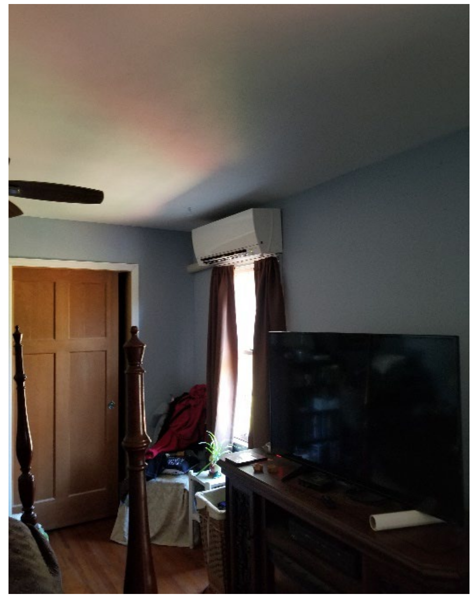
eGauge Information

SunPower Inv 1 & 2 in Garage



SunPower Inv 2 Specs in Garage

Guest Bedroom Indoor Unit



Master Bedroom Indoor Unit

Kitchen/Dining Room Indoor Unit

One Model MUZ-FH12NA (Left)
One Model MUZ-FH18NA (Right)

Outdoor Unit (Model #MUZ-FH12NA) Side of Home

Outdoor Unit (Model #MUZ-FH12NA) Side of Home

Temp/RH Sensor in Living Room

Temp Sensor in Guest Bedroom

Temp Sensor in Kitchen

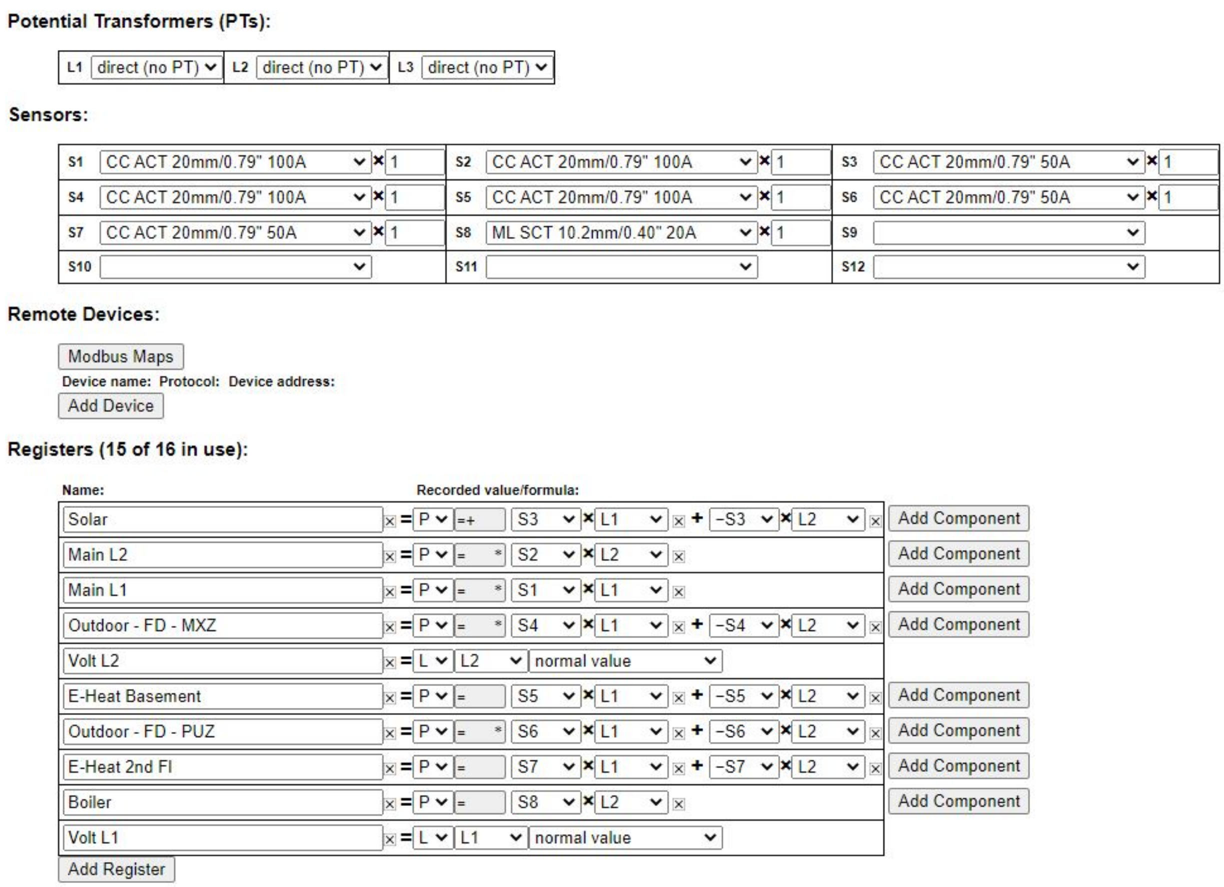
Monitoring Installation Notes – EFG Site 14

Monitoring Installation Date: February 20th, 2019

Installers: Nick Genzel, Juravell

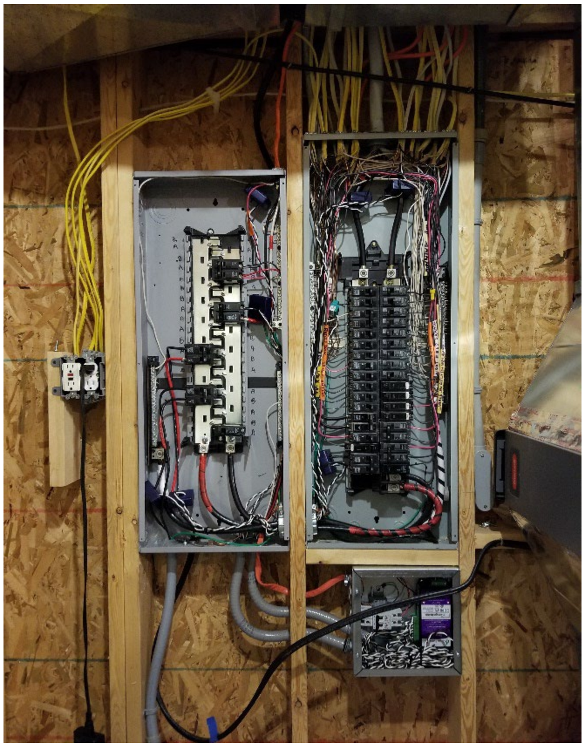
Site Overview: Two-story residence with partially finished basement

eGauge Setup

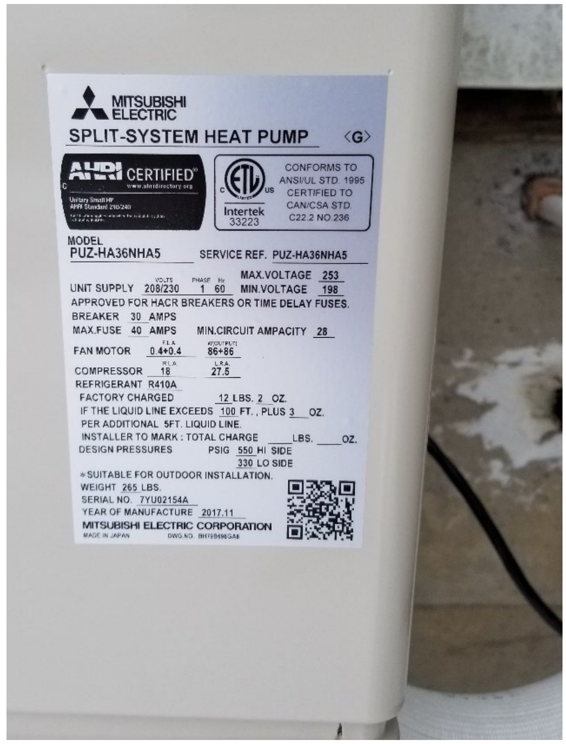


CT	Rating	Data Point	Logging
CT1	100 A	Utility Phase 1	Net, apparent
CT2	100 A	Utility Phase 2	Net, apparent
CT3	50 A	Solar	Net, Positive
CT4	100 A	Heat Pump MXZ	Net, apparent
CT5	100 A	Auxiliary Duct Element – MXZ	Net
CT6	50 A	Heat Pump PUZ	Net, apparent
CT7	50 A	Auxiliary Duct Element – PUZ	Net
CT8	20 A	Boiler	Net

Photos



Main Electrical Panels with eGauge and CTs

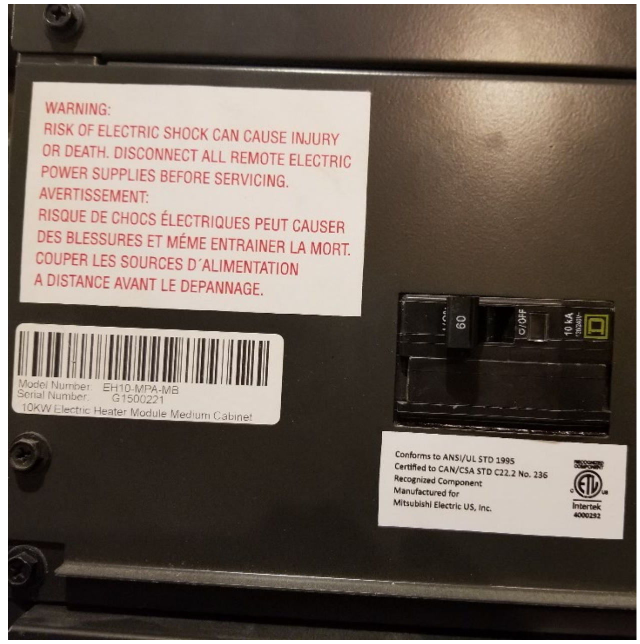


Smaller Outdoor Unit (Model #PUZ-HA36NHA5)

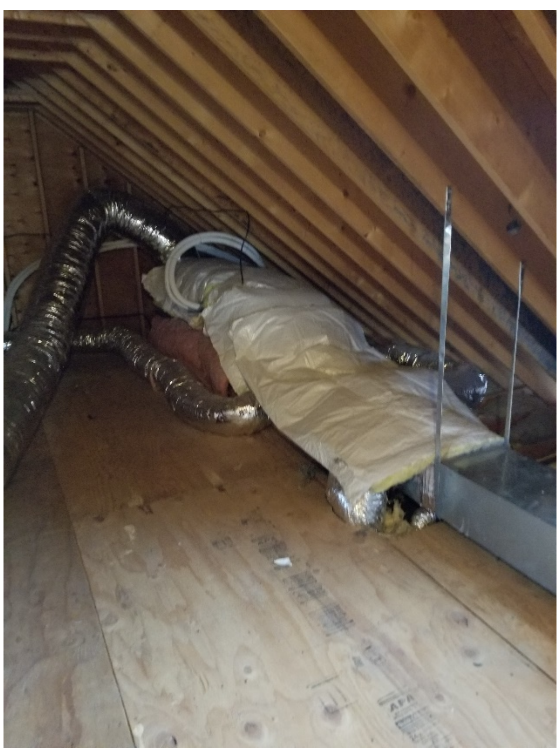
Data Logger Enclosure with eGauge

One of Two Outdoor Units

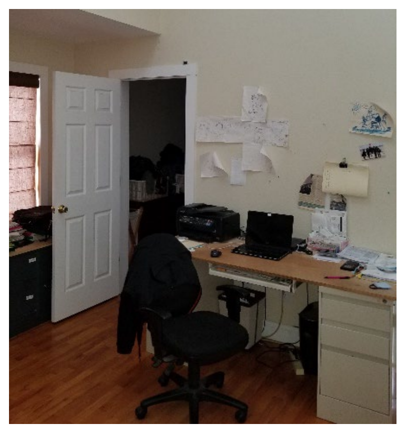
Air Handler Located in Basement



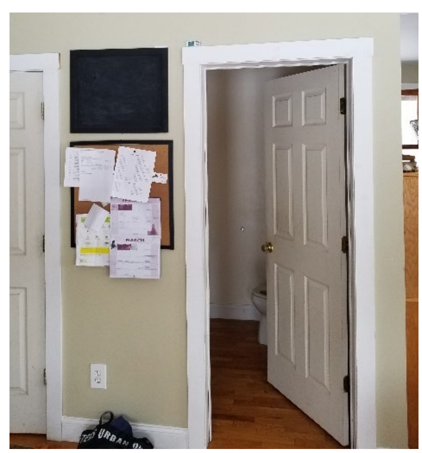
Auxiliary Duct Heating Element



Air Handler Located in Attic



Temperature Data Logger in Upstairs Bedroom



Temperature/RH Data Logger in Living Room

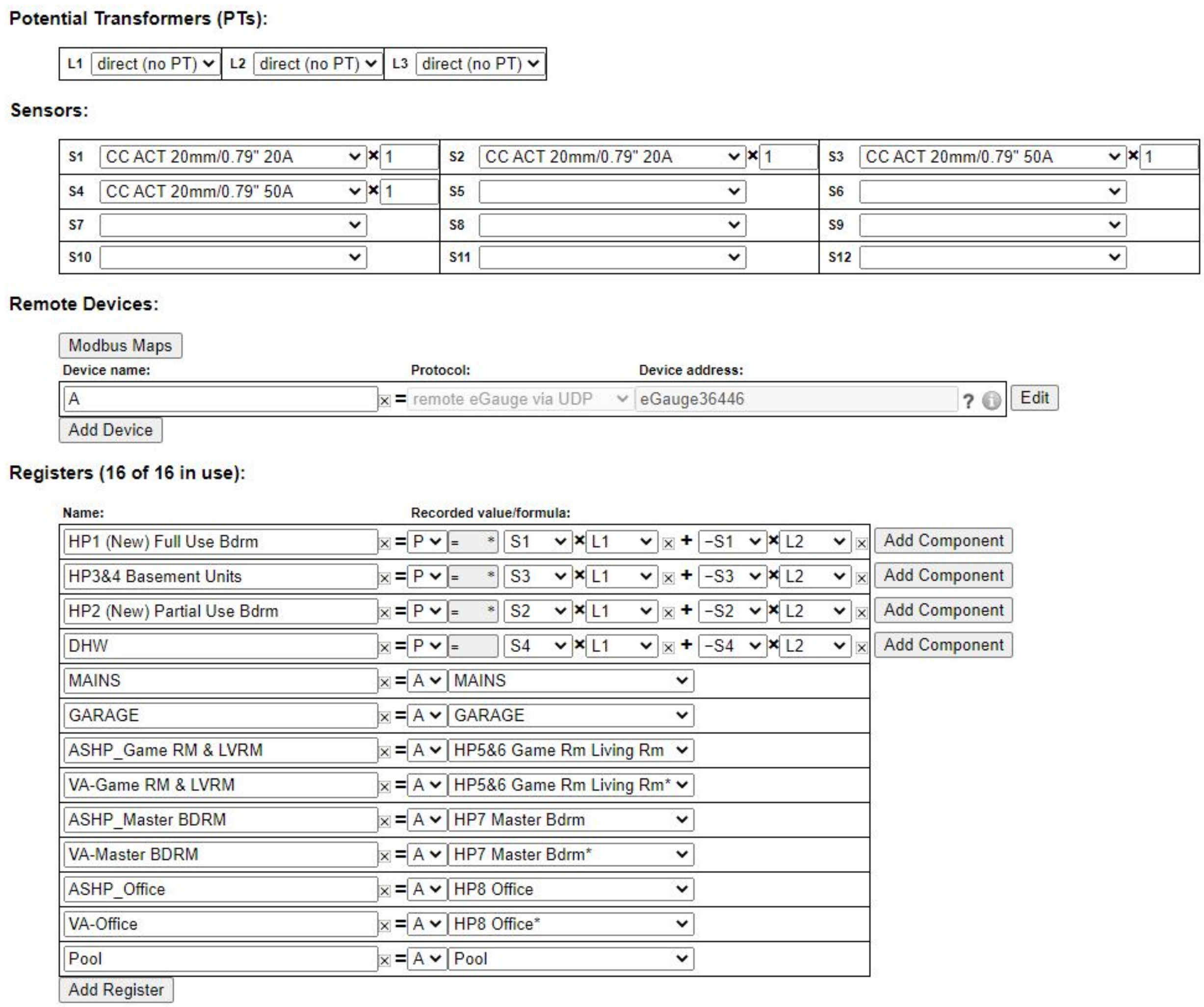
Monitoring Installation Notes – EFG Site 15

Monitoring Installation Date: March 28th, 2019

Installers: Nick Genzel, Juravell

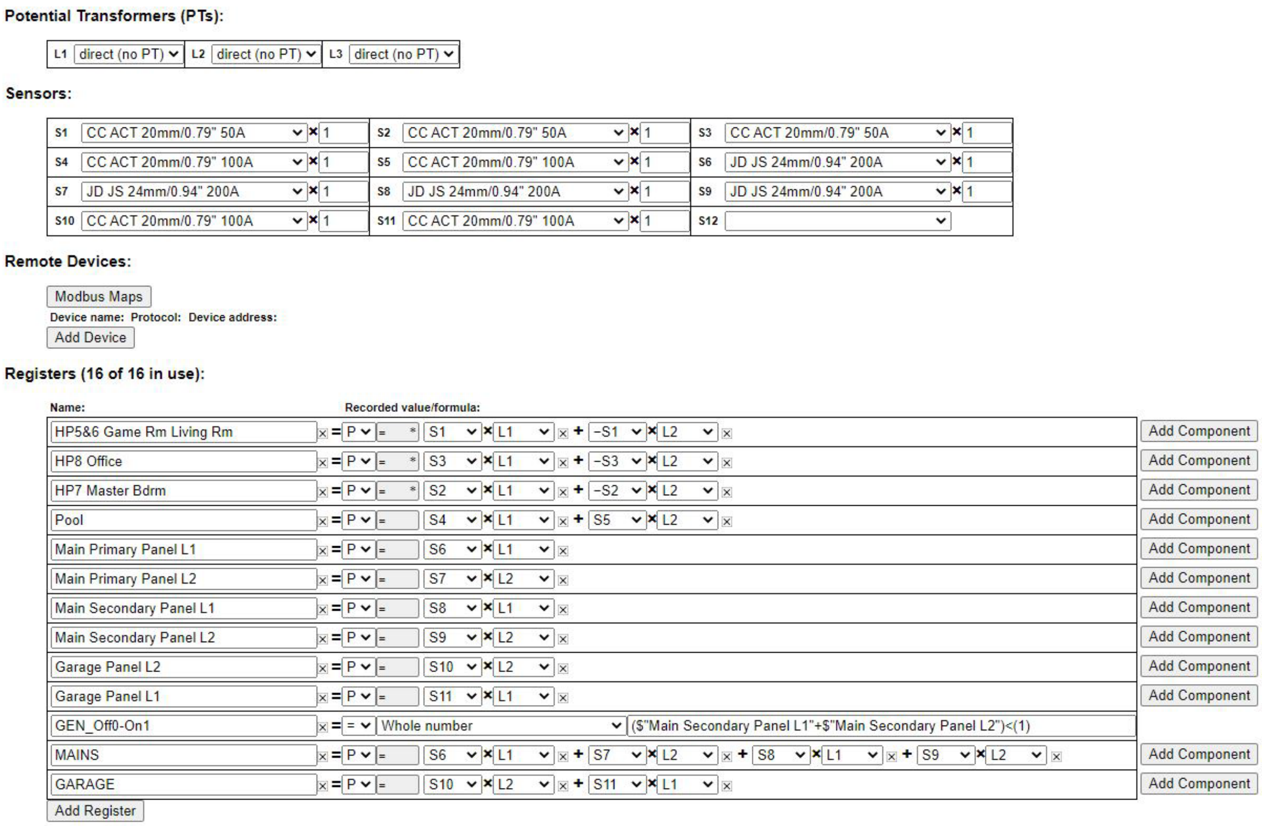
Site Overview: Two-story residence with finished basement

eGauge 36449 Setup



CT	Rating	Data Point	Logging
CT1	20 A	Heat Pump 1 - Bedroom	Net, apparent
CT2	20 A	Heat Pump 2 - Bedroom	Net, apparent
CT3	50 A	Heat Pump 3&4 - Basement	Net, apparent
CT4	50 A	DHW	Net

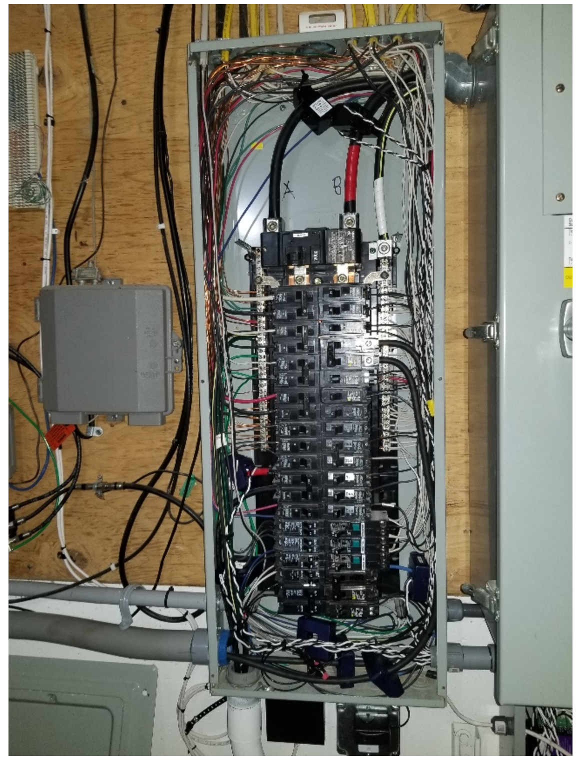
eGauge 36446 Setup



CT	Rating	Data Point	Logging
CT1	50 A	Heat Pump 5&6 - Game & Living Rm	Net, apparent
CT2	50 A	Heat Pump 7 - Master Bedroom	Net, apparent
CT3	50 A	Heat Pump 8 - Office	Net, apparent
CT4	100 A	Pool Phase 1	Net
CT5	100 A	Pool Phase 2	Net
CT6	200 A	Utility Phase 1	Net
CT7	200 A	Utility Phase 2	Net
CT8	200 A	Main Secondary Phase 1	Net
CT9	200 A	Main Secondary Phase 2	Net
CT10	100 A	Garage Phase 1	Net
CT11	100 A	Garage Phase 2	Net

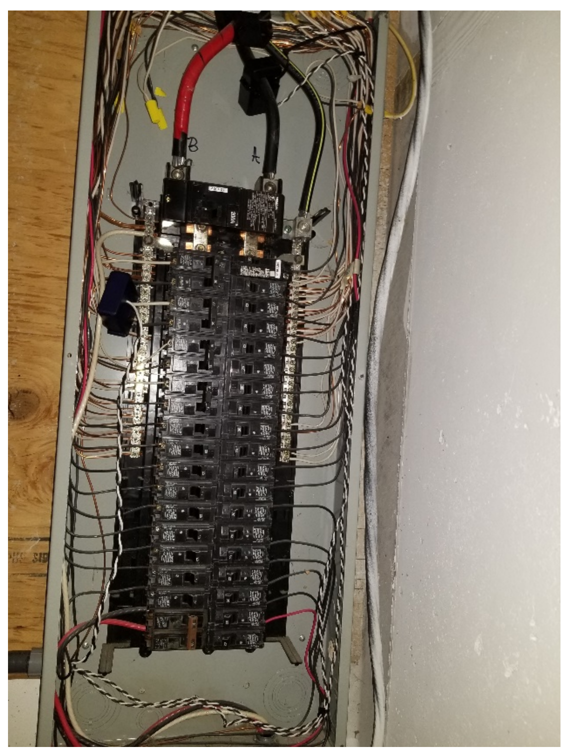
Photos

Main Electrical Panels with eGauge 36446 Enclosure

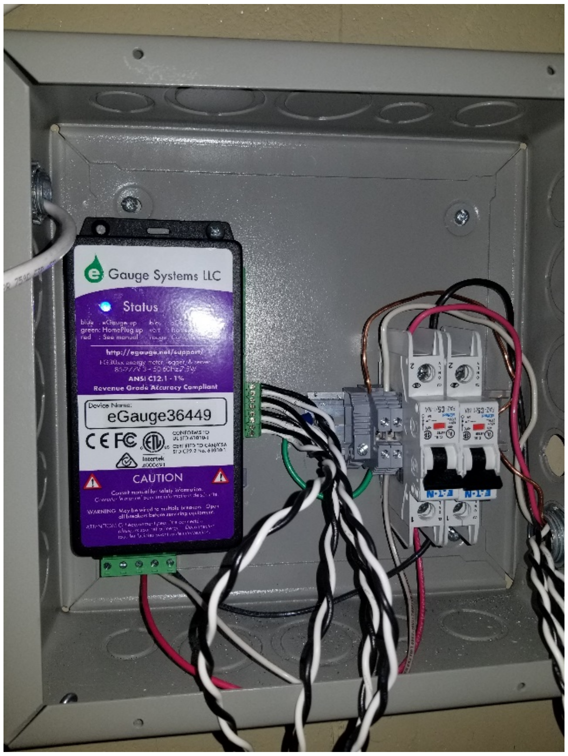


Right Electrical Panel with Installed CTs

eGauge 36446 Enclosure



Left Electrical Panel with Installed CTs



eGauge 36449 Enclosure

Subpanel with eGauge 36449 Enclosure
and Installed CTs

Indoor Section Located in Full Use Bedroom

Temperature Data Logger in Master Bedroom

Temperature/RH Data Logger in Living Room

Monitoring Installation Notes – EFG Site 16

Monitoring Installation Date: March 7th, 2019

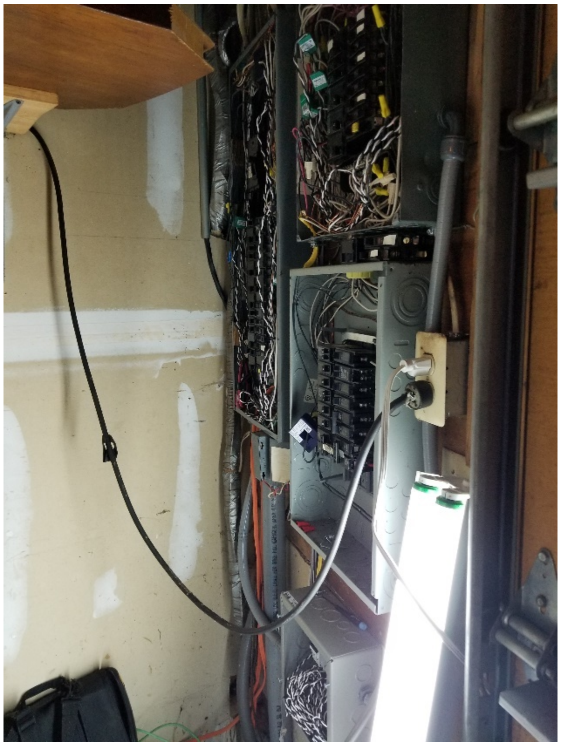
Installers: Nick Genzel

Site Overview: Two-story residence with finished basement

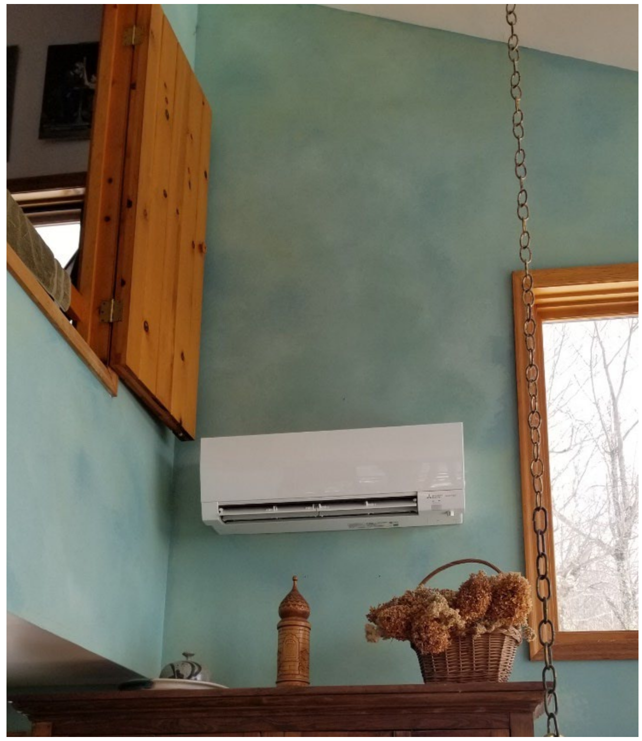
eGauge Setup – No Settings Screen Available

CT	Rating	Data Point	Logging
CT1	100 A	Utility Phase 1	Net, apparent
CT2	100 A	Utility Phase 2	Net, apparent
CT3	20 A	Heat Pump 1 - Living Room	Net, apparent
CT4	20 A	Heat Pump 2 - Living Room	Net, apparent
CT5	20 A	Heat Pump 3 - Finished Basement	Net, apparent
CT6	50 A	Domestic Hot Water Heater 1	Net, apparent
CT7	50 A	Domestic Hot Water Heater 2	Net, apparent
CT8	50 A	Electric Resistance Heat (4 Strips)	Net, apparent
CT9	50 A	Electric Resistance Heat (1 Strip)	Net, apparent

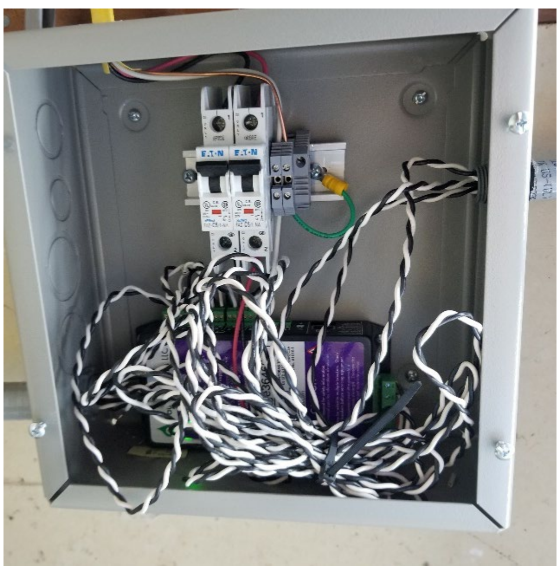
Photos



Main Electrical and Secondary Panels with eGauge and CTs

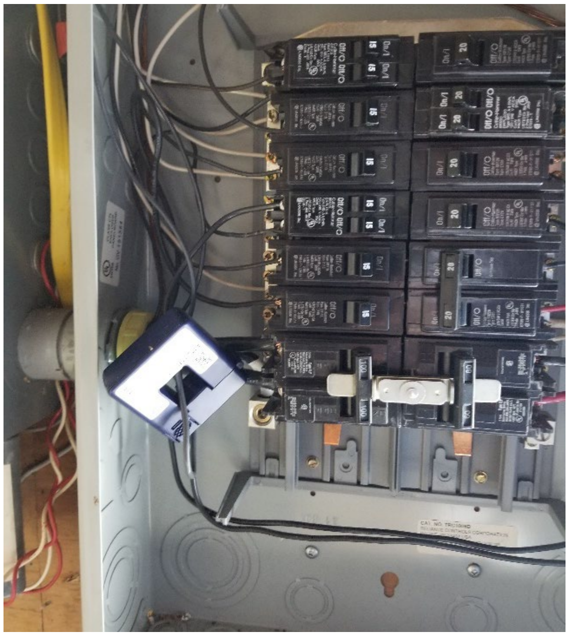


One of two Indoor Sections in Living Room

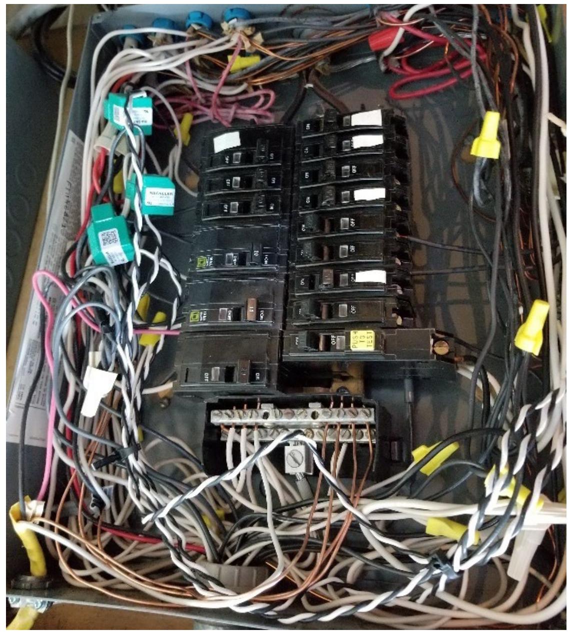


Data Logger Enclosure with eGauge

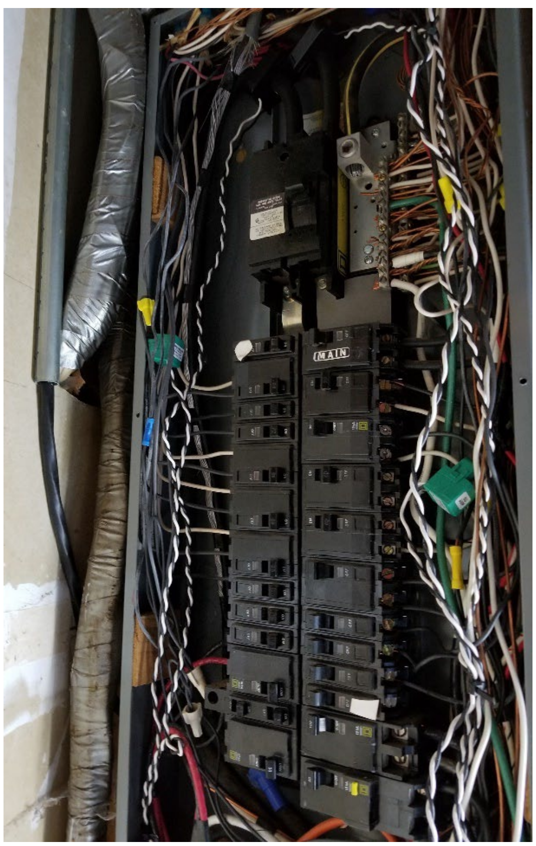
One of two Indoor Sections in Living Room



Secondary Electrical Panel

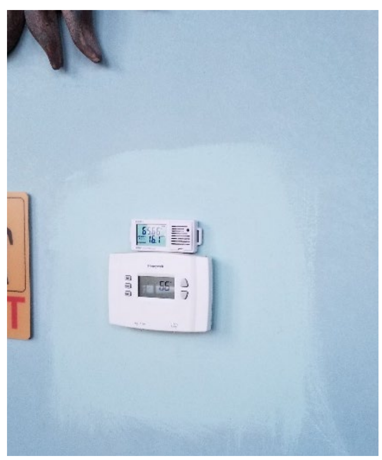


Secondary Electrical Panel



Main Electrical Panel

Temperature Data Logger in Finished Basement



Temperature/RH Data Logger in Living Room

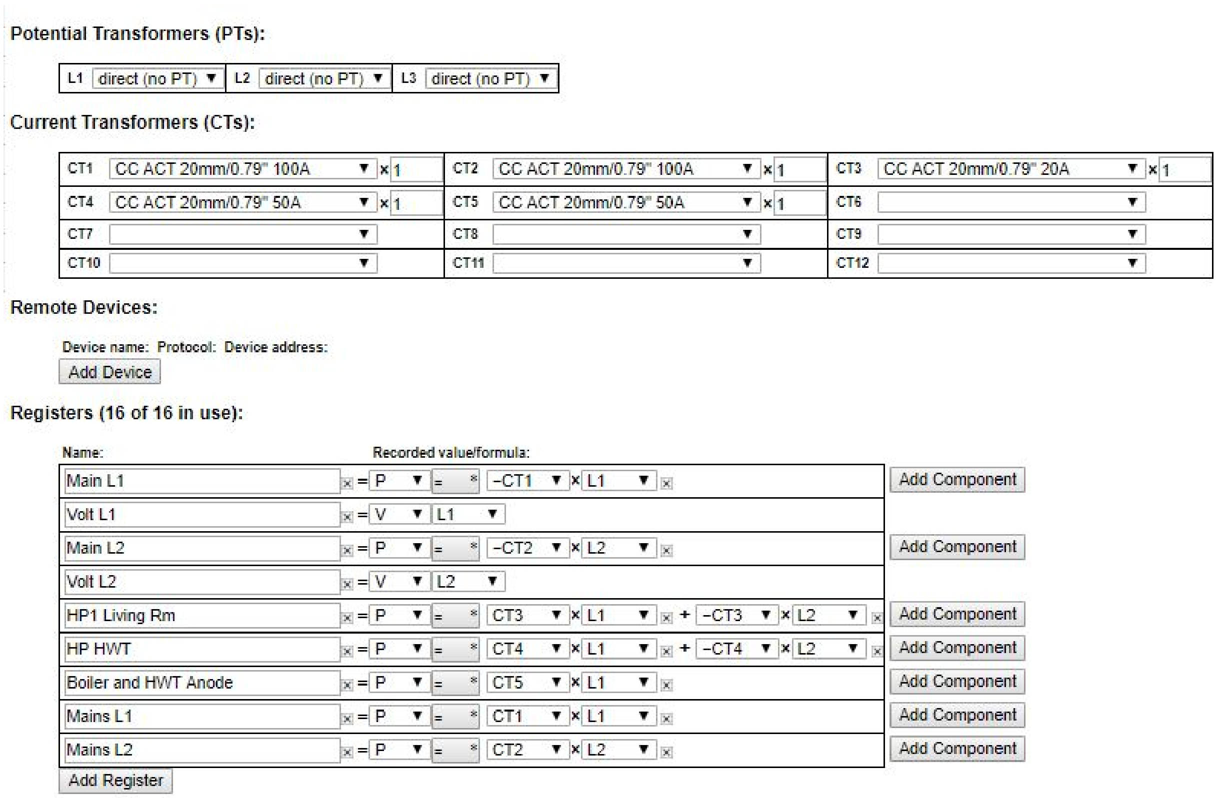
Monitoring Installation Notes – EFG Site 17

Monitoring Installation Date: January 31st, 2019

Installers: Nick Genzel

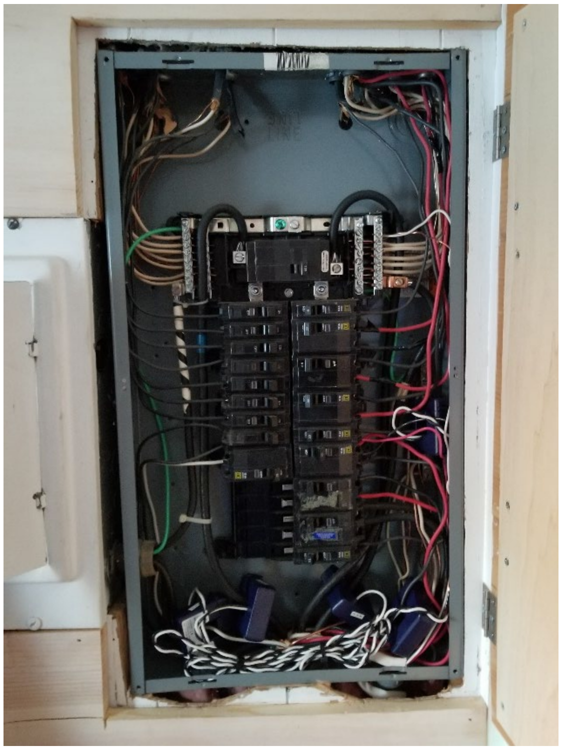
Site Overview: One-story residence

eGauge Setup



CT	Rating	Data Point	Logging
CT1	100 A	Utility Phase 1	Net, apparent
CT2	100 A	Utility Phase 2	Net, apparent
CT3	20 A	Heat Pump 1 - Living Room	Net, apparent
CT4	50 A	Heat Pump Hot Water Heater	Net, apparent
CT5	50 A	Boiler and Hot Water Tank Anode	Net, apparent

Photos



Main Electrical Panel with CTs

Indoor Section in Living Room

Data Logger Enclosure with eGauge

Temperature Data Logger in Living Room

Temperature Data Logger in Master Bedroom

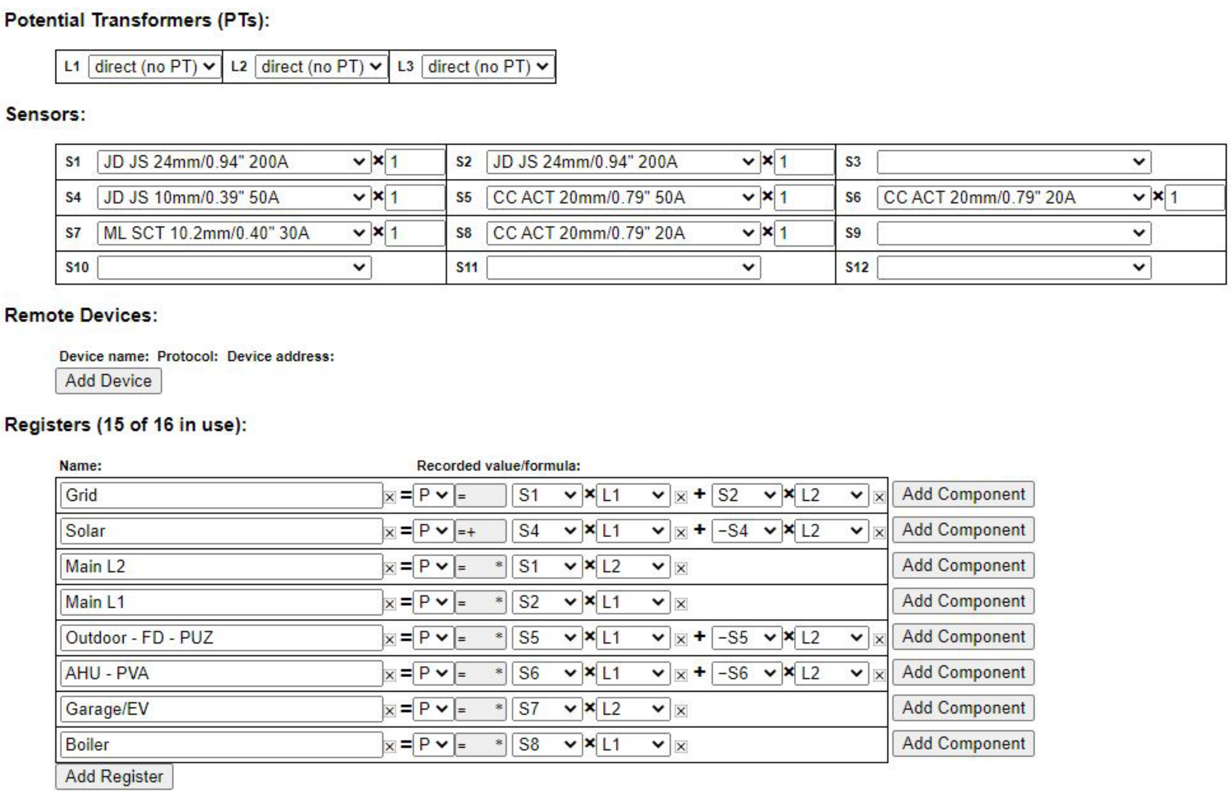
Monitoring Installation Notes – EFG Site 18

Monitoring Installation Date: February 26th, 2019

Installers: Nick Genzel, Juravell

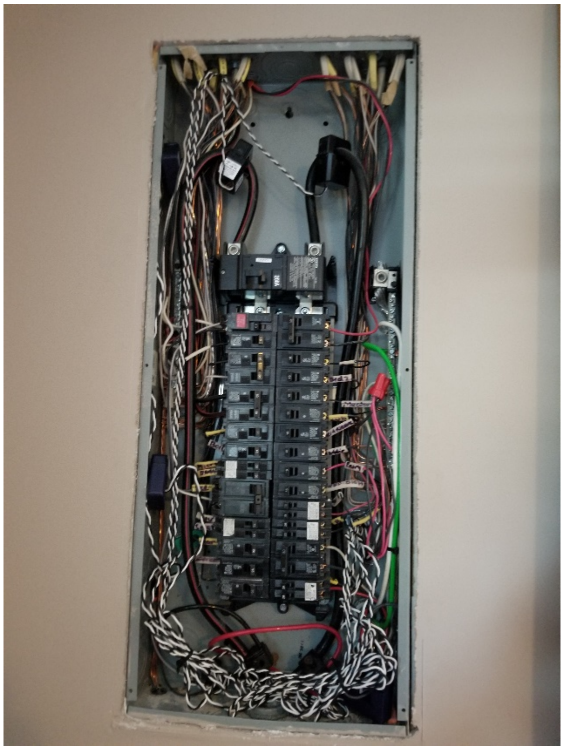
Site Overview: Two-story residence with finished basement

eGauge Setup



CT	Rating	Data Point	Logging
CT1	200 A	Utility Phase 1	Net, apparent
CT2	200 A	Utility Phase 2	Net, apparent
CT3	-	-	-
CT4	50 A	Solar	Net, Positive
CT5	50 A	Heat Pump - PUZ	Net, apparent
CT6	20 A	Air Handler Unit - PVA	Net, apparent
CT7	30 A	Garage and Electric Vehicle	Net, apparent
CT8	20 A	Boiler	Net, apparent

Photos



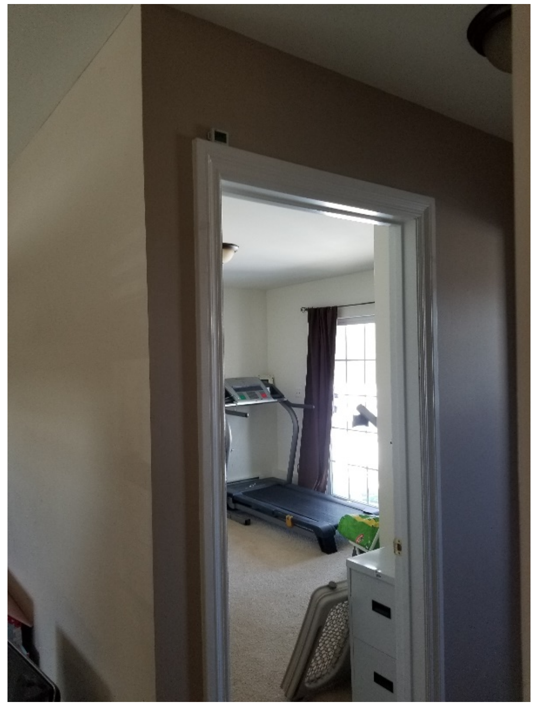
Main Electrical Panels with CTs

Outdoor Unit (Model #PUZ-HA36NHA5)

Data Logger Enclosure with eGauge

Outdoor Unit (Model #PUZ-HA36NHA5)

Air Handler Located in Attic



Temperature Data Logger in Upstairs Hall

Temperature/RH Data Logger in Living Room

Monitoring Installation Notes – EFG Site 19

Monitoring Installation Date: March 6th, 2019

Installers: Nick Genzel

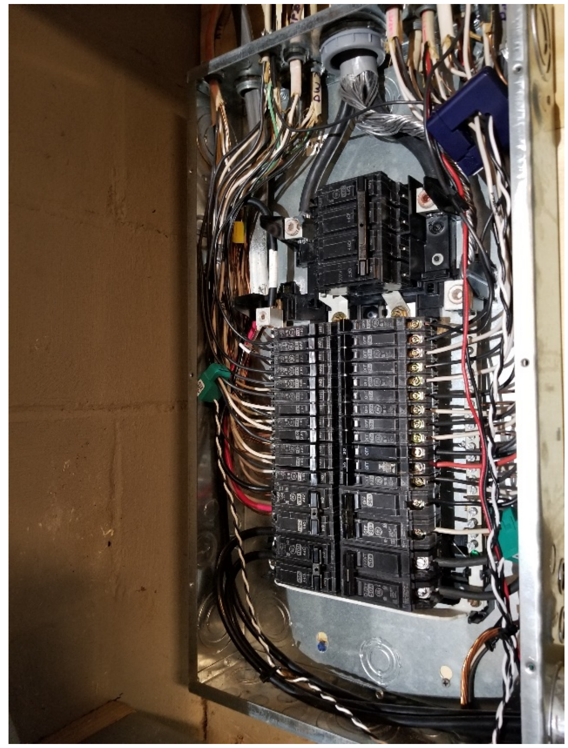
Site Overview: One-story residence with Finished Basement

eGauge Setup – No Settings Screen Available

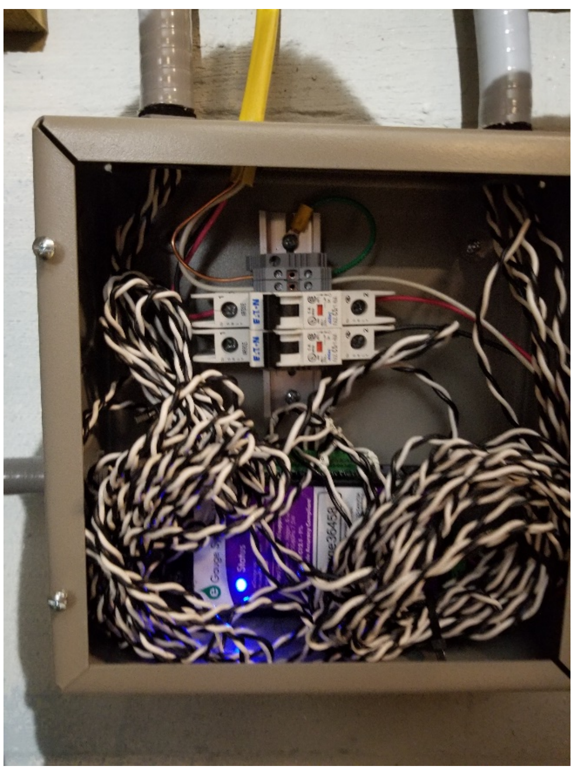
CT	Rating	Data Point	Logging
CT1	100 A	Utility Phase 1	Net
CT2	100 A	Utility Phase 2	Net
CT3	20 A	Heat Pump 1 – Spare Room	Net
CT4	20 A	Heat Pump 2 – Living Room	Net
CT5	20 A	Heat Pump 3 – Dining Room	Net
CT6	20 A	Heat Pump 4 – Master Bedroom	Net
CT7	20 A	Heat Pump 5 – Finished Basement	Net
CT8	50 A	Electric Resistance Heat Basement	Net
CT9	50 A	Electric Resistance Heat (4 Strips)	Net
CT10	50 A	Electric Resistance Heat (3 Strips)	Net
CT11	50 A	Domestic Hot Water Heater	Net
CT12	50 A	Solar	Net

Photos

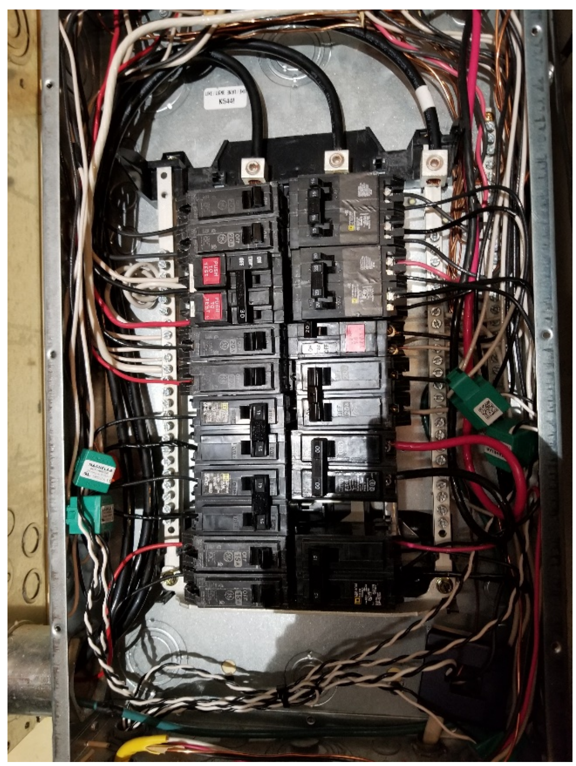
Main Electrical Panels with eGauge



Primary Main Electrical Panel



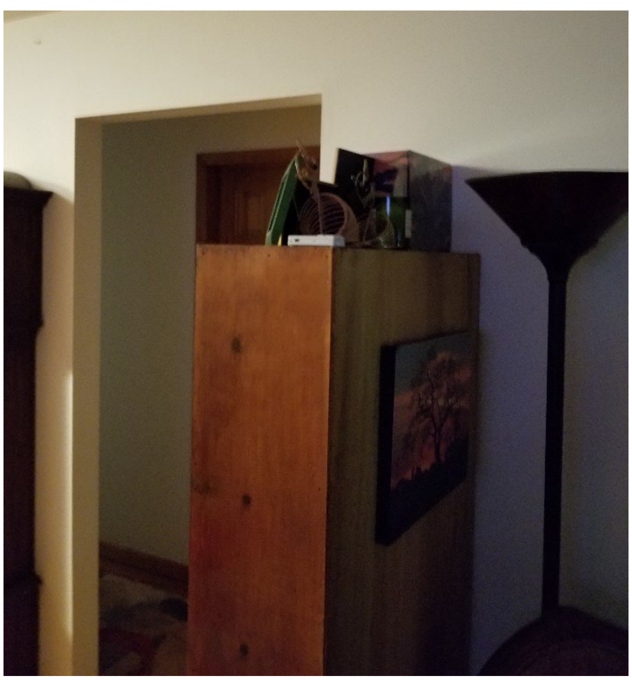
Data Logger Enclosure with eGauge



Secondary Main Electrical Panel

Mains Junction Box with Solar

Temperature Data Logger in Master Bedroom



Temperature/RH Data Logger in Living Room

Monitoring Installation Notes – EFG Site 20

Monitoring Installation Date: March 5th, 2019

Installers: Nick Genzel

Site Overview: One story residence with finished basement

eGauge Setup – No Settings Screen Available

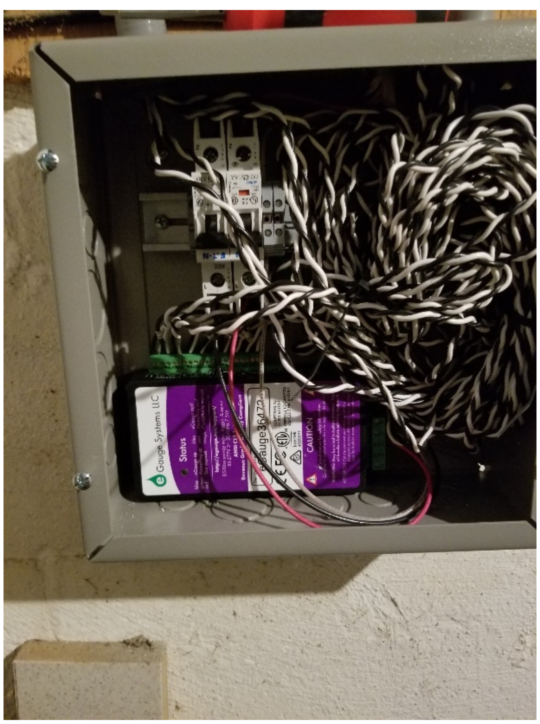
CT	Rating	Data Point	Logging
CT1	100 A	Utility Phase 1	Net
CT2	100 A	Utility Phase 2	Net
CT3	20 A	Heat Pump 1 – Living Room	Net, Apparent
CT4	20 A	Heat Pump 2 – Master Bedroom	Net, Apparent
CT5	20 A	Heat Pump 3 – Bedroom	Net, Apparent
CT6	20 A	Heat Pump 4 – Closet	Net, Apparent
CT7	20 A	Heat Pump 5 – Dining Room	Net, Apparent
CT8	20 A	Domestic Hot Water Heater	Net
CT9	20 A	Electric Resistance Heat Basement	Net
CT10	20 A	Electric Resistance Heat Basement	Net

Photos

Main Electrical Panel with eGauge

Indoor Section

One of Five Outdoor Sections



Data Logger Enclosure with eGauge

One of Five Outdoor Sections

Outdoor Unit (Model #MUZ-FH12NA)

Outdoor Unit (Model #MUZ-FH18NA)

Temperature Data Logger in Living Room


Temperature/RH Data Logger in Living Room

Appendix C. 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.

EFG S1 Savings Analysis

This 1500 sq ft house is in Albany. The house was originally heated by a gas boiler with hydronic baseboard. The boiler was also used for supplemental heating after the 1.5-ton ASHP was installed. ASHP was installed in late 2017. Monitoring began in December 2017. This unit did not ever operate in cooling, instead the pre-existing central AC was still used for cooling. The solar PV array at this house was also monitored

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pump. There is some evidence that the heat pump does setback in the heating mode around mid-night. Figure 2 shows the power use for the house and heat pumps across the monitoring period.

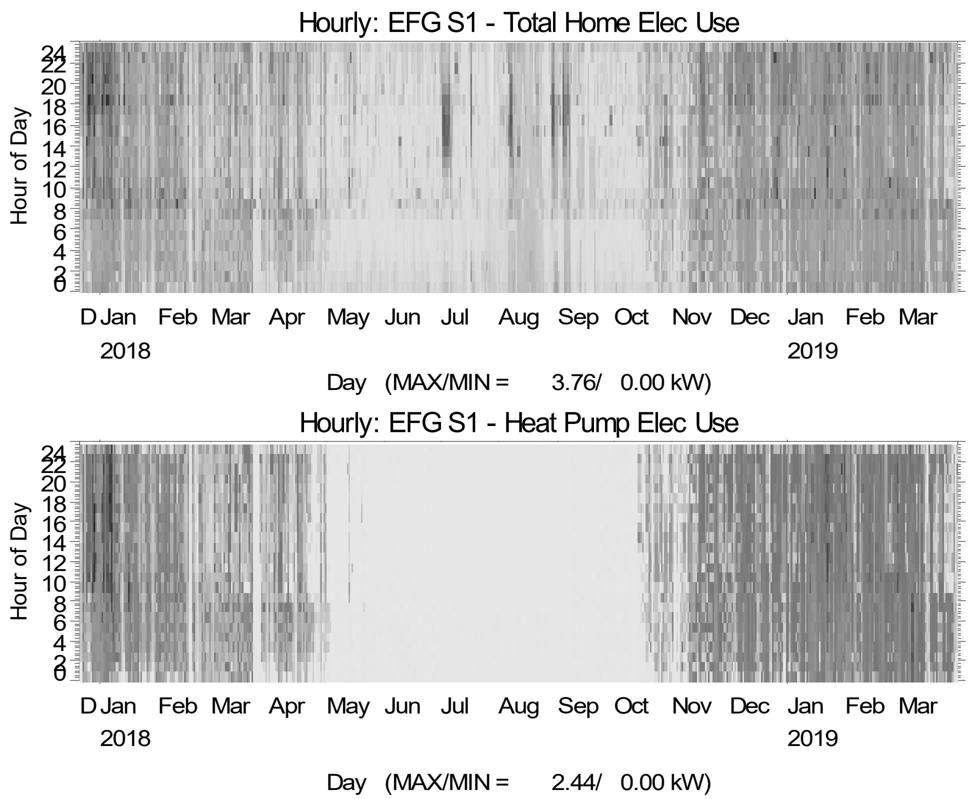


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

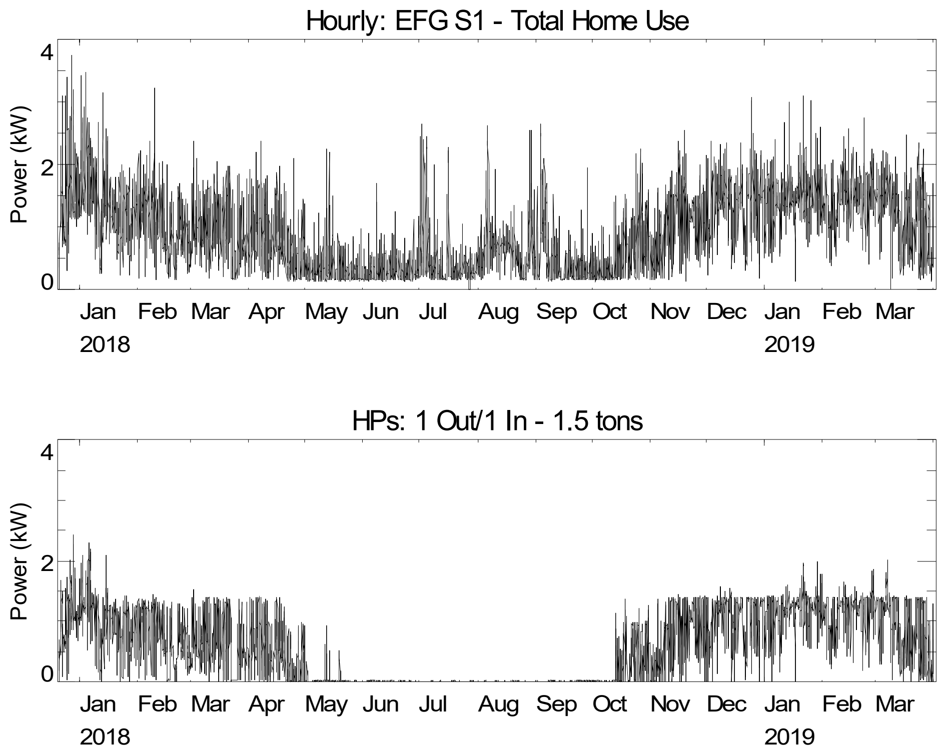


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)
Dec-17	11	404.2	285.9
Jan-18	31	1,003.6	782.9
Feb-18	28	696.2	518.2
Mar-18	31	688.4	477.9
Apr-18	30	591.2	389.6
May-18	31	249.6	18.0
Jun-18	30	221.2	5.8
Jul-18	31	335.5	4.3
Aug-18	31	493.7	4.2
Sep-18	30	325.3	6.2
Oct-18	31	405.0	184.3
Nov-18	30	749.5	566.1
Dec-18	31	1,025.8	787.4
Jan-19	31	1,078.3	889.2
Feb-19	28	943.8	778.4
Mar-19	31	884.4	694.7
Annual	365	6,785.0	3,744.9
Htg Season	243	5,409.3	3,724.4
Jun-Sep	122	1,375.7	20.5

Measured Trends

Daily heat pump power use is shown in Figure 3 as function of daily average outdoor temperature. There is considerable scatter in the data, most likely due to daily variations in how the occupants used the ductless heat pump. The dotted line on the plot represents to a best fit of the trend with temperature. In this case the second change point in trend line around 20˚F reflects the fact that the heat pump unit is sized to only meet part of the heating load. Below the change point the unit is running continuously and cannot provide much additional output to meet the heating load.

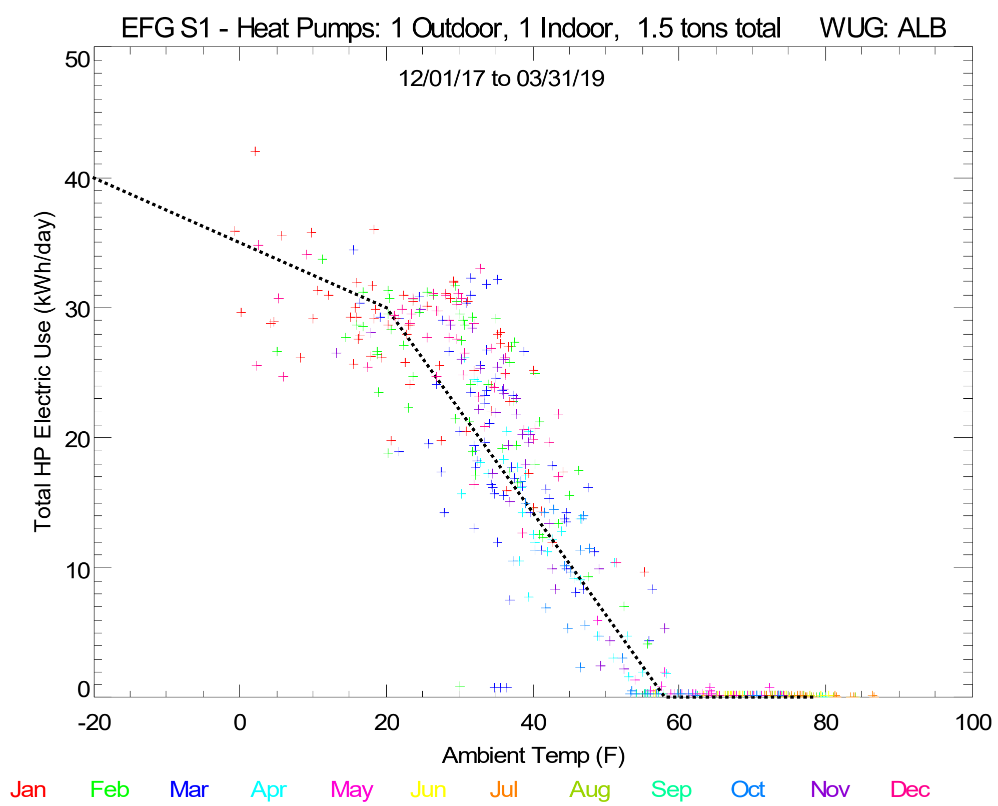


Figure 3. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced some of the natural gas use by the boiler. Figure 4 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. It is not clear why the data point for December 2018 in the post-retrofit period was inconsistent with the overall trend.

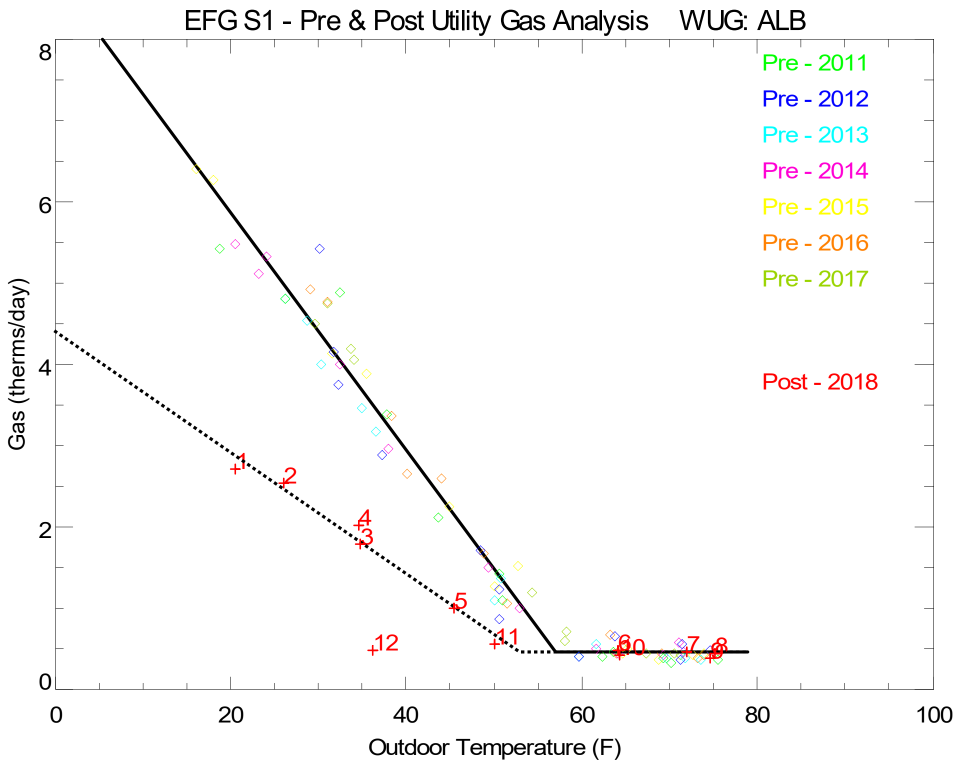


Figure 4. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

Bin Analysis to Predict Seasonal Impacts

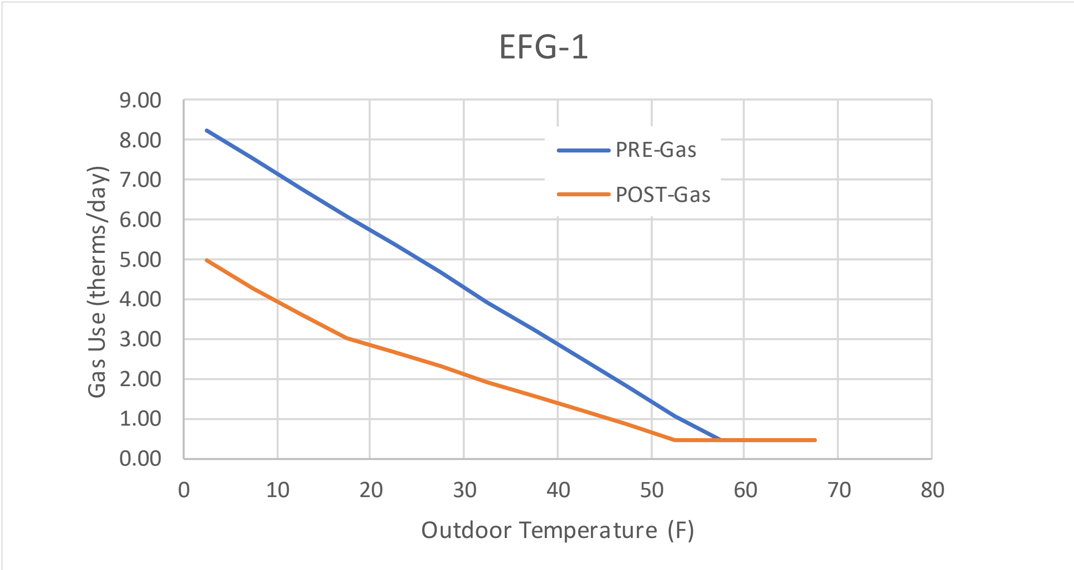
The trend lines above were used in a bin analysis using typical year weather data. Table 2 shows the details of bin analysis and Figure 5 plots the trend lines used for the analysis. The post-retrofit adjustment factor linearly transitions from using the post-retrofit fuel trend to the pre-retrofit fuel trend in order to account for the fact that the heat pump can not meet the entire load at lower temperatures. A factor of zero uses the post-retrofit trend while a factor of 1 uses the pre-retrofit trend. The factor is also selected to provide a consistent trend of the implied COP with temperature as shown in Table 2.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	EFG-1	WEATHER:	Albany	$ 0.117	per kWh
FUEL:	Gas			$ 0.826	per therm
Floor Area	1500	LOCATION:	Albany		

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	12.8	6.5	41.9	10.5	1.3	$ 10.6	$ 13.5	0.63
-22.5	0	12.1	6.1	40.6	9.5	1.5	$ 10.0	$ 12.6	0.56
-17.5	0	11.4	5.7	39.4	8.5	1.7	$ 9.4	$ 11.6	0.49
-12.5	0	10.6	5.4	38.1	7.6	1.9	$ 8.8	$ 10.7	0.42
-7.5	0	9.9	5.0	36.9	6.7	2.0	$ 8.2	$ 9.8	0.35
-2.5	15	9.2	4.6	35.6	5.9	2.1	$ 7.6	$ 9.0	0.28
2.5	36	8.4	4.2	34.4	5.1	2.2	$ 7.0	$ 8.2	0.21
7.5	127	7.7	3.9	33.1	4.4	2.3	$ 6.4	$ 7.5	0.14
12.5	206	7.0	3.5	31.9	3.7	2.4	$ 5.8	$ 6.8	0.07
17.5	435	6.2	3.1	30.6	3.1	2.4	$ 5.2	$ 6.1	
22.5	498	5.5	2.7	28.0	2.7	2.3	$ 4.6	$ 5.5	
27.5	537	4.8	2.4	24.1	2.4	2.3	$ 4.0	$ 4.8	
32.5	654	4.1	2.0	20.1	2.0	2.4	$ 3.3	$ 4.0	
37.5	720	3.3	1.6	16.2	1.6	2.4	$ 2.7	$ 3.2	
42.5	550	2.6	1.3	12.2	1.3	2.5	$ 2.1	$ 2.5	
47.5	573	1.9	0.9	8.3	0.9	2.7	$ 1.5	$ 1.7	
52.5	723	1.1	0.5	4.3	0.5	3.3	$ 0.9	$ 0.9	
57.5	791	0.5	0.5	0.4	0.5	0.0	$ 0.4	$ 0.4	
62.5	943	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	
67.5	682	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	
72.5	497	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	
77.5	420	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	
82.5	274	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	
87.5	61	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	
92.5	13	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	
97.5	5	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	
102.5	0	0.5	0.5	0.0	0.5	0.0	$ 0.4	$ 0.4	

Note: The POST-Gas Adjustment Factor accounts for the fact that the trend line for post-retrofit gas use is not accurate at lower temperatures (since the heat pump can not meet the entire load at these conditions).



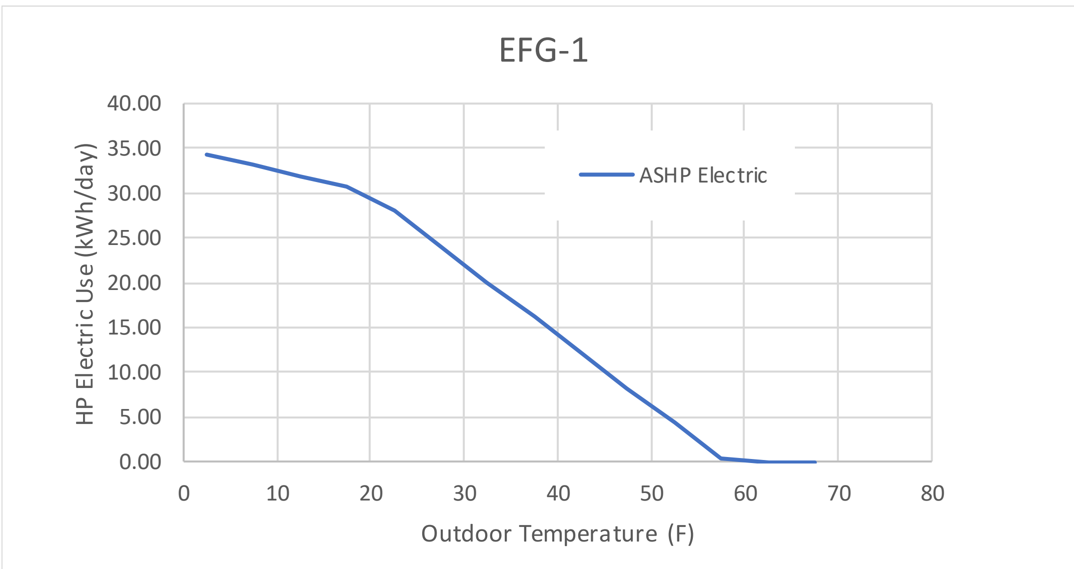


Figure 5. Trends of (Pre and Post Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. Since the base fuel is natural gas, there are no net cost savings. The implied seasonal heating COP is 2.4 in this case.

In this instance the implied COP is calculated from

$$COP = (Fuel_{pre} - Fuel_{post})*eff/(3.412xkWh_{hp}) = (701.8-301.9)*100*0.79 / (3.412*3854)$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Gas (therms/yr)	701.8	301.9	399.8
HP Electric (kWh/yr)		3,854	(3,854)
Total Heating Costs	$580	$699	-$119
Implied Seasonal COP			2.4

Summary Statistics	
0.47	Fuel therms per sq ft per yr
37.0	Htg MBtu per sq ft per yr
57%	Reduction in Fuel Use
3,724	Measured HP for Htg (kWh/yr)
97%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 6 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile.

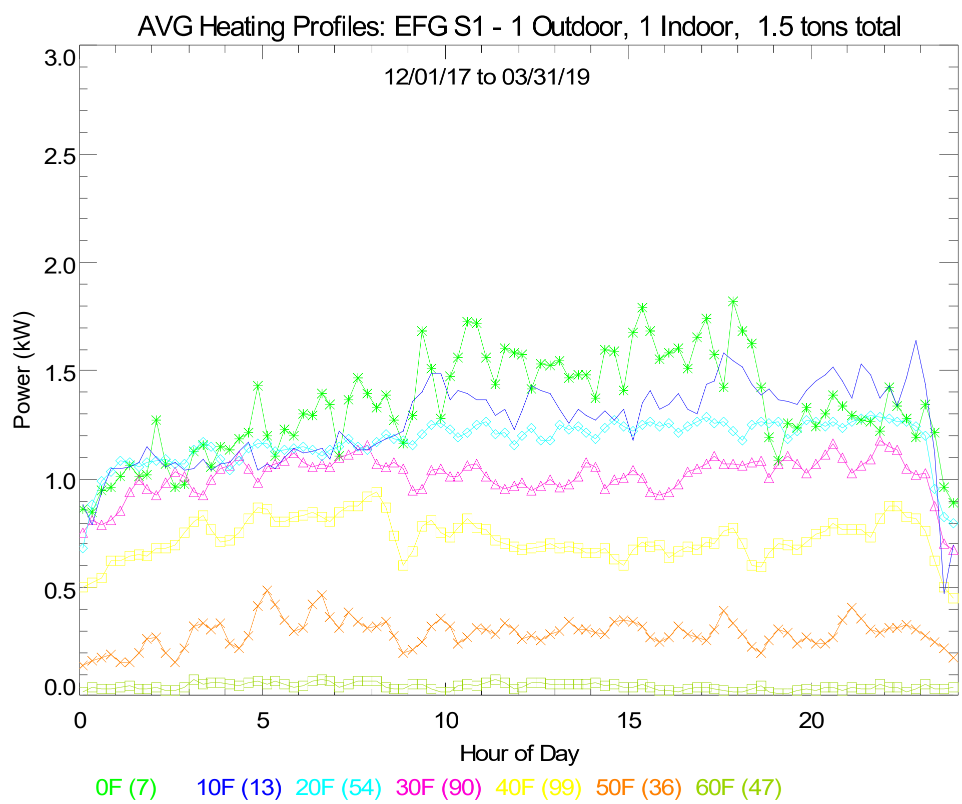


Figure 6. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins

Space Temperatures

Space temperatures and humidity levels are shown in Figure 7. The living space is kept warmer than the master bedroom. The summertime temperatures drift towards 80°F indicating very little cooling. The high RH in the summer reflects the lack of cooling.

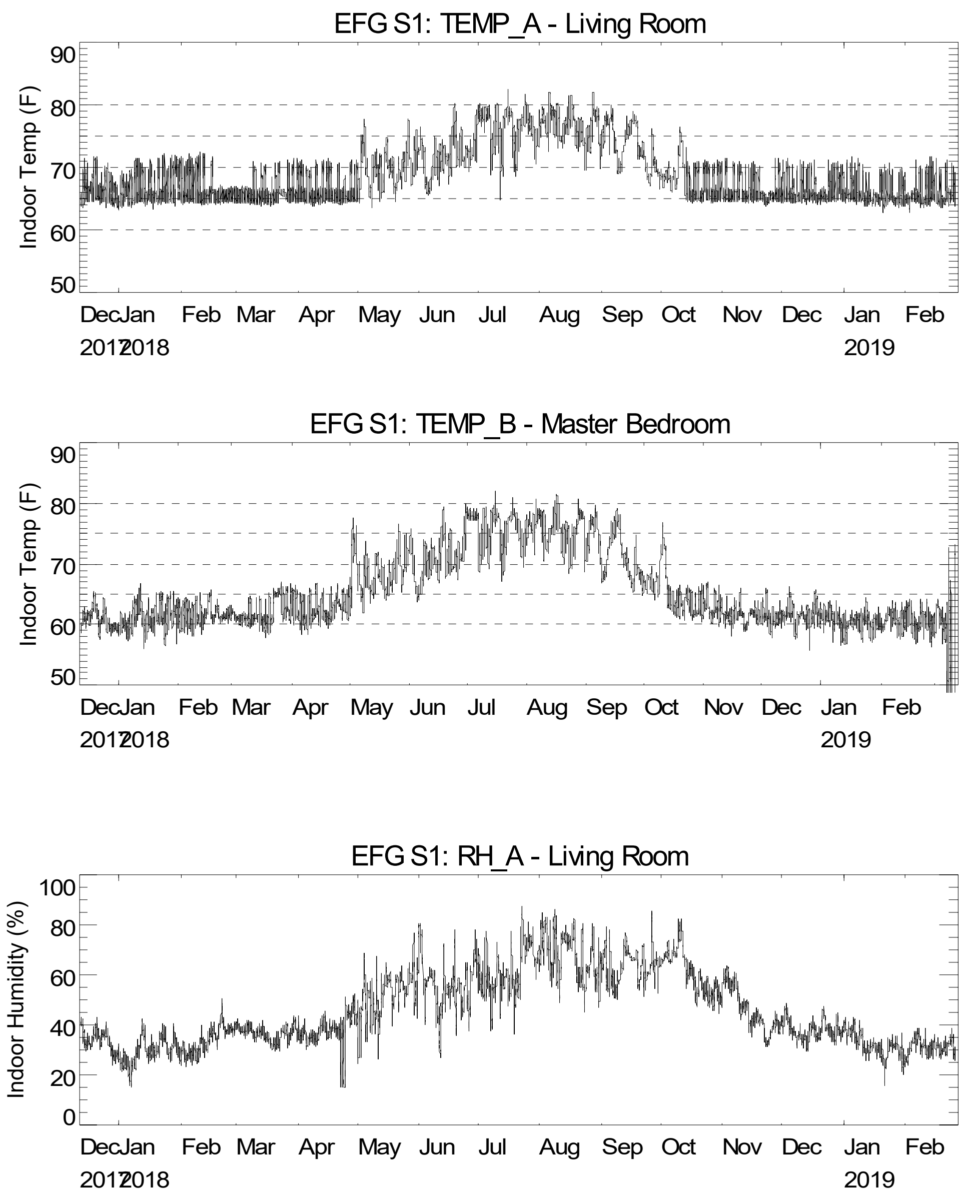


Figure 7. Space Temperatures and Humidity Levels

EFG S2 Savings Analysis

This 2000 sq ft house is in Cotekill, NY near Newburgh. The house was originally heated by baseboard electric heat. The electric baseboard was also used for supplemental heating after the 2.5-ton ASHP was installed. The ASHP was installed in November 2017. Monitoring began in January 2018. This unit was also used for cooling.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. Figure 2 shows the power use for the house and heat pumps across the monitoring period.

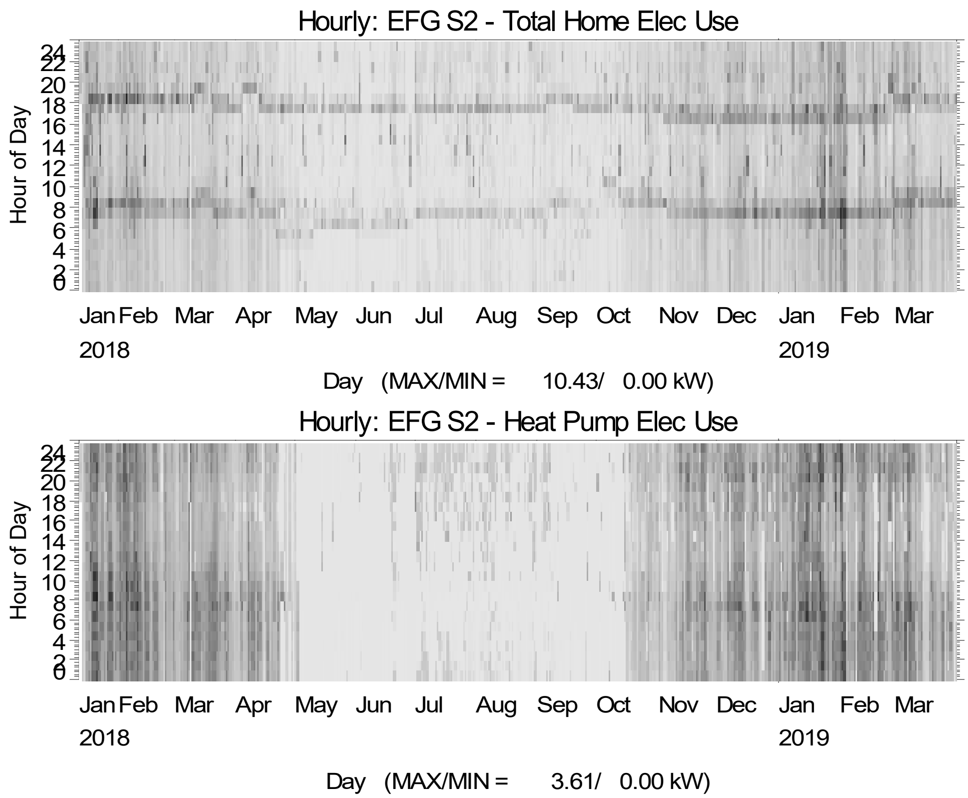


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

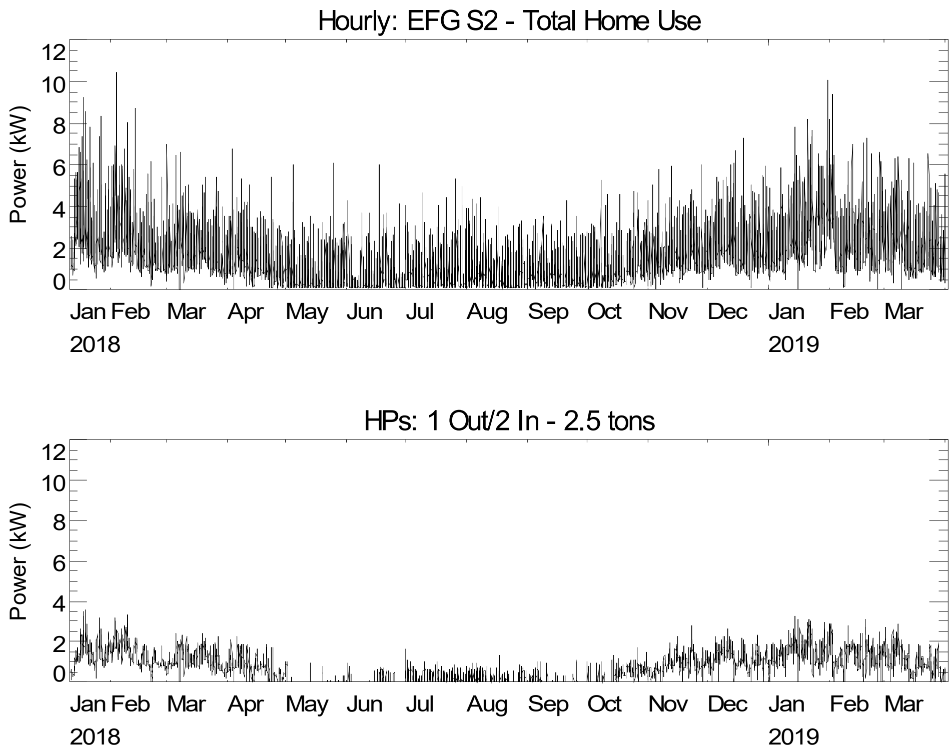


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. It also includes the resistance electric heaters that were monitored.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)
Jan-18	21	1,177.5	675.3	96.2
Feb-18	28	1,391.0	910.4	104.6
Mar-18	31	1,192.6	787.4	43.1
Apr-18	30	843.5	497.5	7.1
May-18	31	406.8	37.1	0.2
Jun-18	30	351.3	49.5	0.1
Jul-18	31	502.1	127.7	0.2
Aug-18	31	469.6	100.4	0.2
Sep-18	30	438.9	51.5	2.0
Oct-18	31	708.8	267.5	18.4
Nov-18	30	1,093.5	640.8	72.3
Dec-18	31	1,391.6	802.1	158.9
Jan-19	31	1,863.2	1,099.4	384.1
Feb-19	28	1,507.3	837.1	304.5
Mar-19	31	1,379.8	686.0	306.7
Annual	365	10,652.9	5,371.3	791.2
Htg Season	243	8,891.0	5,042.2	788.7
Jun-Sep	122	1,761.9	329.1	2.5

Measured Trends

Daily heat pump power use is shown in Figure 3 as function of daily average outdoor temperature. There is moderate scatter in the data, indicating that the occupants used the ductless heat pump in a fairly consistent manner. The dotted line on the plot represents to a best fit of the trend with temperature.

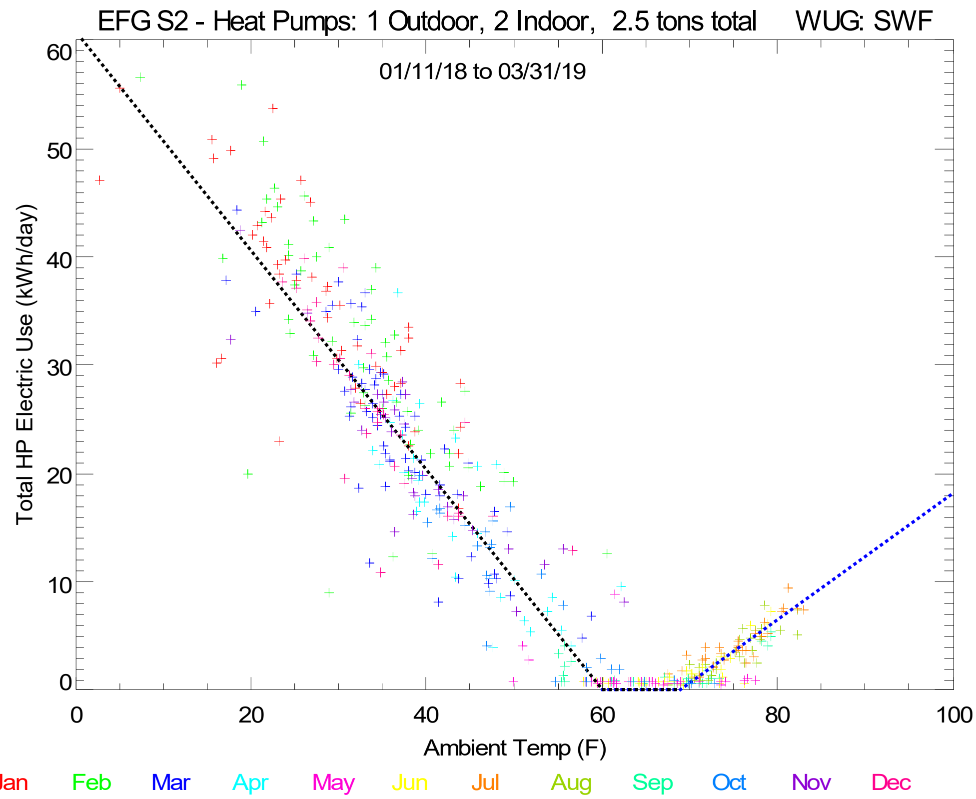


Figure 3. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced baseboard electric heat use. Figure 4 compares the trend of monthly electric with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. The monthly post retrofit data was highly scattered, perhaps indicating several estimated readings, so the measured total house power data for the site (shown in Figure 5) was used to develop the post retrofit trend instead.

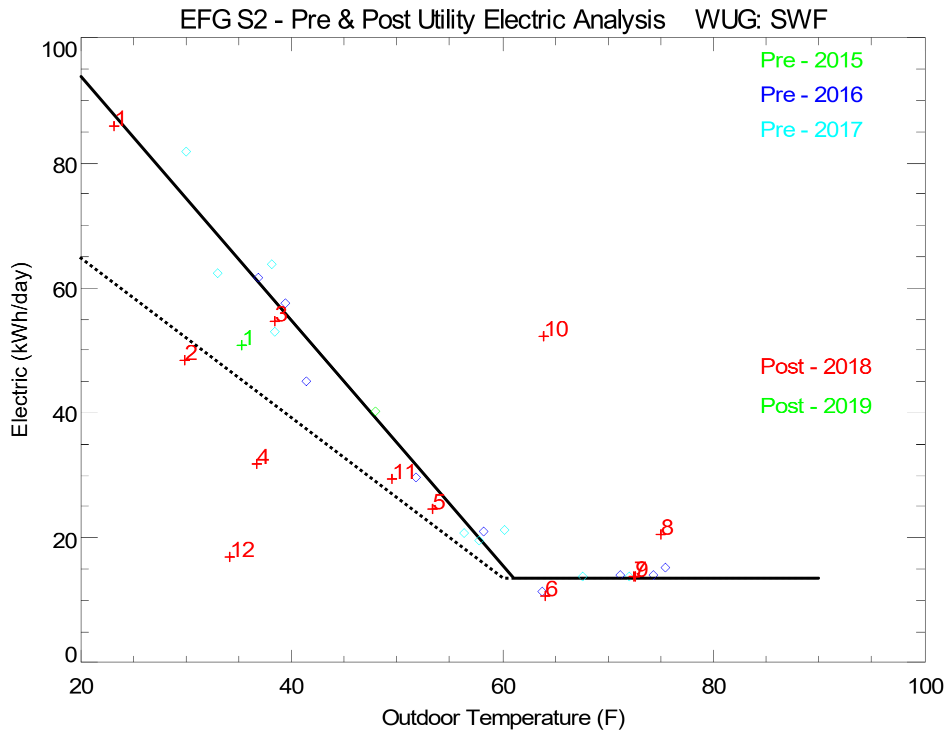


Figure 4. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

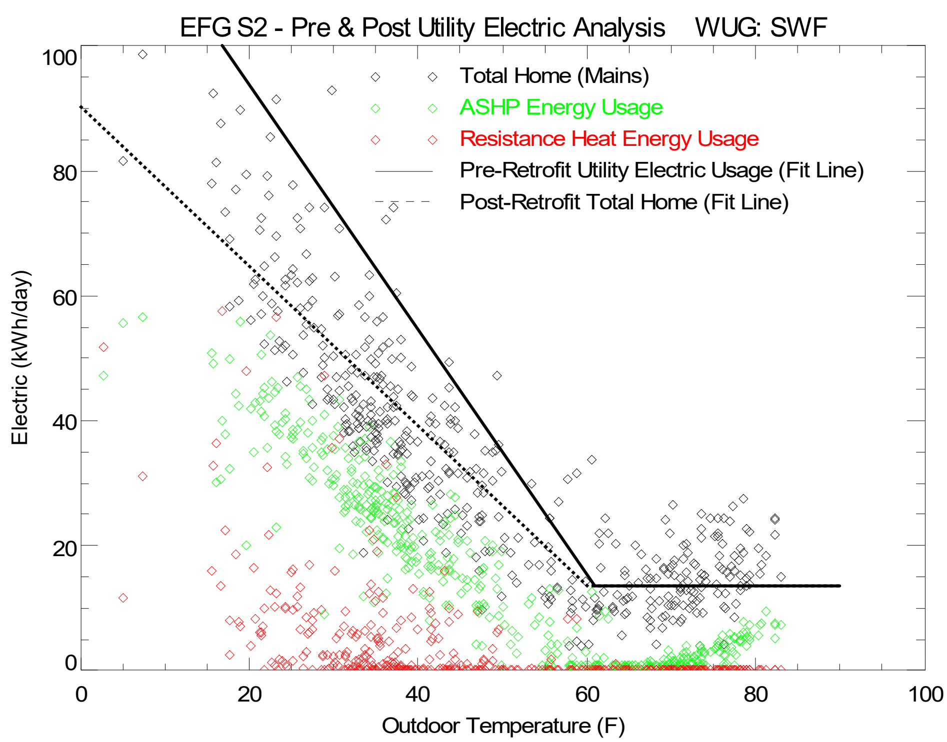


Figure 5. Analysis of Measured Daily Total House Electric Use with Temperature in the Post-Retrofit Period (Solid Line: Pre-Retrofit and Dotted Line: Post-Retrofit). HP and resistance heat electricity also shown.

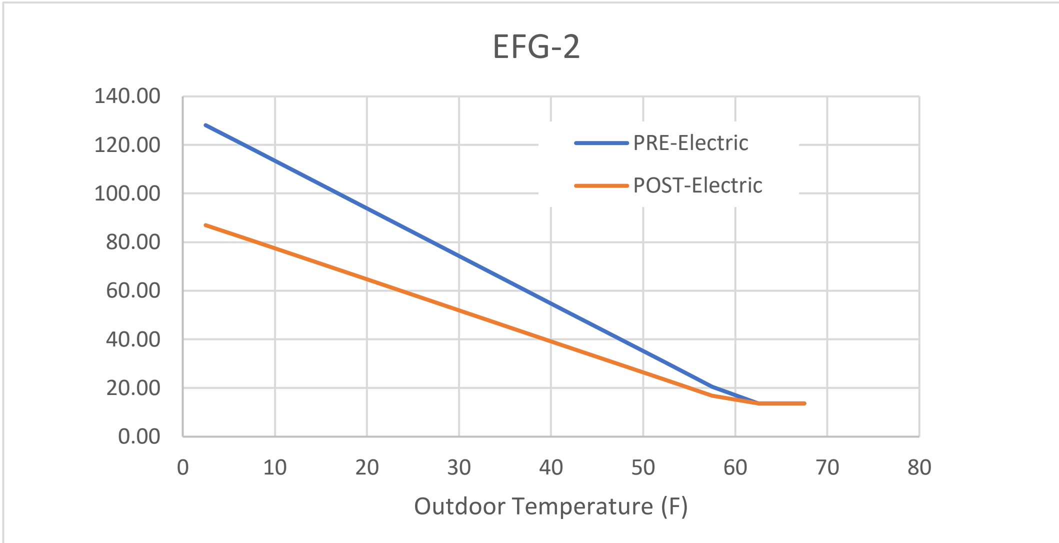
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Newburgh. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	EFG-2		WEATHER:	Newburgh	$	0.150	per kWh	
FUEL:	Electric				$	0.150	per kWh	
Floor Area	2000		LOCATION:	Cottekill				

Temp Bin	Hours	FUEL PRE-Electric (kWh/day)	FUEL POST-Electric (kWh/day)	ASHP Electric (kWh/day)	Adjusted POST-Electric (kWh/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Electric adjustment factor
-27.5	0	186.79	125.27	88.96	125.27	1.69	$ 28.0	$ 32.1	
-22.5	0	177.01	118.90	83.88	118.90	1.69	$ 26.6	$ 30.4	
-17.5	0	167.23	112.52	78.79	112.52	1.69	$ 25.1	$ 28.7	
-12.5	0	157.45	106.14	73.71	106.14	1.70	$ 23.6	$ 27.0	
-7.5	1	147.67	99.77	68.63	99.77	1.70	$ 22.2	$ 25.3	
-2.5	13	137.89	93.39	63.54	93.39	1.70	$ 20.7	$ 23.5	
2.5	36	128.11	87.01	58.46	87.01	1.70	$ 19.2	$ 21.8	
7.5	45	118.33	80.64	53.38	80.64	1.71	$ 17.7	$ 20.1	
12.5	113	108.55	74.26	48.29	74.26	1.71	$ 16.3	$ 18.4	
17.5	222	98.77	67.88	43.21	67.88	1.71	$ 14.8	$ 16.7	
22.5	367	88.99	61.51	38.13	61.51	1.72	$ 13.3	$ 14.9	
27.5	373	79.21	55.13	33.04	55.13	1.73	$ 11.9	$ 13.2	
32.5	764	69.43	48.75	27.96	48.75	1.74	$ 10.4	$ 11.5	
37.5	814	59.65	42.38	22.88	42.38	1.76	$ 8.9	$ 9.8	
42.5	727	49.87	36.00	17.79	36.00	1.78	$ 7.5	$ 8.1	
47.5	668	40.09	29.62	12.71	29.62	1.82	$ 6.0	$ 6.3	
52.5	480	30.31	23.25	7.63	23.25	1.93	$ 4.5	$ 4.6	
57.5	748	20.53	16.87	2.54	16.87	2.44	$ 3.1	$ 2.9	
62.5	831	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
67.5	902	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
72.5	538	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
77.5	603	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
82.5	358	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
87.5	134	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
92.5	23	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
97.5	1	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	
102.5	0	13.68	13.68	0.00	13.68	0.00	$ 2.1	$ 2.1	



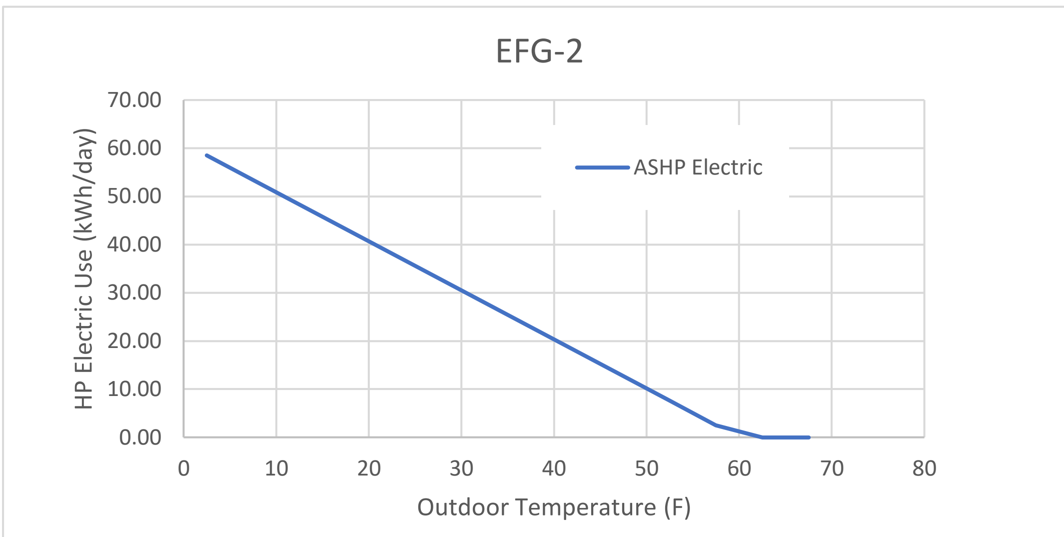


Figure 6. Trends of (Pre and Post Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. Since the base fuel is electric, the savings calculation only considers the pre- and post-retrofit electric use. The implied seasonal heating COP is 1.8, using both electric savings and heat pump energy use which is shown on the bottom of the table.

In this instance the implied COP is calculated from

$$COP = (kWh_{pre} - kWh_{post} + kWh_{hp})/kW_{hp} = (9555 - 5944 + 4739) / 4739$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Total Heat (kWh/yr)	9,555	5,944	3,611
		-	-
Total Heating Costs	$1,433	$892	$542
Implied Seasonal COP			1.8
HP Electric (kWh/yr)			4,739

Summary Statistics	
4.78	Fuel kWh per sq ft per yr
16.3	Htg MBtu per sq ft per yr
38%	Reduction in Fuel Use
5,042	Measured HP for Htg (kWh/yr)
106%	Measured as % of Typical yr

The resistance heat circuits were also measured in this house. Table 4 uses the measured resistance heating use in the post-retrofit period to isolate the savings associated with the heat pump alone. Since resistance space heating is minimal, there is not much difference between the seasonal implied COP for the heat pump alone and the COP for the overall system (including resistance heating).

Table 4. Results of Bin Analysis Showing Seasonal Impact to Resistant Heating Use

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Resistance (kWh/yr)	9,555	791	8,764
ASHP (kWh/yr)		4,739	(4,739)
Total Heat (kWh/yr)	9,555	5,530	4,025
Total Heating Costs	$1,433	$829	$604
Implied ASHP COP			1.8
Overall COP Including Resistance			1.7

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

Figure 7 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

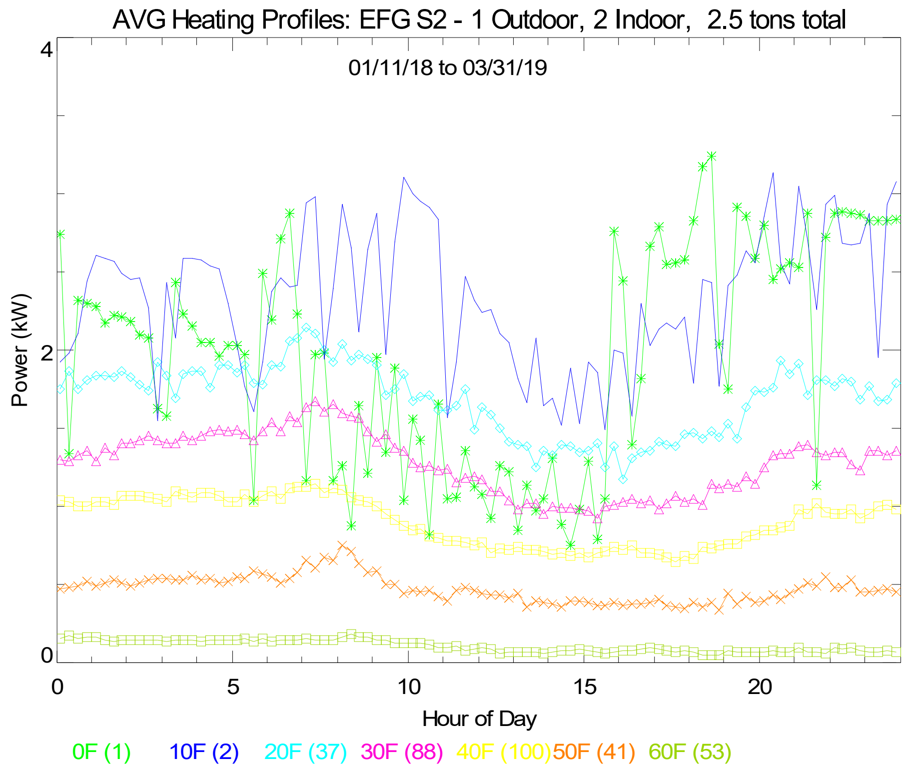


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

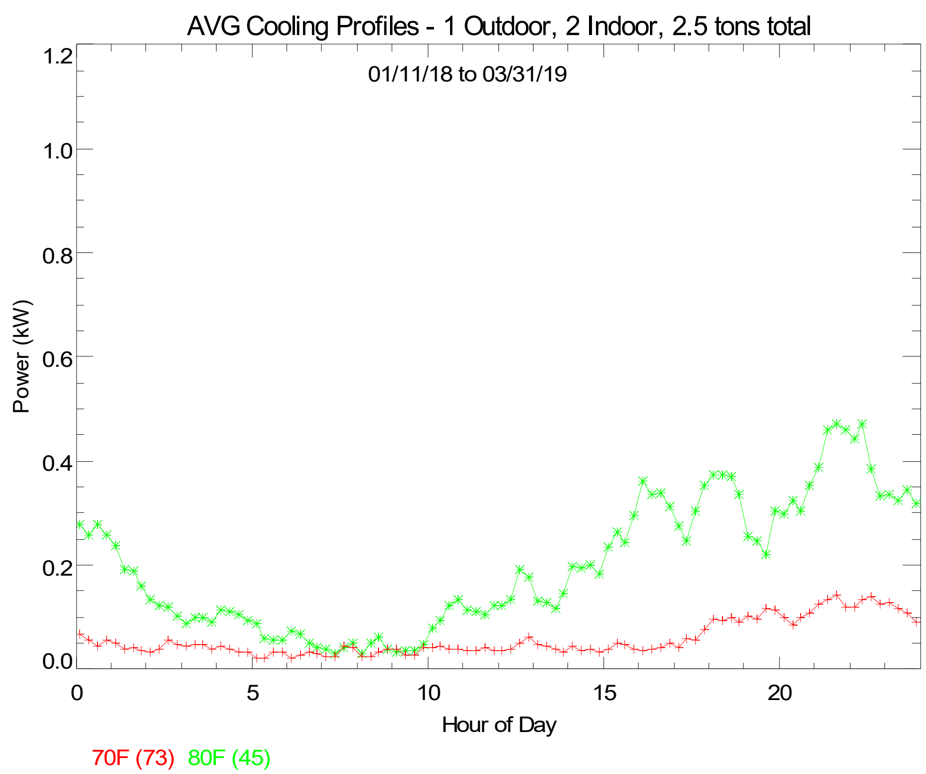


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9. The living space is about the same temperature as the master bedroom. The summertime temperatures drift towards 80°F indicating very little cooling. The RH in the summer mostly stays below 60% RH when there is cooling operation, as would be expected.

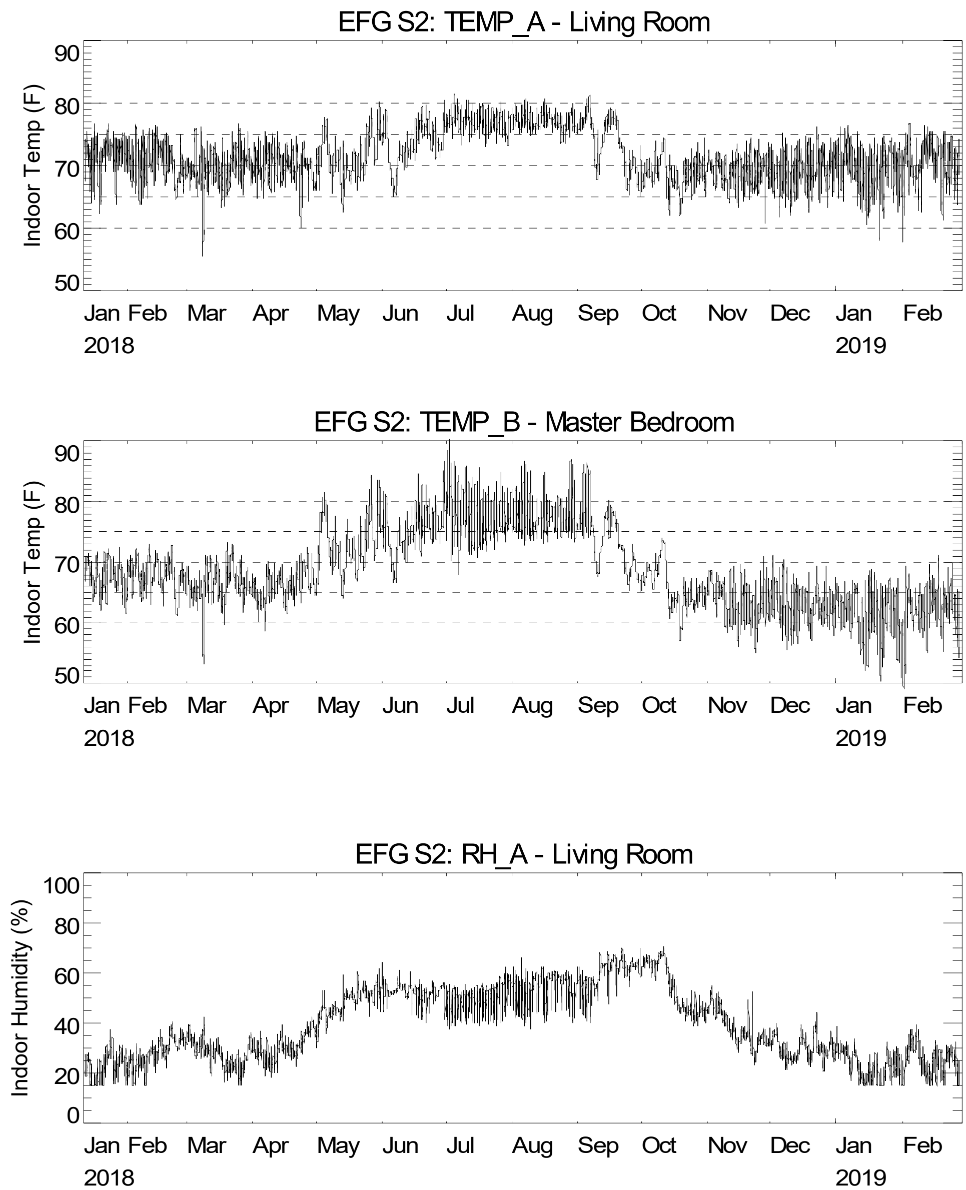


Figure 9. Space Temperatures and Humidity Levels

EFG S3 Savings Analysis

This 2000 sq ft house is in Athens, NY near Albany. The house was originally heated by an oil boiler with hydronic baseboard. The boiler was also used for supplemental heating after the 3-ton ASHP was installed. ASHP was installed on January 19, 2018. Monitoring began in March 2018. This unit frequently operates in cooling. The solar PV array at this site was also monitored.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pump. There is some evidence that the heat pump use setback in the heating mode. Figure 2 shows the power use for the house and heat pumps across the monitoring period.

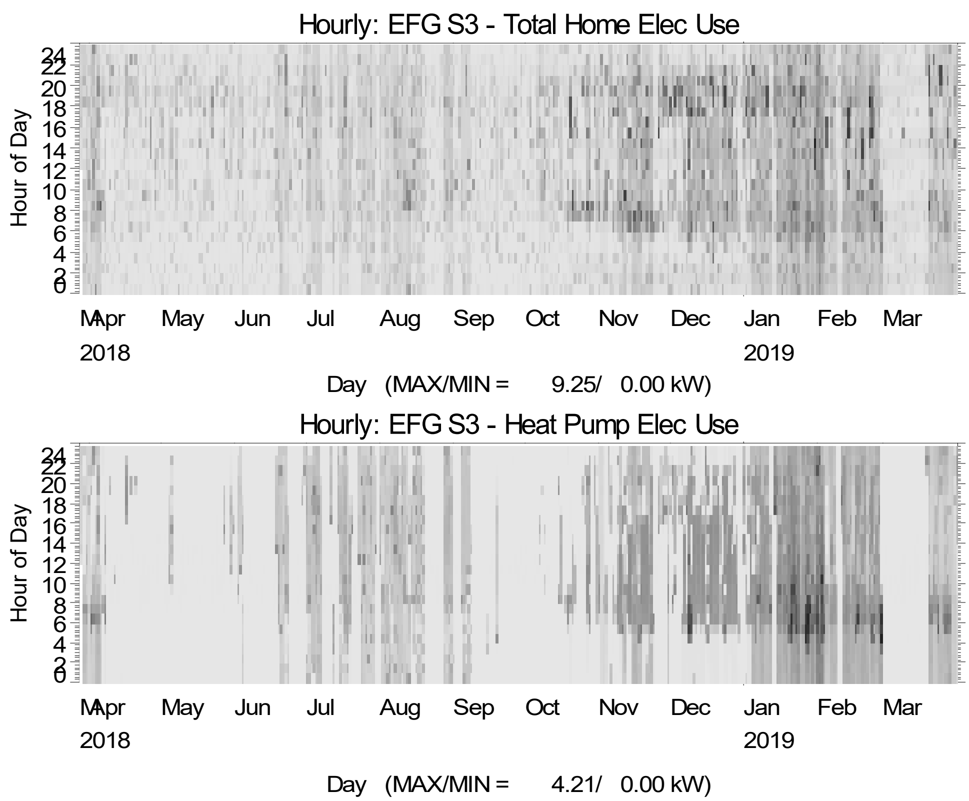


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

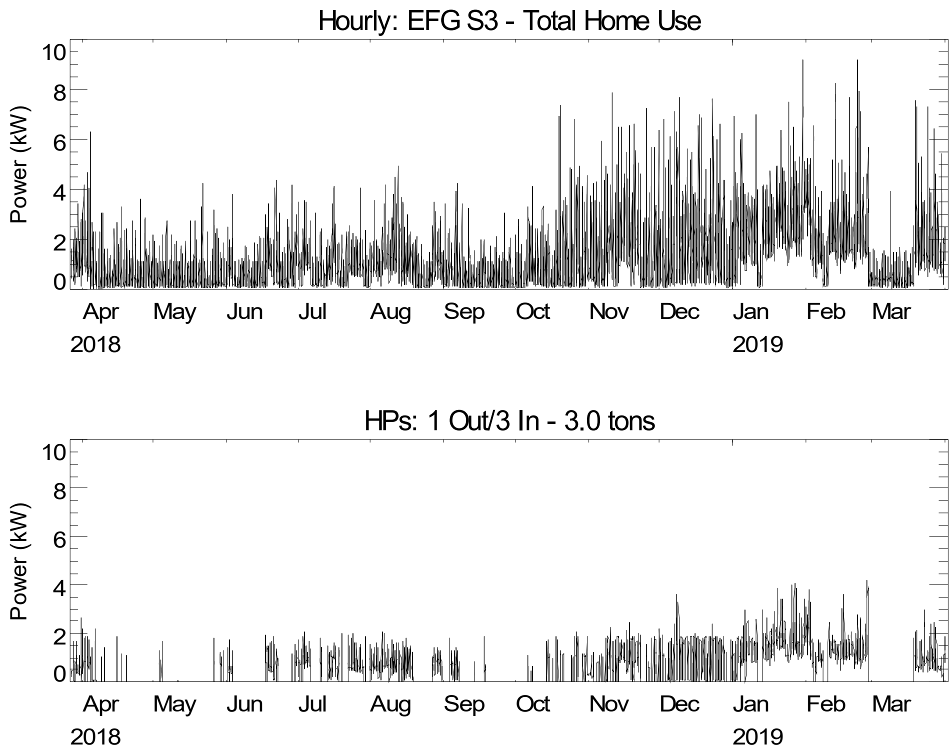


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)	Boiler Runtime (hrs)
Mar-18	7	128.4	58.6	-	5.3
Apr-18	30	524.5	111.0	-	54.8
May-18	31	369.3	44.3	-	14.0
Jun-18	30	480.2	146.3	-	9.0
Jul-18	31	654.2	375.9	-	9.2
Aug-18	31	743.0	383.2	-	8.7
Sep-18	30	399.4	91.9	-	9.1
Oct-18	31	705.2	142.8	-	26.6
Nov-18	30	1,140.7	462.4	-	46.6
Dec-18	31	1,273.3	562.6	-	68.6
Jan-19	31	1,757.0	1,038.1	-	65.4
Feb-19	28	1,408.9	774.2	-	56.3
Mar-19	31	763.9	280.5	-	61.9
Annual	365	10,219.6	4,413.2	-	430.2
Htg Season	243	7,942.8	3,415.9	-	394.2
Jun-Sep	122	2,276.8	997.3	-	36.0

Measured Trends

Daily heat pump power use is shown in Figure 3 as function of daily average outdoor temperature (from Albany Airport). There was considerable scatter in the daily energy use data, possibly due to daily variations in how the occupants used the ductless heat pump. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy in the summer is also apparent at this site.

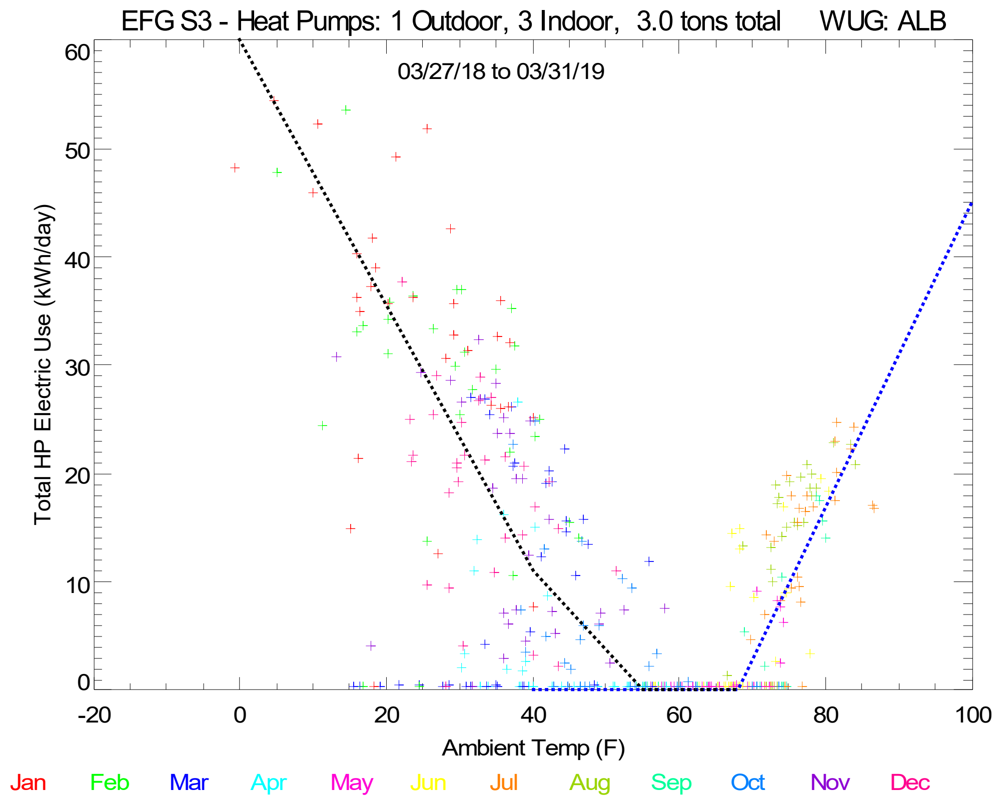


Figure 3. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced some of the fuel oil use by the boiler. Figure 4 compares the trend of fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. Limited post-retrofit data was available to confirm the fuel use trend in this period.

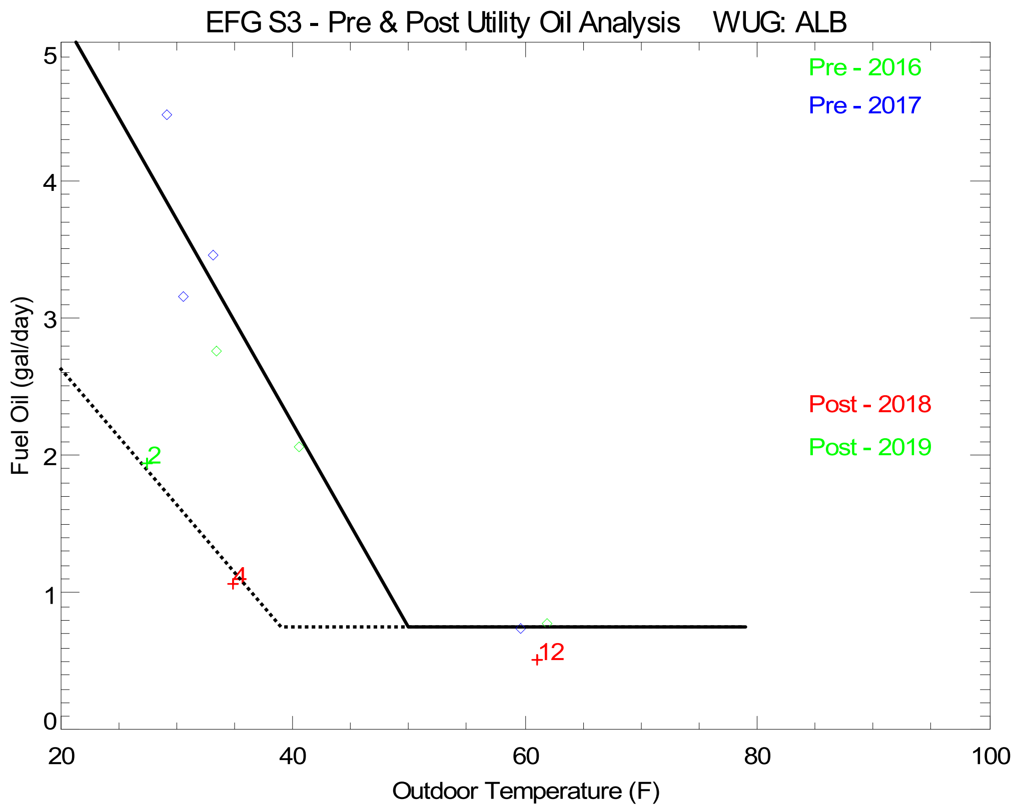


Figure 4. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

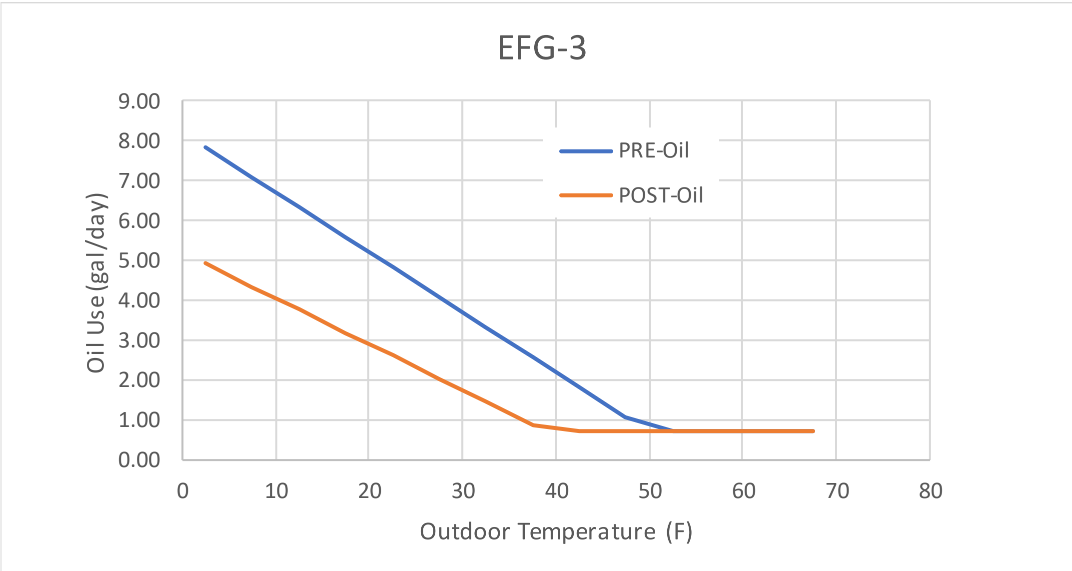
<u>Bin Analysis to Predict Seasonal Impacts</u>

The trend lines above were used in a bin analysis using typical year weather data. Table 2 shows the details of bin analysis and Figure 5 plots the trend lines used for the analysis. In this case there is a consistent trend of the implied COP with temperature as shown in Table 2.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE: **EFG-3** WEATHER: **Albany** $ 0.117 per kWh
FUEL: **Oil** $ 2.487 per gal (oil)
Floor Area 2000 LOCATION: Athens

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	12.2	7.3	93.7	7.3	1.7	$ 30.4	$ 29.1	
-22.5	0	11.5	6.8	87.6	6.8	1.7	$ 28.6	$ 27.2	
-17.5	0	10.8	6.3	81.4	6.3	1.7	$ 26.8	$ 25.2	
-12.5	0	10.0	5.8	75.3	5.8	1.8	$ 24.9	$ 23.3	
-7.5	0	9.3	5.3	69.2	5.3	1.8	$ 23.1	$ 21.4	
-2.5	15	8.5	4.9	63.1	4.9	1.9	$ 21.2	$ 19.4	
2.5	36	7.8	4.4	56.9	4.4	1.9	$ 19.4	$ 17.5	
7.5	127	7.1	3.9	50.8	3.9	2.0	$ 17.5	$ 15.5	
12.5	206	6.3	3.4	44.7	3.4	2.1	$ 15.7	$ 13.6	
17.5	435	5.6	2.9	38.6	2.9	2.2	$ 13.9	$ 11.7	
22.5	498	4.8	2.4	32.4	2.4	2.4	$ 12.0	$ 9.7	
27.5	537	4.1	1.9	26.3	1.9	2.7	$ 10.2	$ 7.8	
32.5	654	3.3	1.4	20.2	1.4	3.1	$ 8.3	$ 5.8	
37.5	720	2.6	0.9	14.1	0.9	3.8	$ 6.5	$ 3.9	
42.5	550	1.9	0.8	9.2	0.8	3.9	$ 4.6	$ 2.9	
47.5	573	1.1	0.8	5.5	0.8	2.1	$ 2.8	$ 2.5	
52.5	723	0.8	0.8	1.8	0.8	0.0	$ 1.9	$ 2.1	
57.5	791	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
62.5	943	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
67.5	682	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
72.5	497	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
77.5	420	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
82.5	274	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
87.5	61	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
92.5	13	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
97.5	5	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	
102.5	0	0.8	0.8	0.0	0.8	0.0	$ 1.9	$ 1.9	



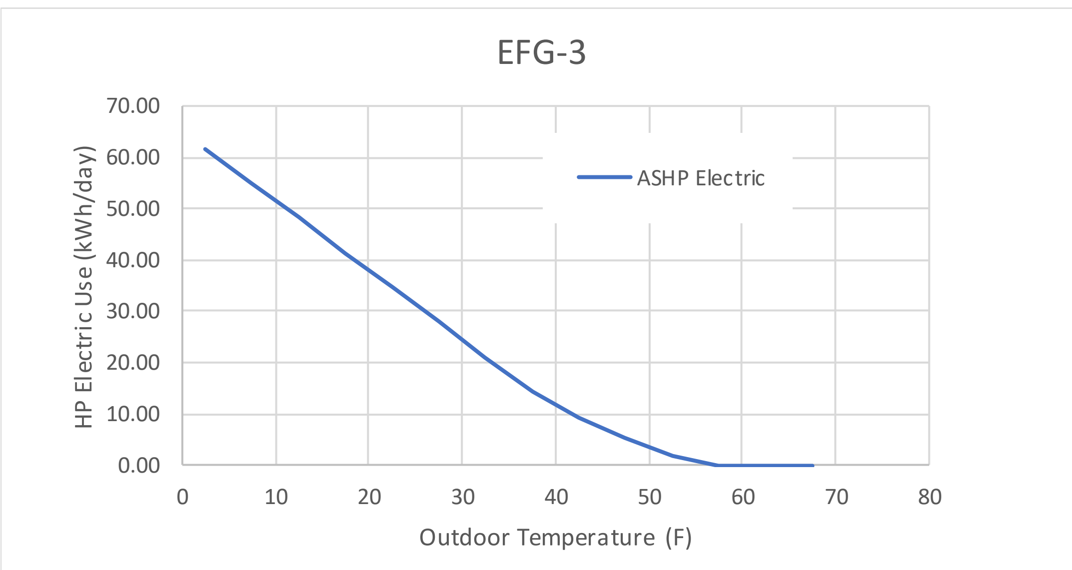


Figure 5. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 2.6 in this case.

In this instance the implied COP is calculated from

$$COP = (Fuel_{pre} - Fuel_{post})*eff/(3.412xkWh_{hp}) = (503.4-166.4)*139*0.79 / (3.412*4107)$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Oil (gal/yr)	503.4	166.4	337.0
HP Electric (kWh/yr)		4,107	(4,107)
Total Heating Costs	$1,252	$893	$359
Implied Seasonal COP			2.6

Summary Statistics	
0.25	Fuel gal per sq ft per yr
27.6	Htg MBtu per sq ft per yr
67%	Reduction in Fuel Use
3,416	Measured HP for Htg (kWh/yr)
83%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 6 and Figure 7 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 7 shows the temperature bins associated with cooling operation.

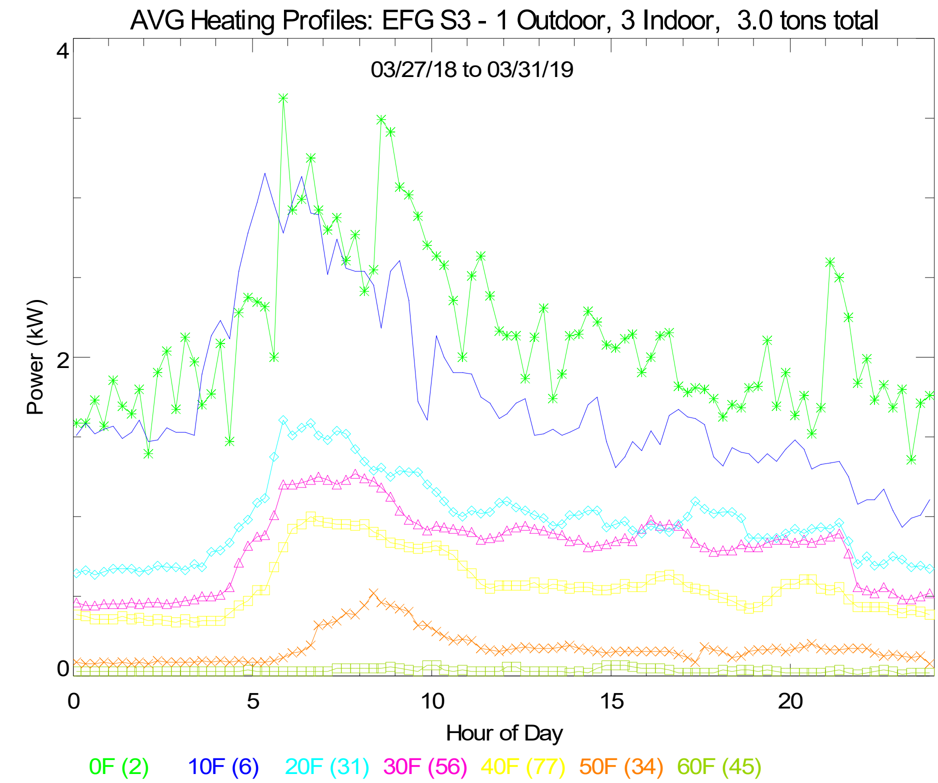


Figure 6. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

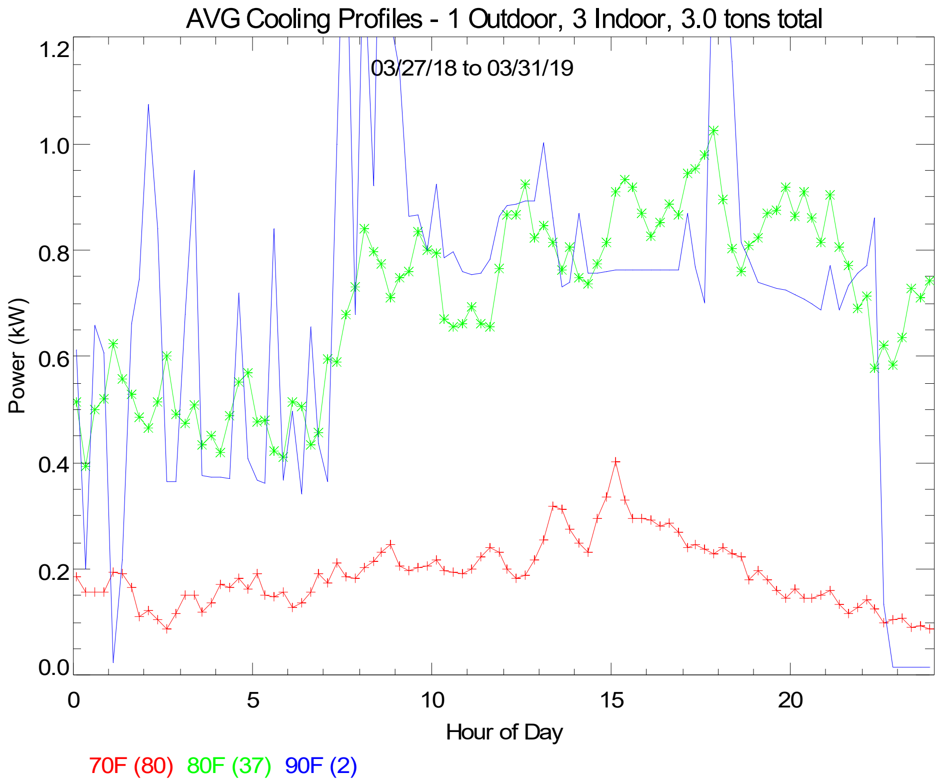


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 8.

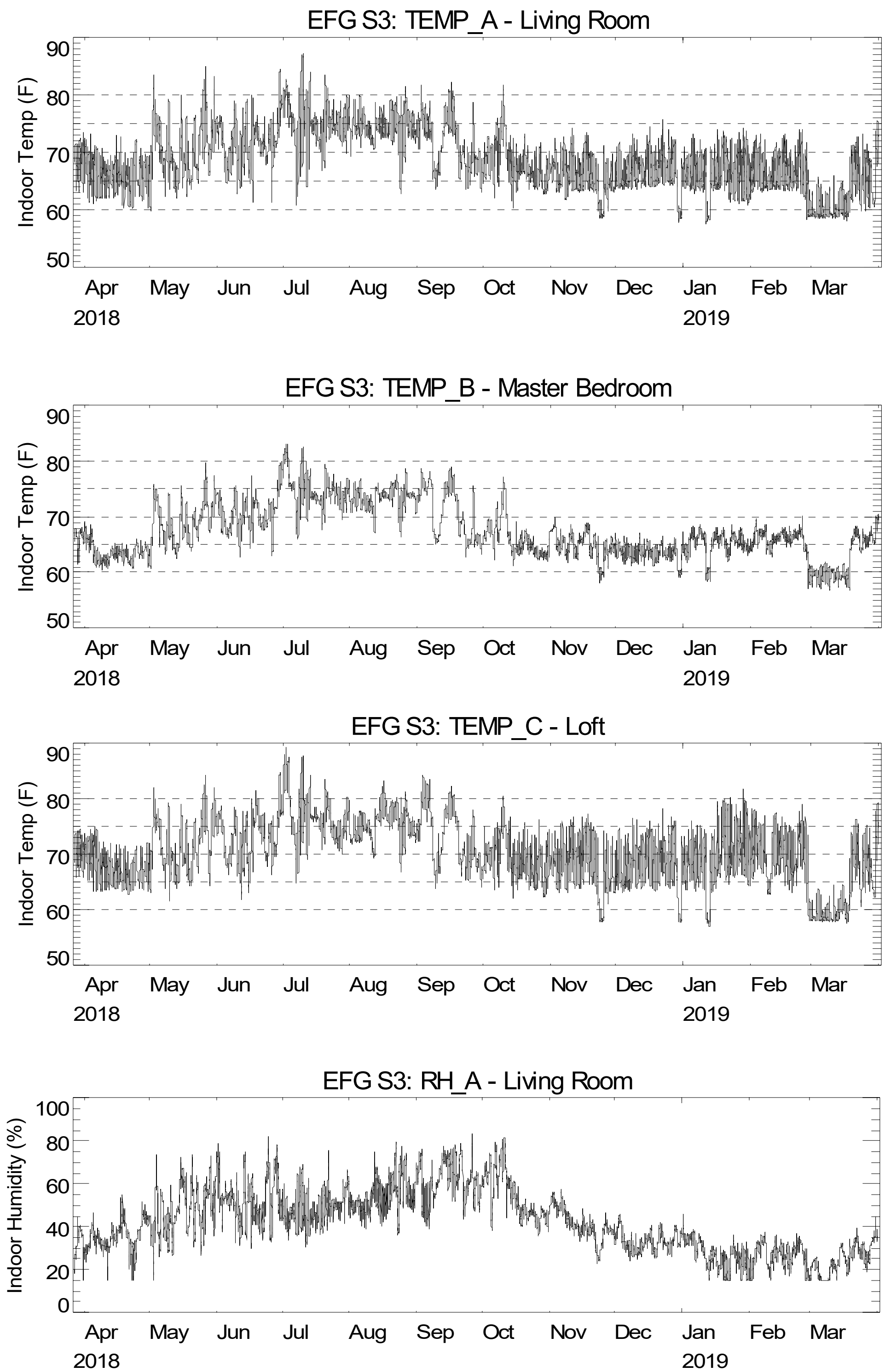


Figure 8. Space Temperatures and Humidity Levels

EFG S4 Savings Analysis

This 1576 sq ft house is in Germantown, NY just south of Albany. The house was originally heated by baseboard electric heat. The electric baseboard was also used for supplemental heating after the 1.5-ton ASHP was installed. The ASHP was installed in December 2017. Monitoring began in January 2018. This unit was also used to provide some cooling.

The homeowner indicated to EFG staff that before the heat pump was installed she had kept her set points relatively low (i.e., under 60°F) to control electric costs. After the heat pump was installed, she claimed to have increased her space temperature set points (the plots in Figure 8 imply set points near 65°F). This behavior—or take-back effect—may have confounded the savings analysis and made the results slightly conservative for this site.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pump. Figure 2 shows the power use for the house and heat pump across the monitoring period.

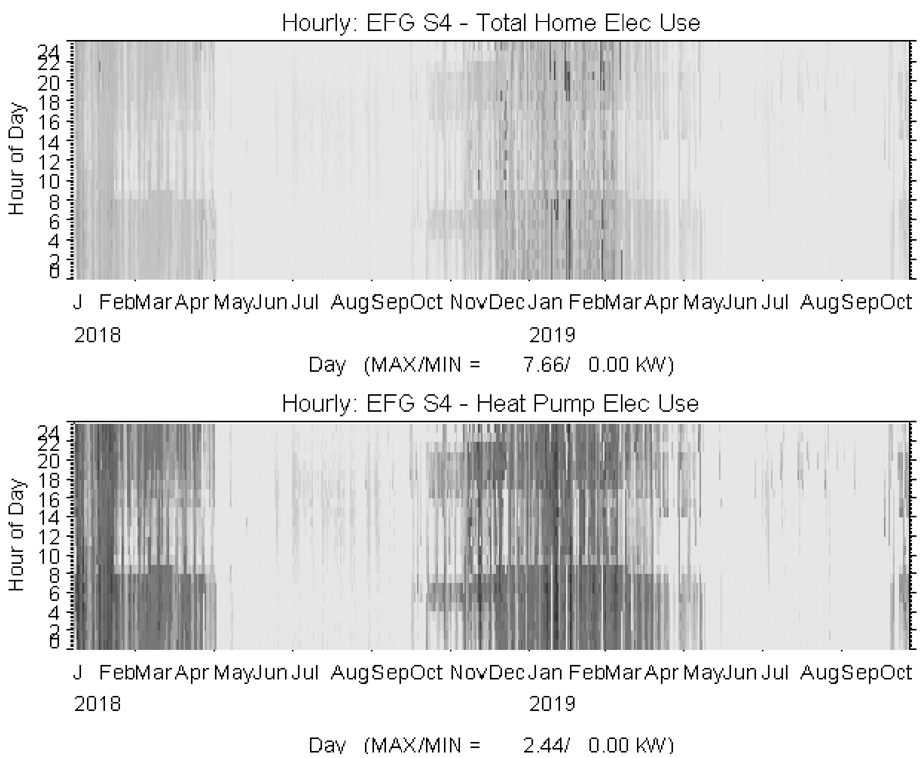


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

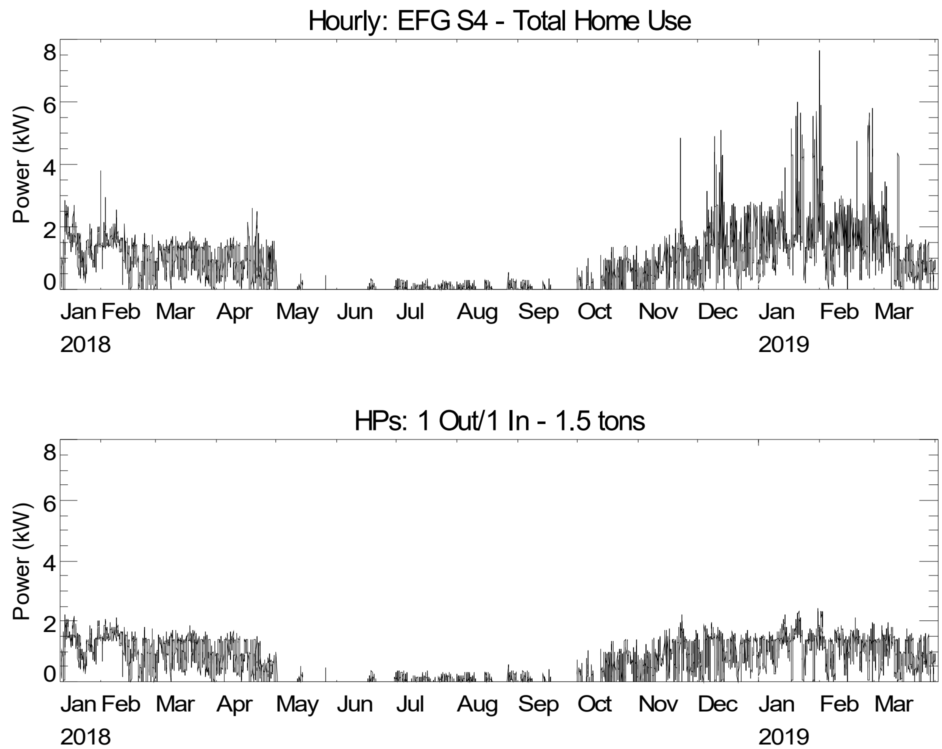


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. It also includes the resistance electric heaters that were monitored.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)	Boiler Runtime (hrs)
Jan-18	20	668.3	605.4	62.8	-
Feb-18	28	820.3	811.1	9.2	-
Mar-18	31	798.8	798.6	0.3	-
Apr-18	30	598.1	552.8	45.4	-
May-18	31	20.0	19.9	0.2	-
Jun-18	30	13.4	13.3	0.2	-
Jul-18	31	47.9	47.7	0.2	-
Aug-18	31	45.5	45.4	0.2	-
Sep-18	30	25.3	25.2	0.1	-
Oct-18	31	250.7	250.5	0.2	-
Nov-18	30	582.6	570.8	11.8	-
Dec-18	31	1,105.4	770.0	335.5	-
Jan-19	31	1,429.1	971.0	458.1	-
Feb-19	28	1,236.6	806.3	430.3	-
Mar-19	31	854.3	714.0	140.4	-
Annual	365	5,737.1	4,876.3	861.4	-
Htg Season	243	5,605.0	4,744.7	860.7	-
Jun-Sep	122	132.1	131.6	0.7	-

Measured Trends

Daily heat pump power use is shown in Figure 3 as function of daily average outdoor temperature. There is moderate scatter in the data, indicating that the occupants used the ductless heat pump in a fairly consistent manner. The dotted line on the plot represents to a best fit of the trend with temperature.

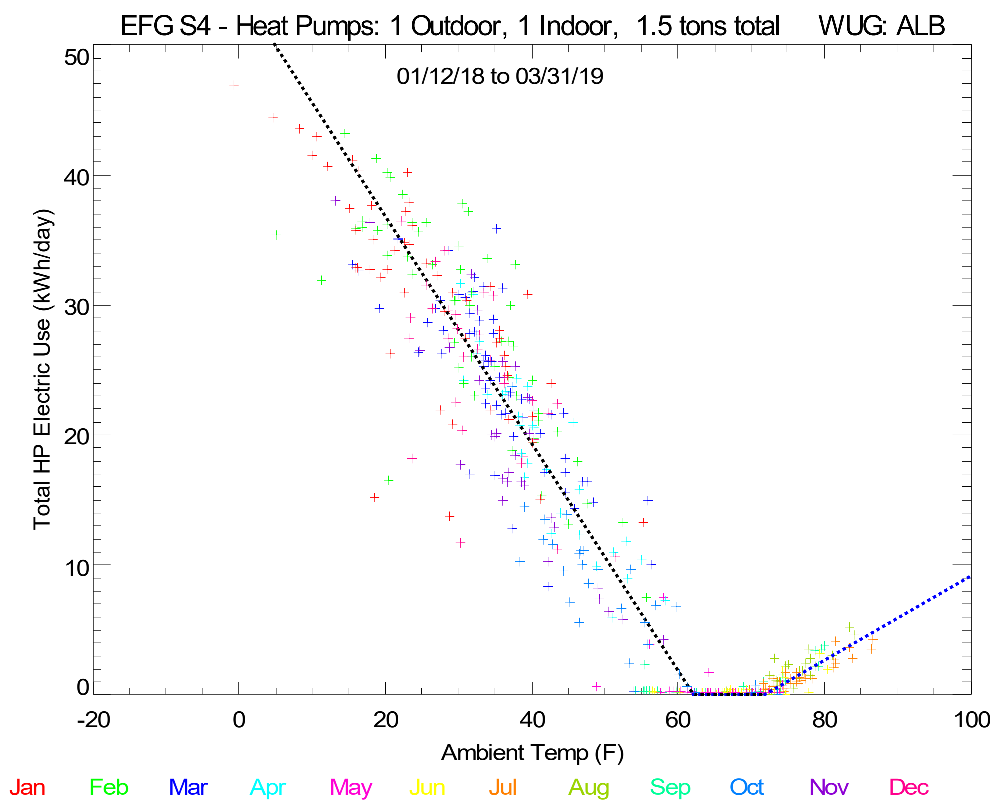


Figure 3. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced baseboard electric heat use. Figure 4 compares the trend of monthly electric with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period.

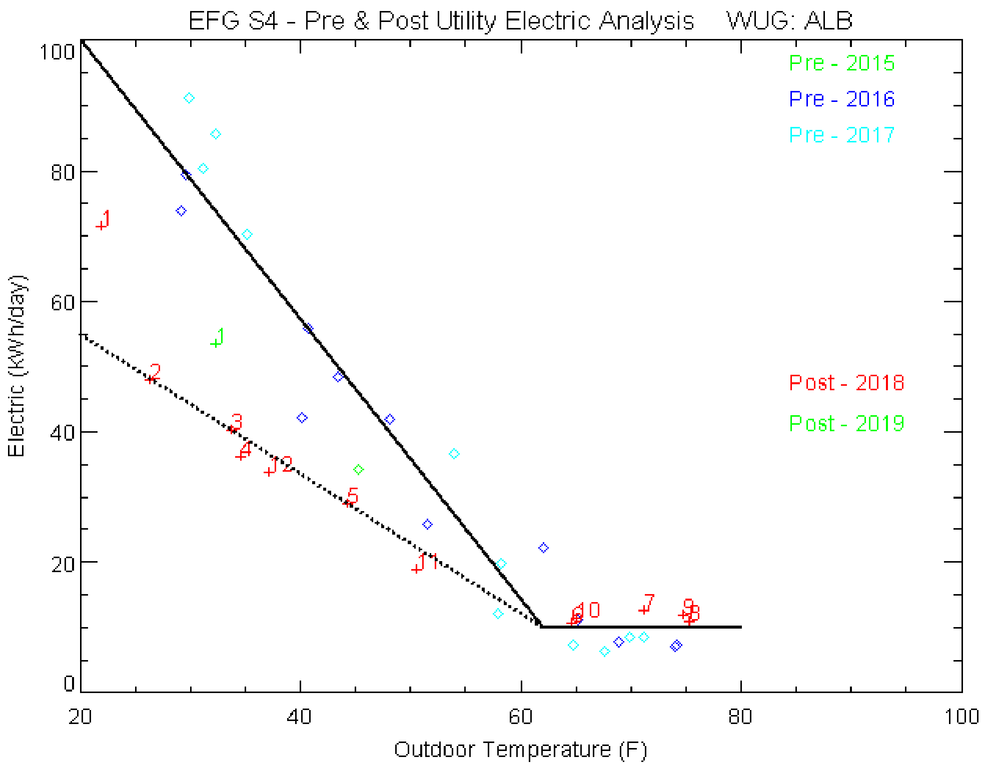


Figure 4. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

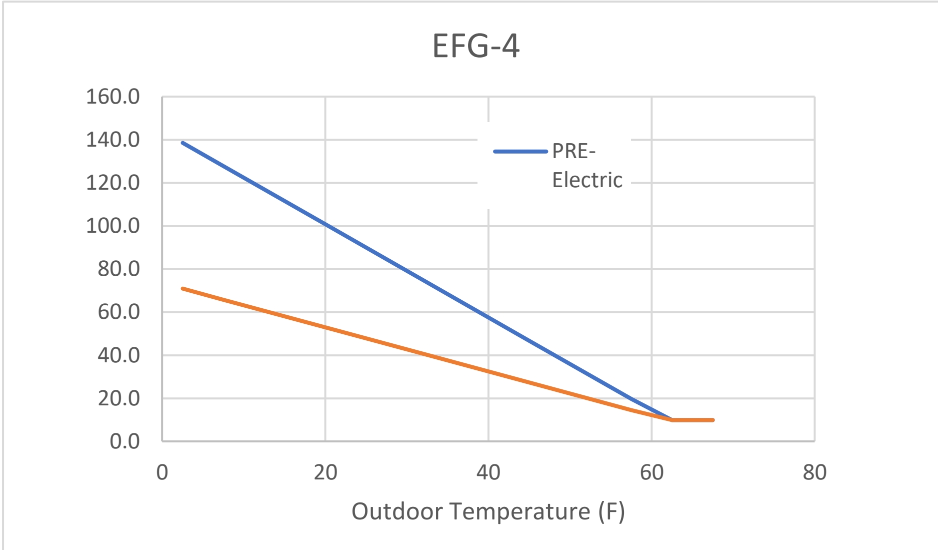
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Albany. Table 2 shows the details of bin analysis and Figure 5 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE: **EFG-4** WEATHER: **Albany** $ 0.117 per kWh
FUEL: **Electric** $ 0.117 per kWh
Floor Area 1576 LOCATION: Germantown

Temp Bin	Hours	FUEL PRE-Electric (kWh/day)	FUEL POST-Electric (kWh/day)	ASHP Electric (kWh/day)	Adjusted POST-Electric (kWh/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Electric adjustment factor
-27.5	0	203.5	101.6	78.2	101.6	2.3	$ 23.7	$ 21.0	
-22.5	0	192.7	96.5	73.9	96.5	2.3	$ 22.5	$ 19.9	
-17.5	0	181.9	91.4	69.5	91.4	2.3	$ 21.2	$ 18.8	
-12.5	0	171.1	86.3	65.1	86.3	2.3	$ 20.0	$ 17.7	
-7.5	0	160.3	81.2	60.8	81.2	2.3	$ 18.7	$ 16.6	
-2.5	15	149.4	76.0	56.4	76.0	2.3	$ 17.4	$ 15.5	
2.5	36	138.6	70.9	52.0	70.9	2.3	$ 16.2	$ 14.3	
7.5	127	127.8	65.8	47.6	65.8	2.3	$ 14.9	$ 13.2	
12.5	206	117.0	60.7	43.3	60.7	2.3	$ 13.7	$ 12.1	
17.5	435	106.2	55.6	38.9	55.6	2.3	$ 12.4	$ 11.0	
22.5	498	95.4	50.4	34.5	50.4	2.3	$ 11.1	$ 9.9	
27.5	537	84.6	45.3	30.2	45.3	2.3	$ 9.9	$ 8.8	
32.5	654	73.8	40.2	25.8	40.2	2.3	$ 8.6	$ 7.7	
37.5	720	63.0	35.1	21.4	35.1	2.3	$ 7.3	$ 6.6	
42.5	550	52.2	30.0	17.0	30.0	2.3	$ 6.1	$ 5.5	
47.5	573	41.3	24.8	12.7	24.8	2.3	$ 4.8	$ 4.4	
52.5	723	30.5	19.7	8.3	19.7	2.3	$ 3.6	$ 3.3	
57.5	791	19.7	14.6	3.9	14.6	2.3	$ 2.3	$ 2.2	
62.5	943	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
67.5	682	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
72.5	497	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
77.5	420	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
82.5	274	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
87.5	61	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
92.5	13	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
97.5	5	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	
102.5	0	10.0	10.0	0.0	10.0	0.0	$ 1.2	$ 1.2	



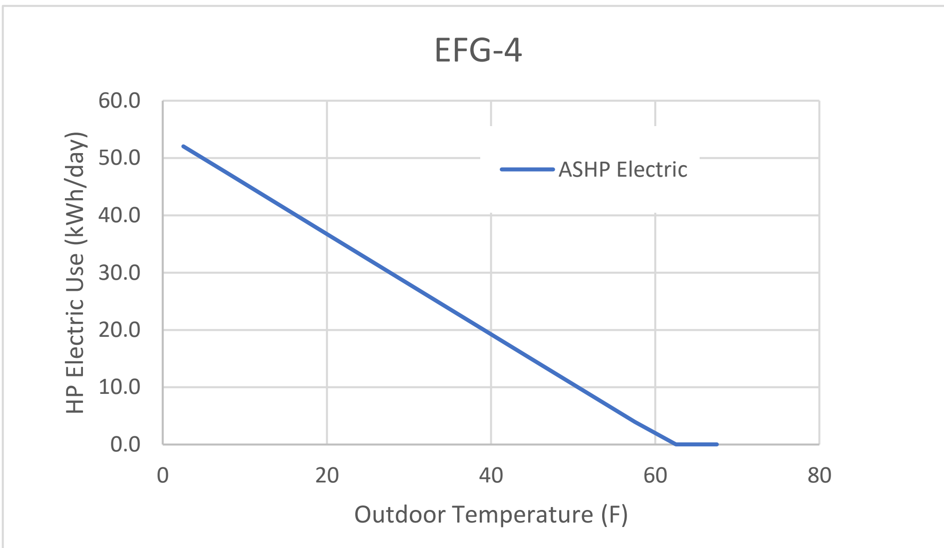


Figure 5. Trends of (Pre and Post Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. Since the base fuel is electric, the savings calculation only considers the pre- and post-retrofit electric use. The implied seasonal heating COP is 2.3, using both electric savings and heat pump energy use which is shown on the bottom of the table.

In this instance the implied COP is calculated from

$$COP = (kWh_{pre} - kWh_{post} + kWh_{hp})/kW_{hp} = (12987 - 6150 + 5251) / 5251$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Total Heat (kWh/yr)	12,987	6,150	6,837
		-	-
Total Heating Costs	$1,516	$718	$798
Implied Seasonal COP			2.3
HP Electric (kWh/yr)			5,251

Summary Statistics	
8.24	Fuel kWh per sq ft per yr
28.1	Htg MBtu per sq ft per yr
53%	Reduction in Fuel Use
4,745	Measured HP for Htg (kWh/yr)
90%	Measured as % of Typical yr

Table 4 uses measured resistance heating use in the post-retrofit period and determines the savings as result of installing the heat pump. An implied COP including measured resistance heating is provided. The implied COP was slightly lower with this approach that uses the measured resistance heating power.

Table 4. Results of Bin Analysis Showing Seasonal Impact to Resistant Heating Use

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Resistance (kWh/yr)	12,987	861	12,126
ASHP (kWh/yr)		5,251	(5,251)
Total Heat (kWh/yr)	12,987	6,112	6,875
Total Heating Costs	$1,516	$713	$802
Implied ASHP COP			2.3
Overall COP Including Resistance			2.1

Average Heat Pump Demand Profiles

Figure 6 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 7 shows the temperature bins associated with cooling operation.

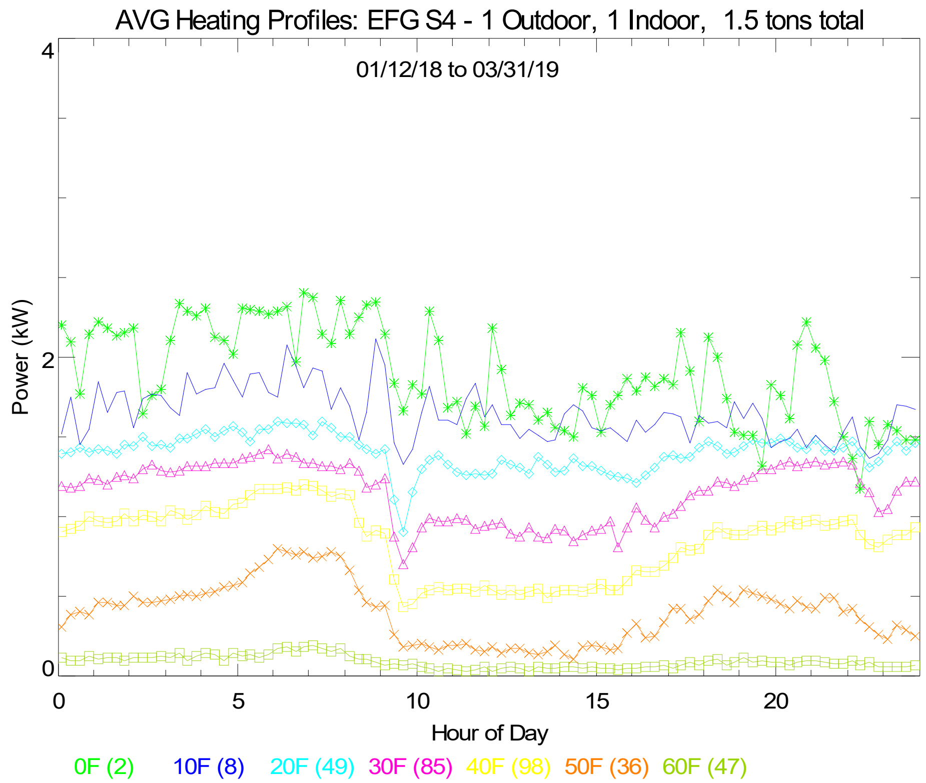


Figure 6. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

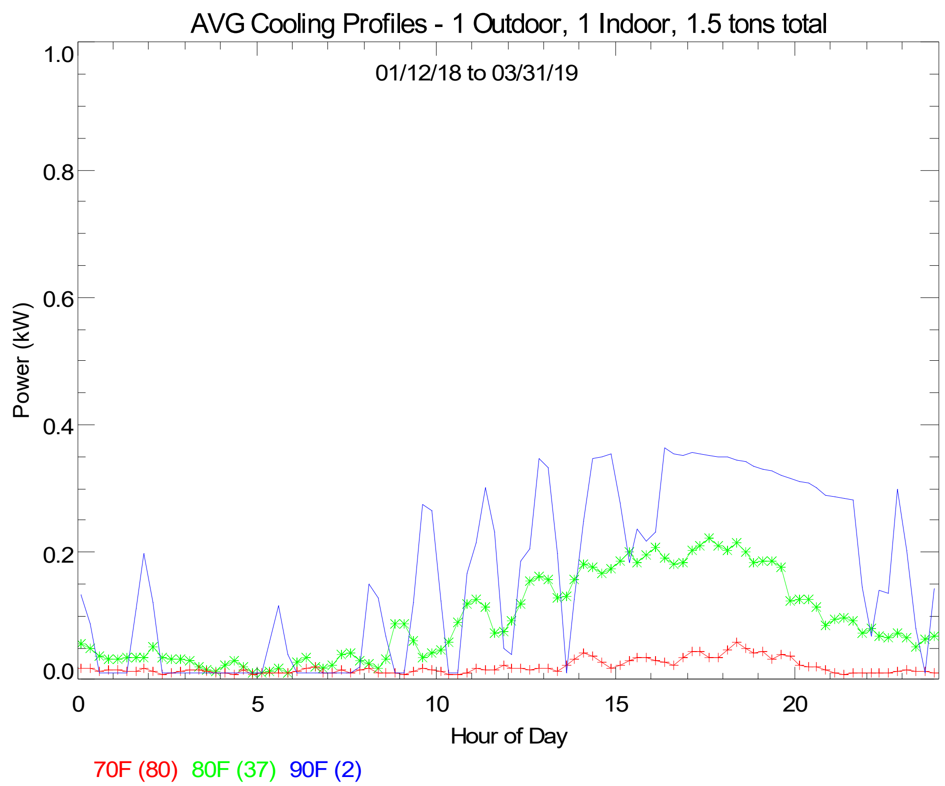


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 8. The summertime temperatures are only partially controlled indicating very little cooling. The high RH in the summer reflects the lack of cooling and/or poor dehumidification.

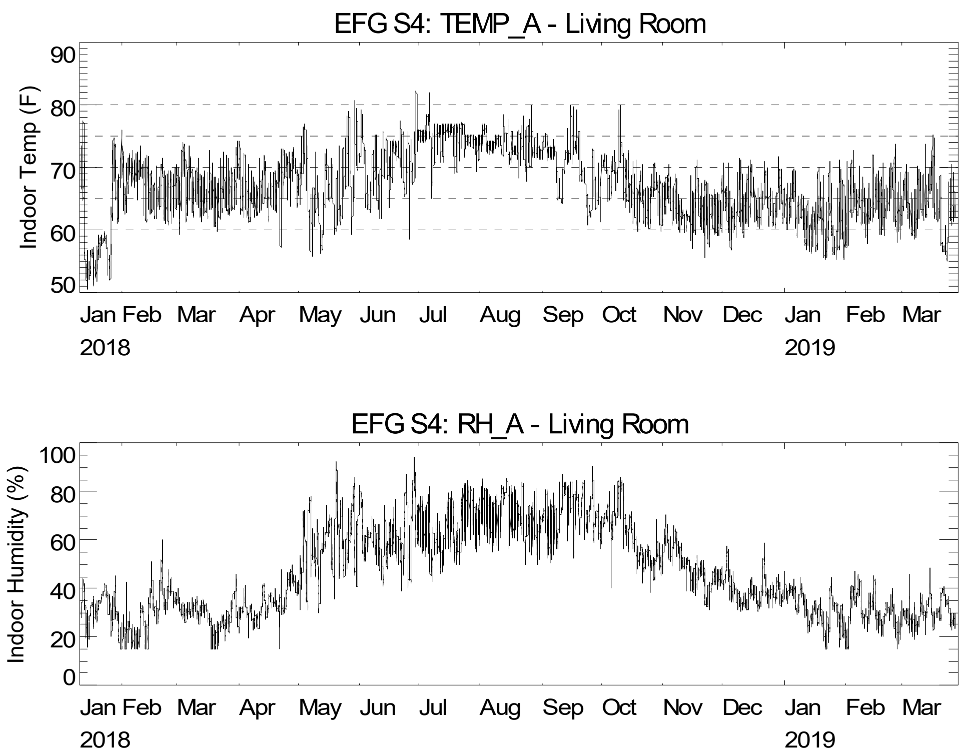
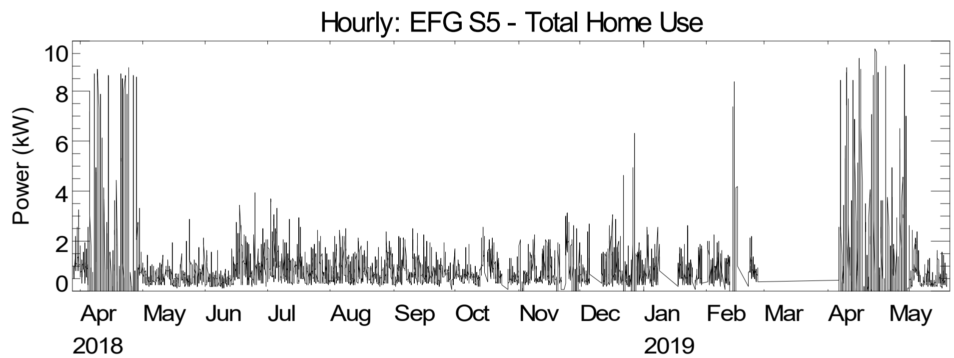


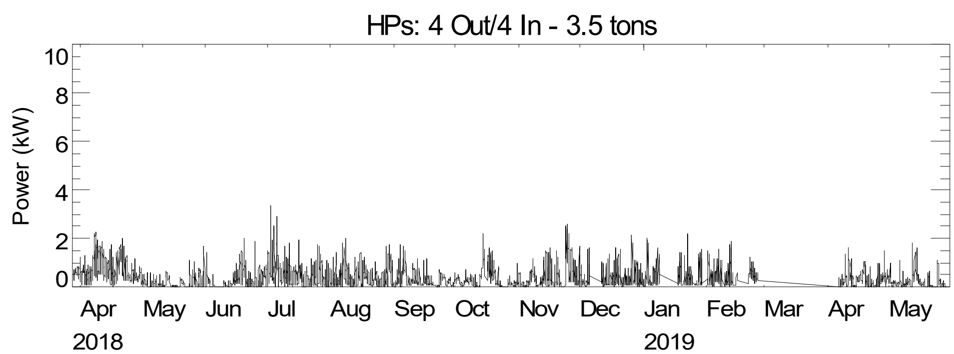
Figure 8. Space Temperatures and Humidity Levels

EFG S5 Savings Analysis

This 2286 sq ft house is located in Kingston, NY near Newburgh. The house was originally heated by a gas-fired steam boiler. This house has the highest fuel use per sq ft of twenty homes in the project. DHW is provided by a gas-fired hot water tank. Two ASHPs ductless were originally installed in August 2016. Two more ASHP units were installed in January 2018 as part of this project. The four ASHPs have a total installed cooling capacity of 3.5 tons. Monitoring began in April 2018. Occupancy changed several times in this house, which lead to a loss of data as well as inconsistent pre- and post-retrofit operating patterns.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed





heat pumps.

Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use for the individual heat pumps.

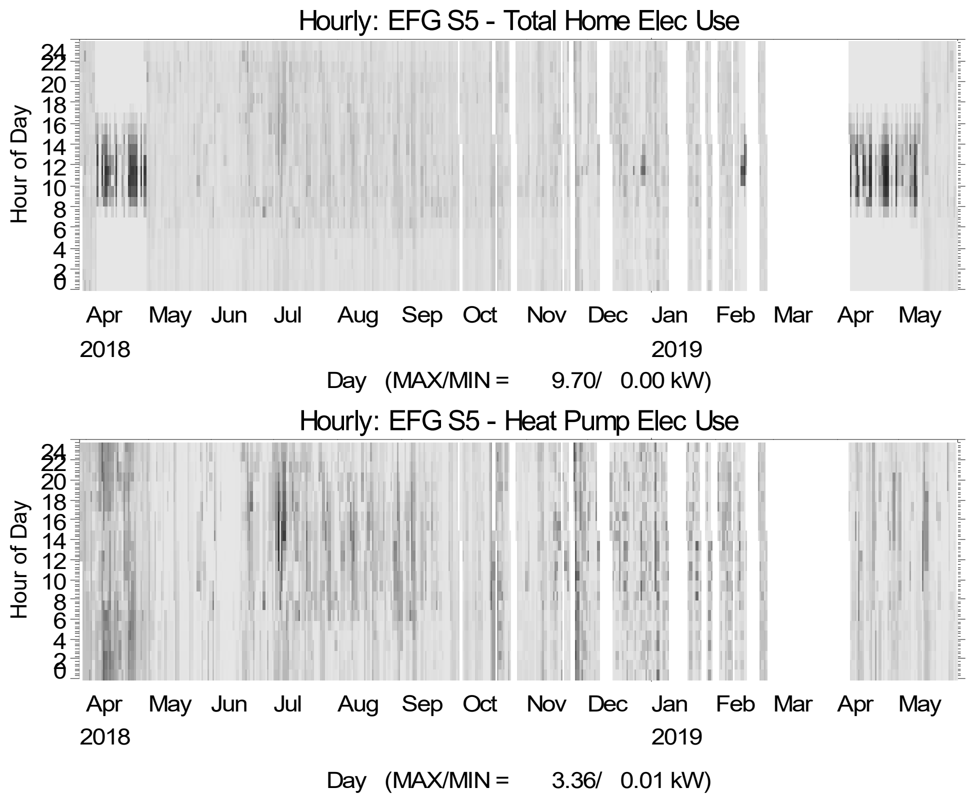
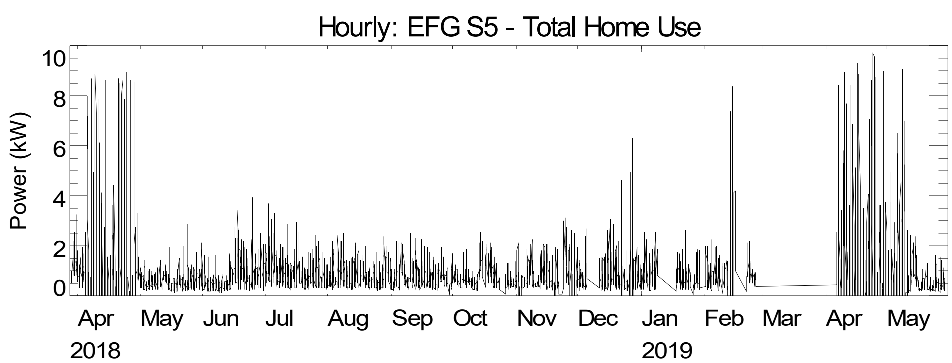


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.



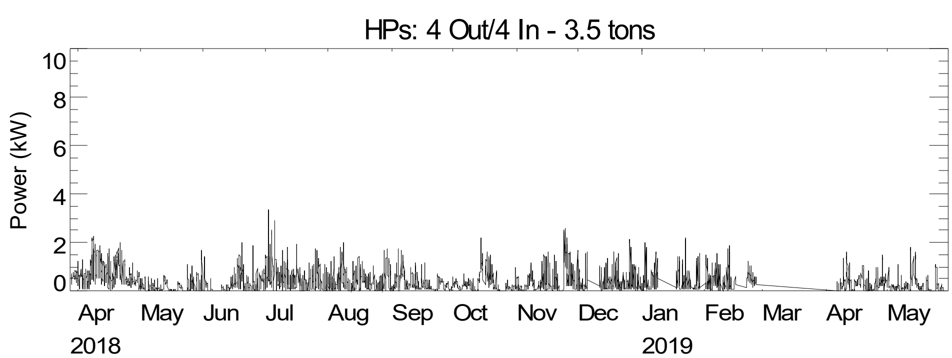


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

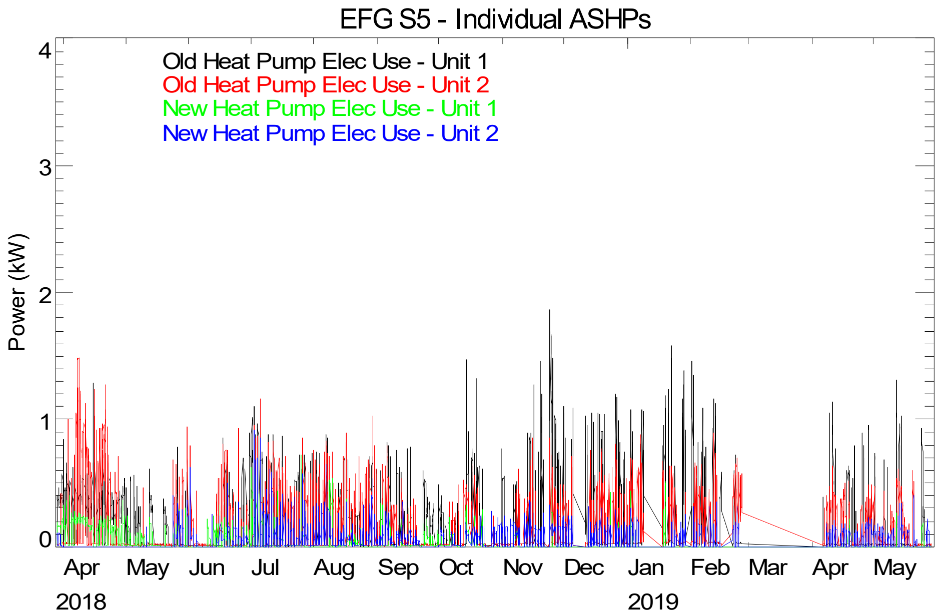


Figure 3. Power Use for Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pumps over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Solar (kWh)
Mar-18	4	92.3	49.2	50.0
Apr-18	30	833.7	545.5	570.2
May-18	31	443.3	127.8	676.2
Jun-18	30	511.7	173.3	692.1
Jul-18	31	709.3	406.0	782.2
Aug-18	31	621.9	320.4	654.5
Sep-18	30	539.7	206.9	412.6
Oct-18	29	499.0	216.6	341.5
Nov-18	29	497.5	290.3	191.1
Dec-18	26	458.5	221.7	174.9
Jan-19	20	355.8	180.5	93.1
Feb-19	20	346.0	176.0	204.1
Mar-19	25	729.2	187.3	449.1
Apr-19	29	484.4	149.0	545.0
Annual	331	6,196.3	2,655.8	5,216.4
Htg Season	209	3,813.7	1,549.2	2,675.0
Jun-Sep	122	2,382.6	1,106.6	2,541.4

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature (using weather data from Stewart Airport). The dotted line on the plot represents to a best fit of the trend with temperature. The degree of fit for heating is very poor due to the changes in occupancy. A trend of energy in the summer is also apparent at this site.

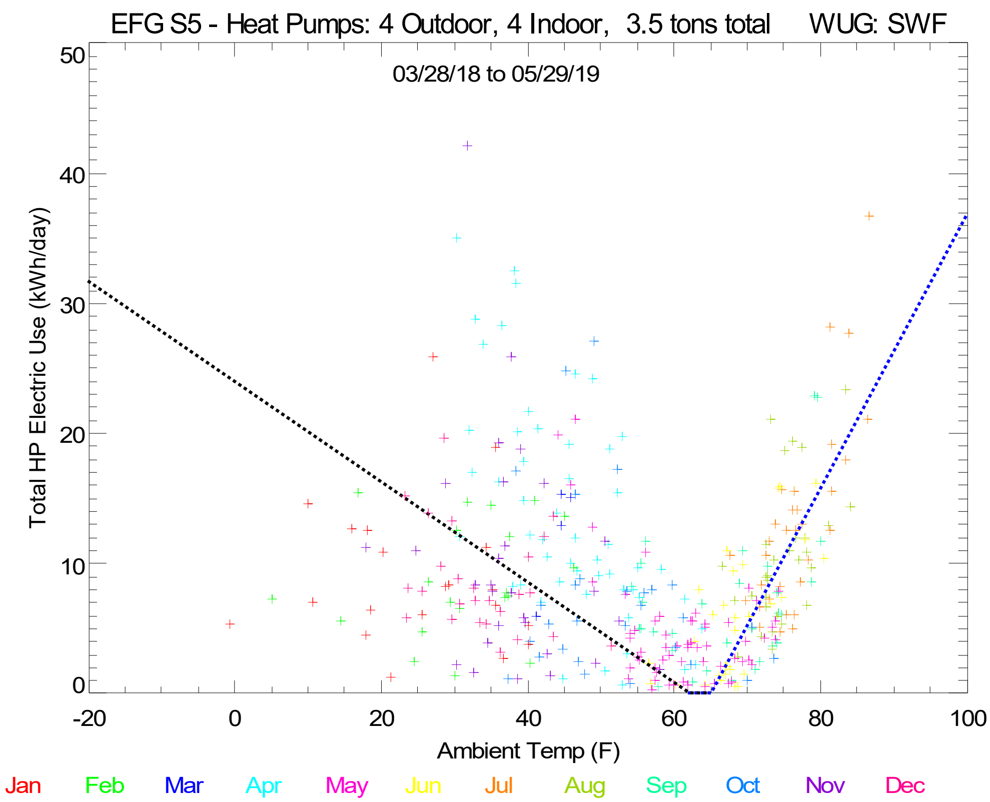


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced some of the fuel oil use by the boiler. Figure 5 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. A limited amount of post-retrofit data was available to confirm the fuel use trend in this period.

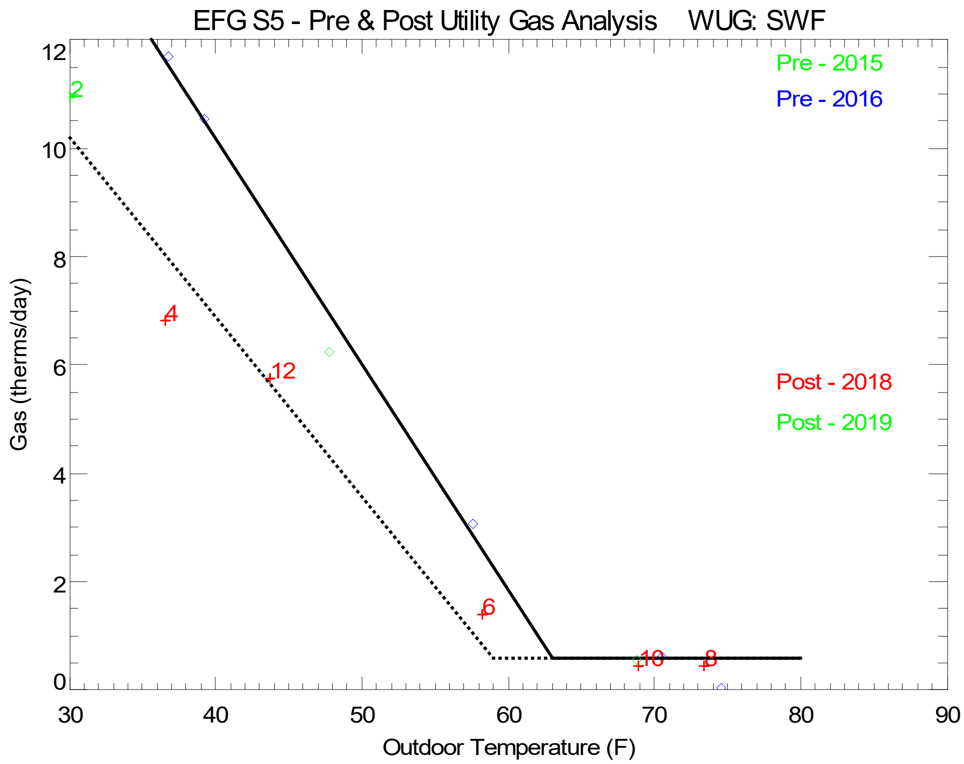


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

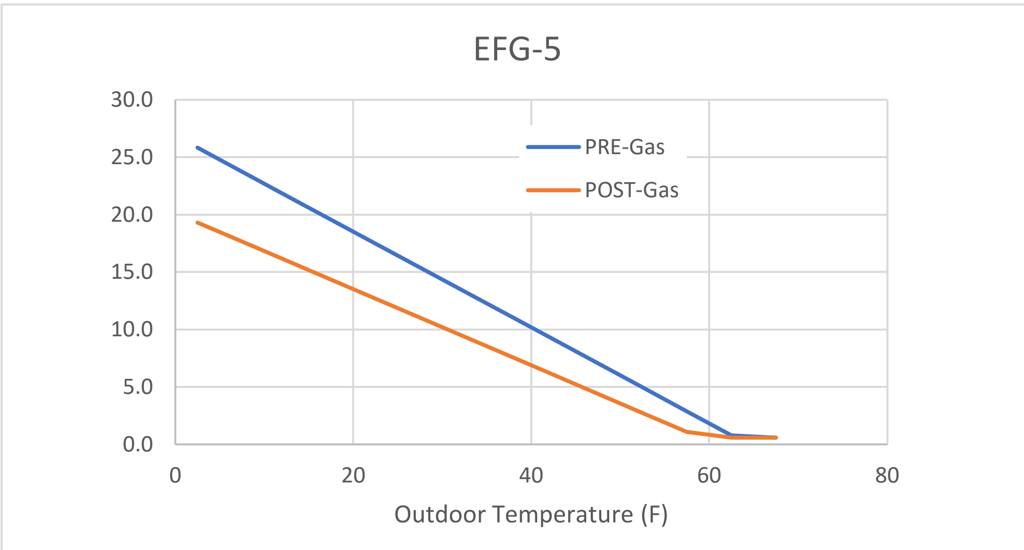
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Newburgh. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	**EFG-5**	WEATHER:	**Newburgh**	$	0.150	per kWh
FUEL:	**Gas**			$	1.469	per therm
Floor Area	2286	LOCATION:	Kingston			

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	38.3	29.3	34.5	29.3	6.1	$ 56.3	$ 48.1	
-22.5	0	36.2	27.6	32.6	27.6	6.1	$ 53.2	$ 45.4	
-17.5	0	34.2	25.9	30.7	25.9	6.2	$ 50.2	$ 42.7	
-12.5	0	32.1	24.3	28.8	24.3	6.3	$ 47.1	$ 40.0	
-7.5	1	30.0	22.6	26.8	22.6	6.4	$ 44.0	$ 37.3	
-2.5	13	27.9	21.0	24.9	21.0	6.4	$ 41.0	$ 34.5	
2.5	36	25.8	19.3	23.0	19.3	6.6	$ 37.9	$ 31.8	
7.5	45	23.7	17.7	21.0	17.7	6.7	$ 34.9	$ 29.1	
12.5	113	21.6	16.0	19.1	16.0	6.8	$ 31.8	$ 26.4	
17.5	222	19.6	14.3	17.2	14.3	7.0	$ 28.7	$ 23.6	
22.5	367	17.5	12.7	15.2	12.7	7.3	$ 25.7	$ 20.9	
27.5	373	15.4	11.0	13.3	11.0	7.6	$ 22.6	$ 18.2	
32.5	764	13.3	9.4	11.4	9.4	8.0	$ 19.5	$ 15.5	
37.5	814	11.2	7.7	9.5	7.7	8.6	$ 16.5	$ 12.7	
42.5	727	9.1	6.1	7.5	6.1	9.5	$ 13.4	$ 10.0	
47.5	668	7.1	4.4	5.6	4.4	11.0	$ 10.4	$ 7.3	
52.5	480	5.0	2.7	3.7	2.7	14.0	$ 7.3	$ 4.6	
57.5	748	2.9	1.1	1.7	1.1	23.9	$ 4.2	$ 1.9	
62.5	831	0.8	0.6	0.0	0.6	#######	$ 1.2	$ 0.9	
67.5	902	0.6	0.6	0.0	0.6	0.0	$ 0.9	$ 0.9	
72.5	538	0.6	0.6	0.0	0.6	0.0	$ 0.9	$ 0.9	
77.5	603	0.6	0.6	0.0	0.6	0.0	$ 0.9	$ 0.9	
82.5	358	0.6	0.6	0.0	0.6	0.0	$ 0.9	$ 0.9	
87.5	134	0.6	0.6	0.0	0.6	0.0	$ 0.9	$ 0.9	
92.5	23	0.6	0.6	0.0	0.6	0.0	$ 0.9	$ 0.9	
97.5	1	0.6	0.6	0.0	0.6	0.0	$ 0.9	$ 0.9	
102.5	0	0.6	0.6	0.0	0.6	0.0	$ 0.9	$ 0.9	



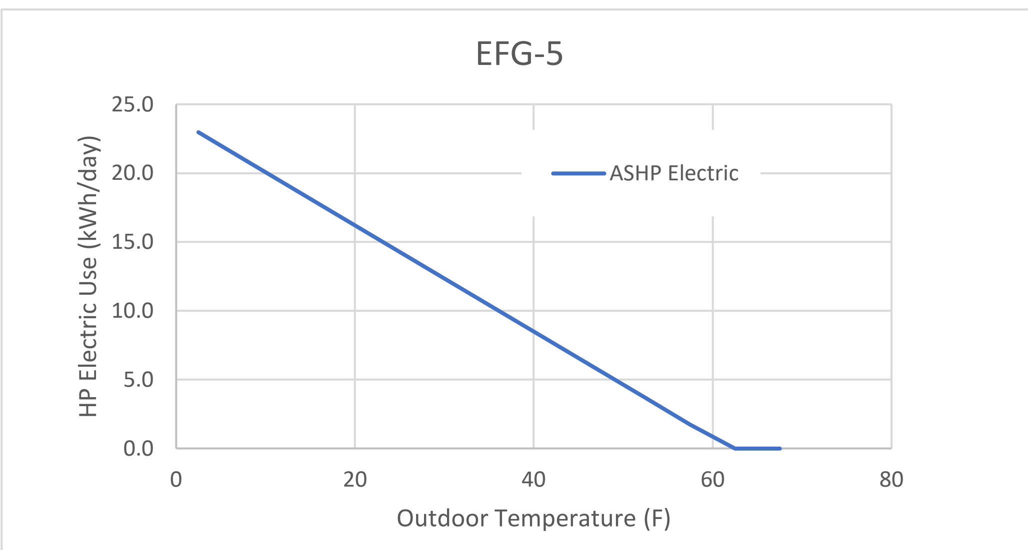


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is impossibly high in this case. The changes in ownership / occupancy resulted in an invalid pre-to-post comparison.

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	**PRE-Retrofit**	**POST-Retrofit**	**Savings**
Gas (therms/yr)	2,231	1,470	760
HP Electric (kWh/yr)		1,972	(1,972)
Total Heating Costs	$3,276	$2,455	$821
Implied Seasonal COP			8.9

Summary Statistics	
0.98	Fuel therms per sq ft per yr
77.1	Htg MBtu per sq ft per yr
34%	Reduction in Fuel Use
1,549	Measured HP for Htg (kWh/yr)
79%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

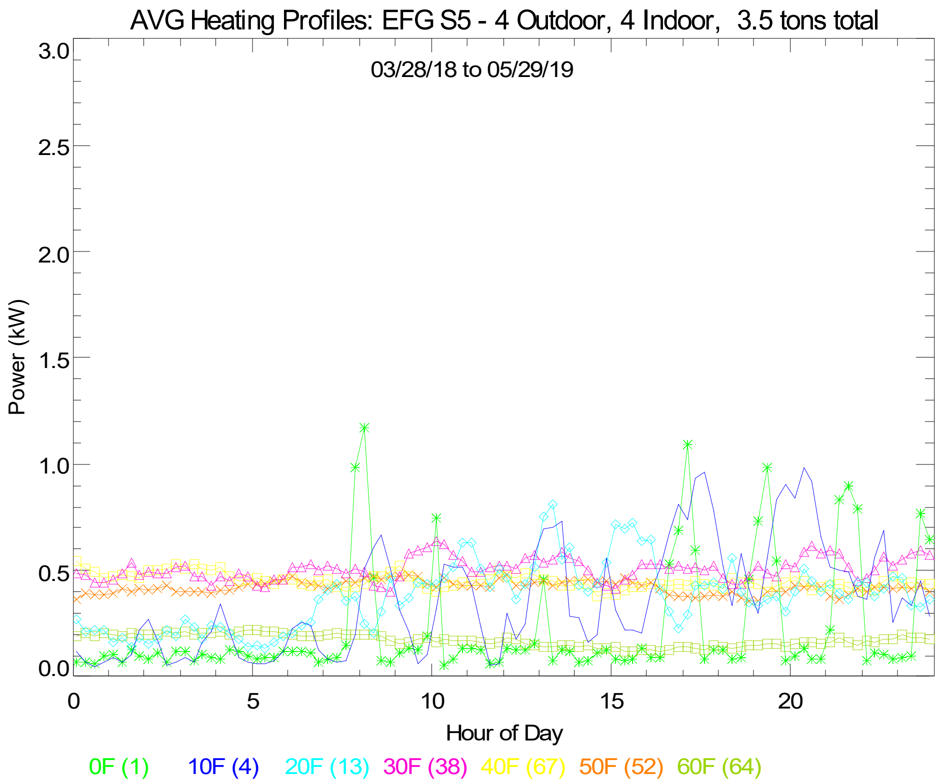


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

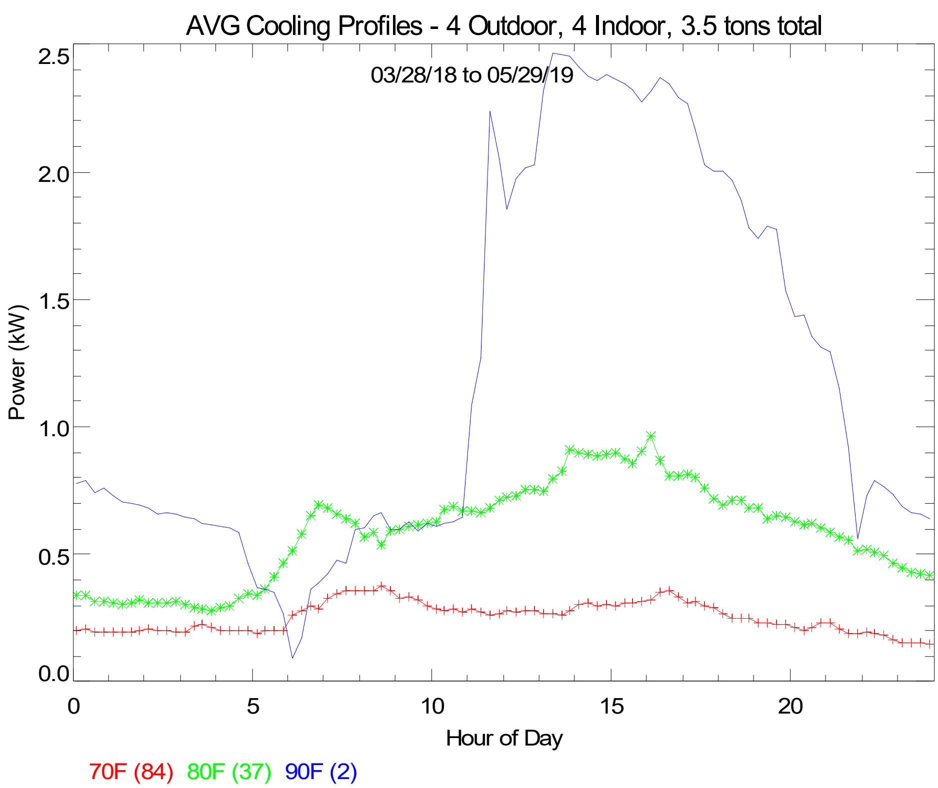


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

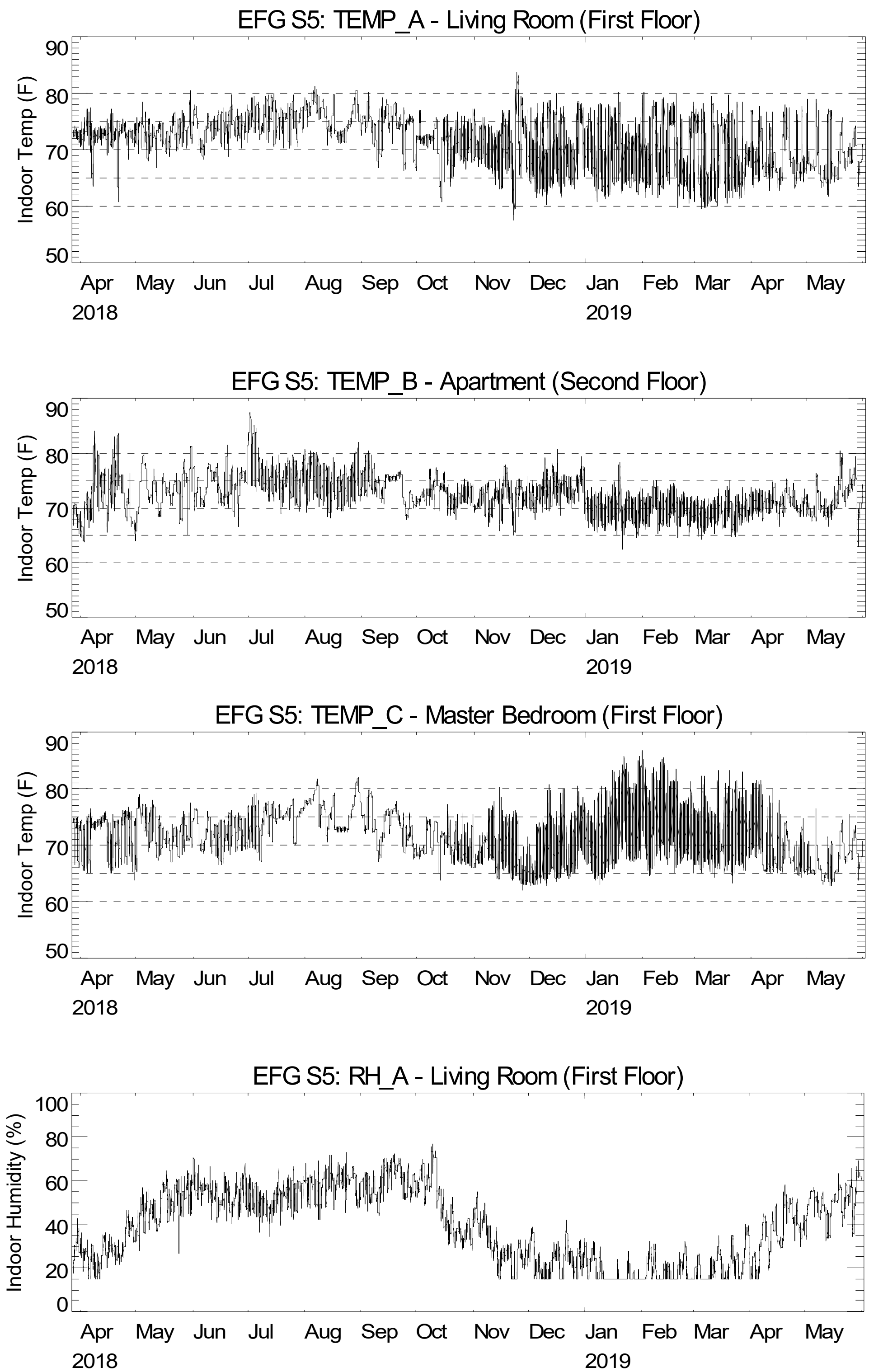


Figure 9. Space Temperatures and Humidity Levels

EFG S6 Savings Analysis

This two-story 1,700 sq ft house is located in Albany, NY. The house was originally heated by a high efficiency gas furnace, which is now used for supplemental heating for three 1-ton ASHP units that were installed in April of 2018. The home also has a separate gas-fired hot water tank.

Monitoring began in May 2018, but an adjustment within the electrical panel in the Fall of 2018 resulted in a CT pin becoming detached from the logger. This was then corrected in April of 2019 and monitoring continued through May 2020.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps starting in May 2019. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use for the individual heat pumps.

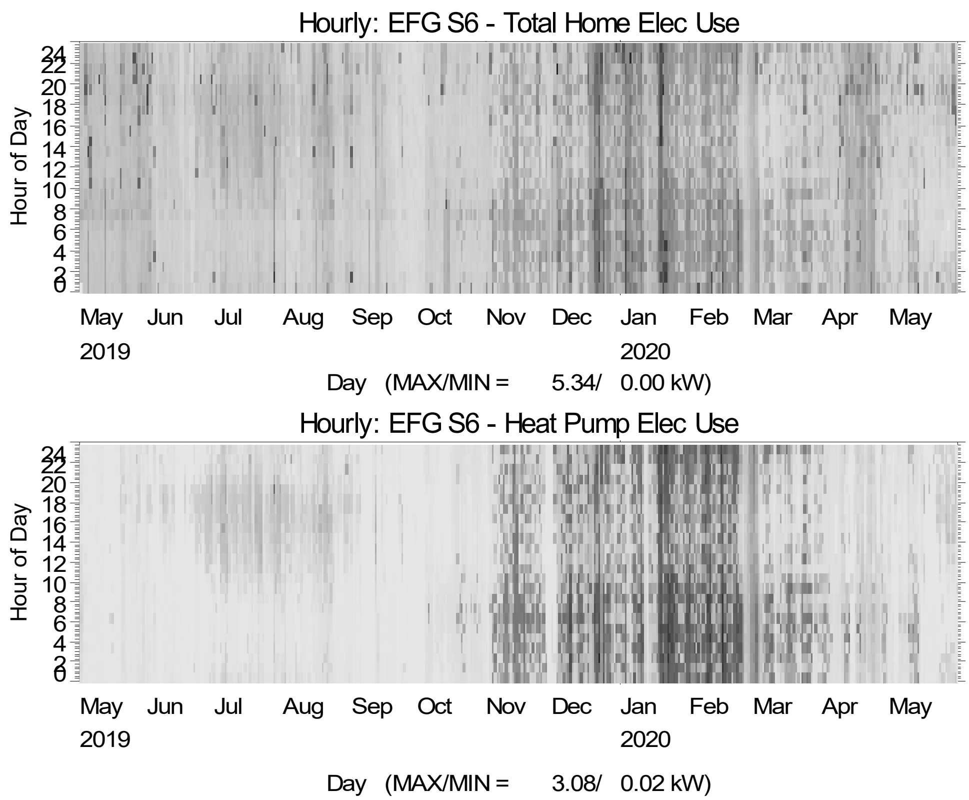


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

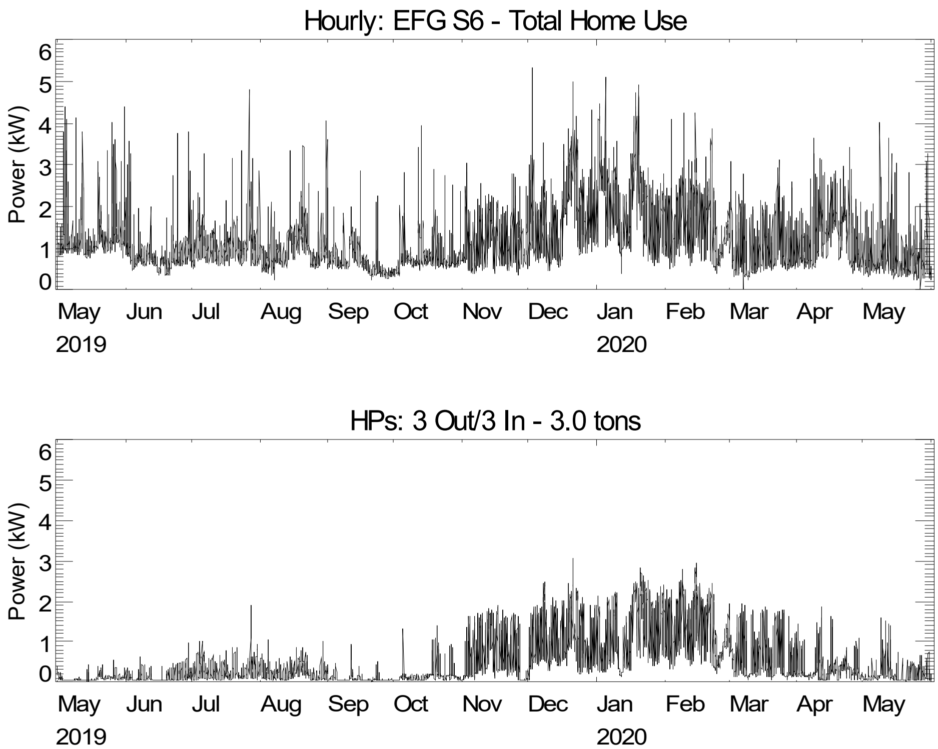


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

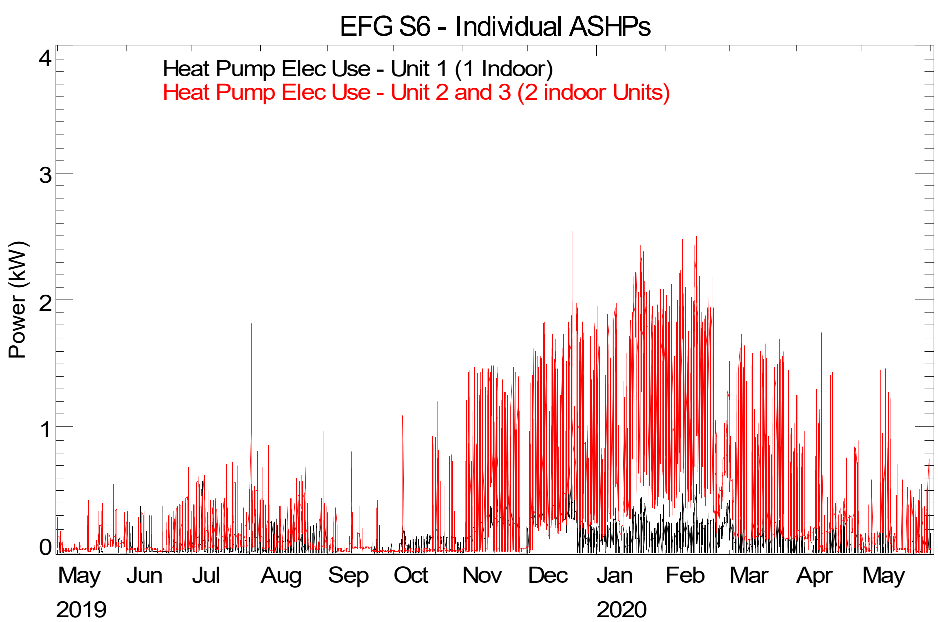


Figure 3. Power Use for Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)
May-19	31	933.0	64.7
Jun-19	30	594.5	84.5
Jul-19	31	809.1	207.1
Aug-19	31	732.8	160.3
Sep-19	30	479.3	52.3
Oct-19	31	571.2	99.0
Nov-19	30	860.1	492.0
Dec-19	31	1,302.5	769.9
Jan-20	31	1,528.7	941.3
Feb-20	29	1,141.0	930.1
Mar-20	31	756.6	460.7
Apr-20	30	924.9	210.5
May-20	31	572.9	134.9
Annual	366.0	10,633.7	4,472.4
Htg Season	244.0	8,018.0	3,968.2
Jun-Sep	122.0	2,615.7	504.2

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature (from Albany Airport). The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy in the summer is also apparent at this site.

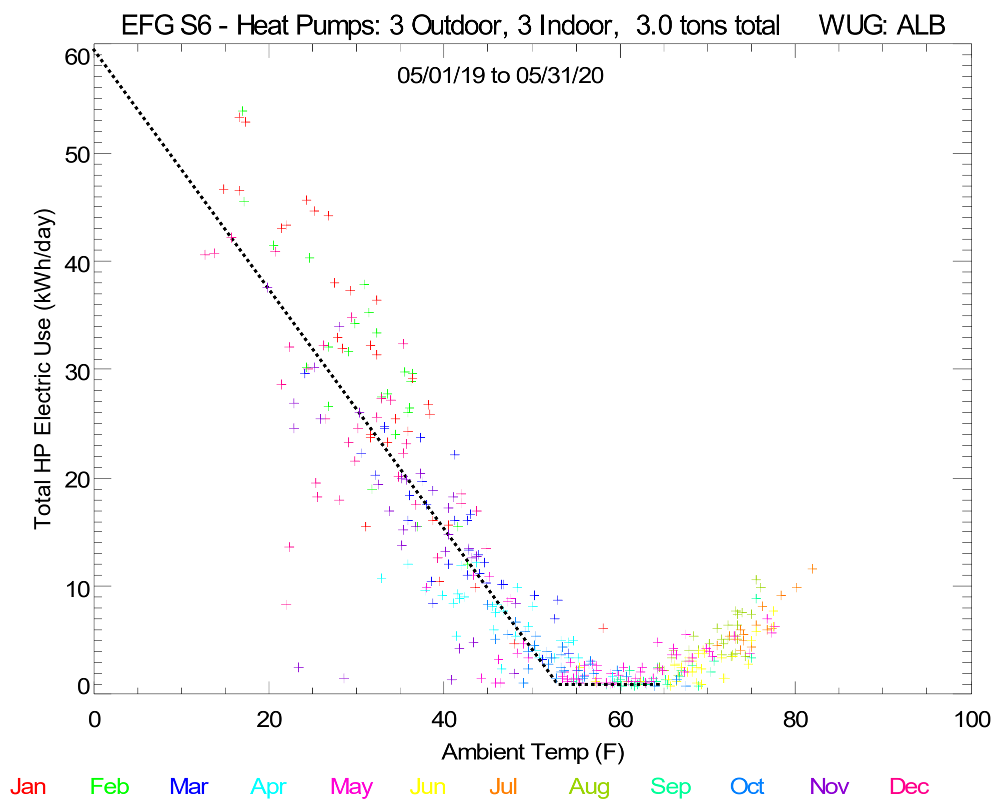


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced most of the gas use for the furnace. Figure 5 compares the trend of monthly gas use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period.

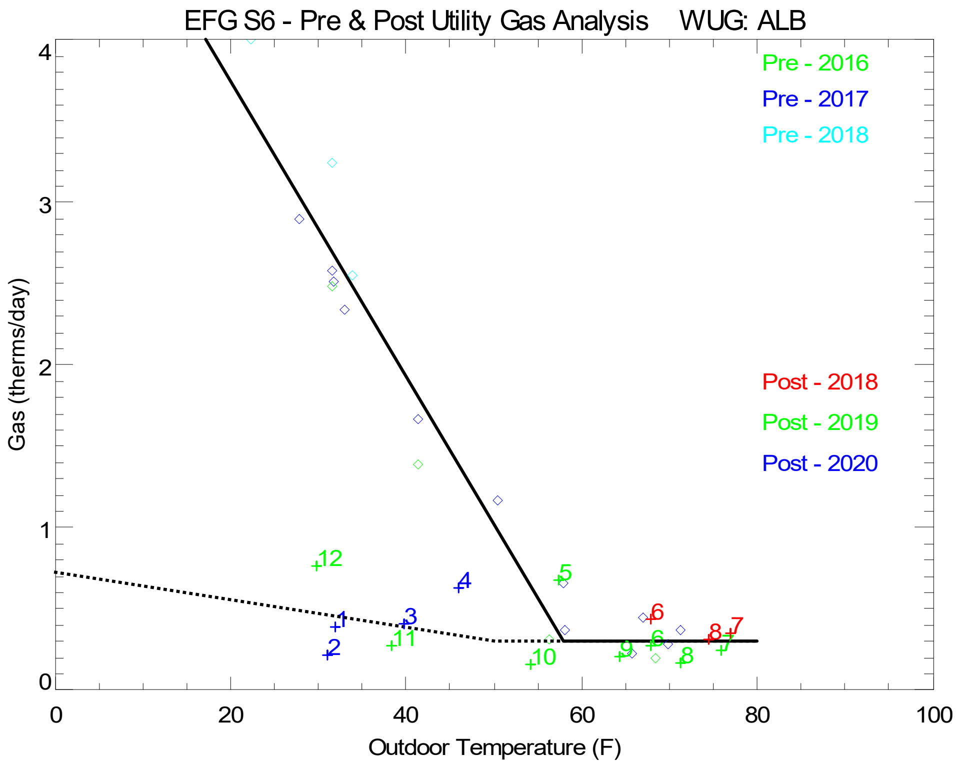


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

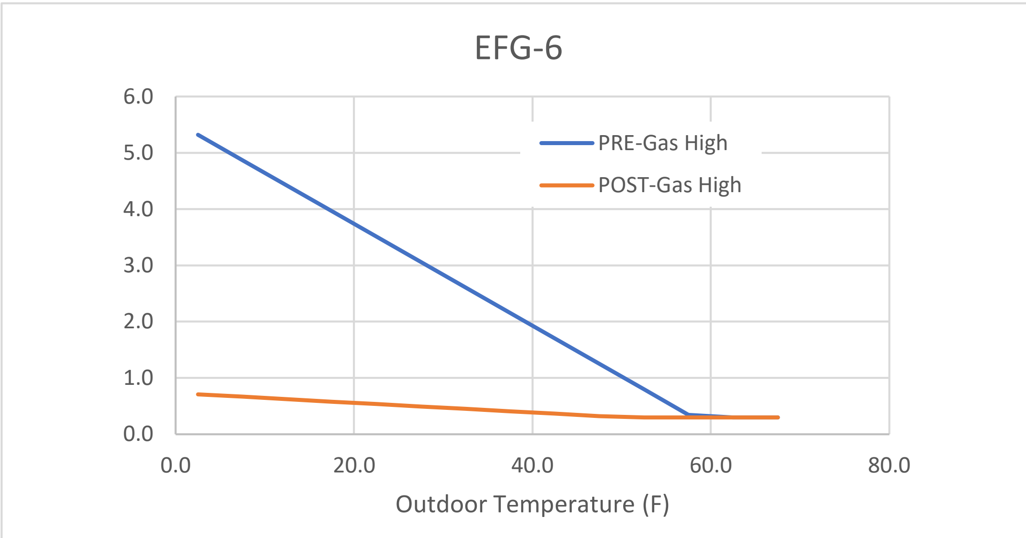
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Albany. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis. In this case there is a consistent trend of the implied COP with temperature as shown in Table 2.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE: EFG-6 — WEATHER: Albany — $ 0.117 per kWh
FUEL: Gas High Eff — $ 0.826 per therm
Floor Area 1700 — LOCATION: Albany

Temp Bin	Hours	FUEL PRE-Gas High (therms/day)	FUEL POST-Gas High (therms/day)	ASHP Electric (kWh/day)	Adjusted POST-Gas High (therms/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Gas High adjustment factor
-27.5	0	8.0	1.0	89.9	1.0	2.1	$ 6.64	$ 11.28	
-22.5	0	7.6	0.9	84.3	0.9	2.1	$ 6.27	$ 10.60	
-17.5	0	7.1	0.9	78.8	0.9	2.1	$ 5.89	$ 9.93	
-12.5	0	6.7	0.8	73.3	0.8	2.1	$ 5.52	$ 9.25	
-7.5	0	6.2	0.8	67.8	0.8	2.1	$ 5.14	$ 8.57	
-2.5	15	5.8	0.8	62.3	0.8	2.1	$ 4.77	$ 7.89	
2.5	36	5.3	0.7	56.7	0.7	2.1	$ 4.40	$ 7.21	
7.5	127	4.9	0.7	51.2	0.7	2.2	$ 4.02	$ 6.53	
12.5	206	4.4	0.6	45.7	0.6	2.2	$ 3.65	$ 5.85	
17.5	435	4.0	0.6	40.2	0.6	2.2	$ 3.28	$ 5.17	
22.5	498	3.5	0.5	34.7	0.5	2.3	$ 2.90	$ 4.49	
27.5	537	3.1	0.5	29.1	0.5	2.3	$ 2.53	$ 3.81	
32.5	654	2.6	0.5	23.6	0.5	2.4	$ 2.15	$ 3.13	
37.5	720	2.2	0.4	18.1	0.4	2.5	$ 1.78	$ 2.45	
42.5	550	1.7	0.4	12.6	0.4	2.8	$ 1.41	$ 1.77	
47.5	573	1.2	0.3	7.1	0.3	3.5	$ 1.03	$ 1.09	
52.5	723	0.8	0.3	1.6	0.3	8.5	$ 0.66	$ 0.43	
57.5	791	0.3	0.3	1.0	0.3	1.2	$ 0.29	$ 0.36	
62.5	943	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	
67.5	682	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	
72.5	497	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	
77.5	420	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	
82.5	274	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	
87.5	61	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	
92.5	13	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	
97.5	5	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	
102.5	0	0.3	0.3	1.0	0.3	0.0	$ 0.25	$ 0.36	



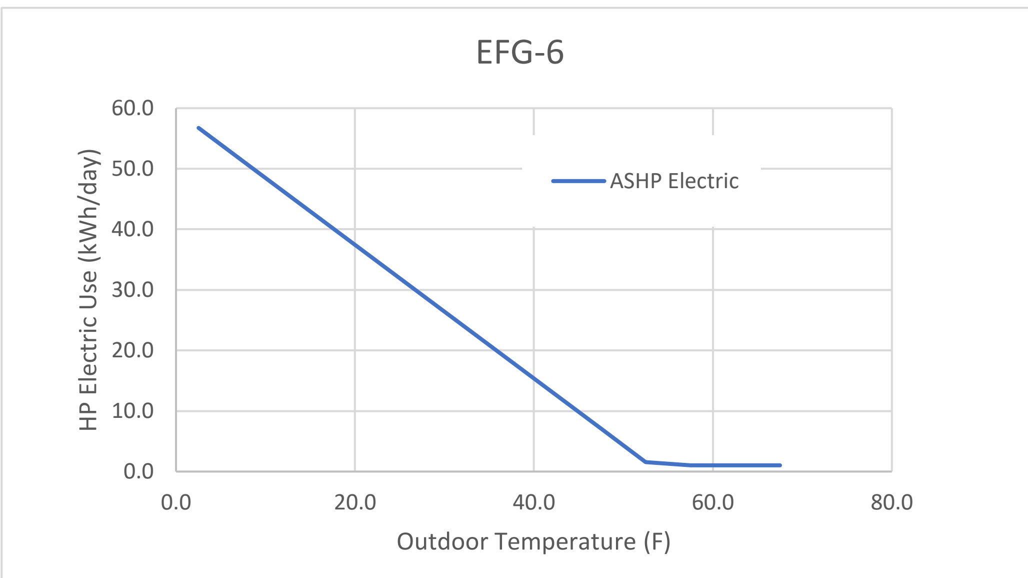


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 2.4 in this case.

In this instance the implied COP is calculated from

$$COP = (Fuel_{pre} - Fuel_{post})*eff/(3.412xkWh_{hp}) = (455-29)*100*0.90 / (3.412*4679)$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Gas High Eff (therms/yr)	455	29	426
HP Electric (kWh/yr)		4,679	(4,679)
Total Heating Costs	$376	$570	-$194
Implied Seasonal COP			2.4

Summary Statistics	
0.27	Fuel therms per sq ft per yr
24.1	Htg MBtu per sq ft per yr
94%	Reduction in Fuel Use
3,968	Measured HP for Htg (kWh/yr)
85%	Measured as % of Typical yr

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

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

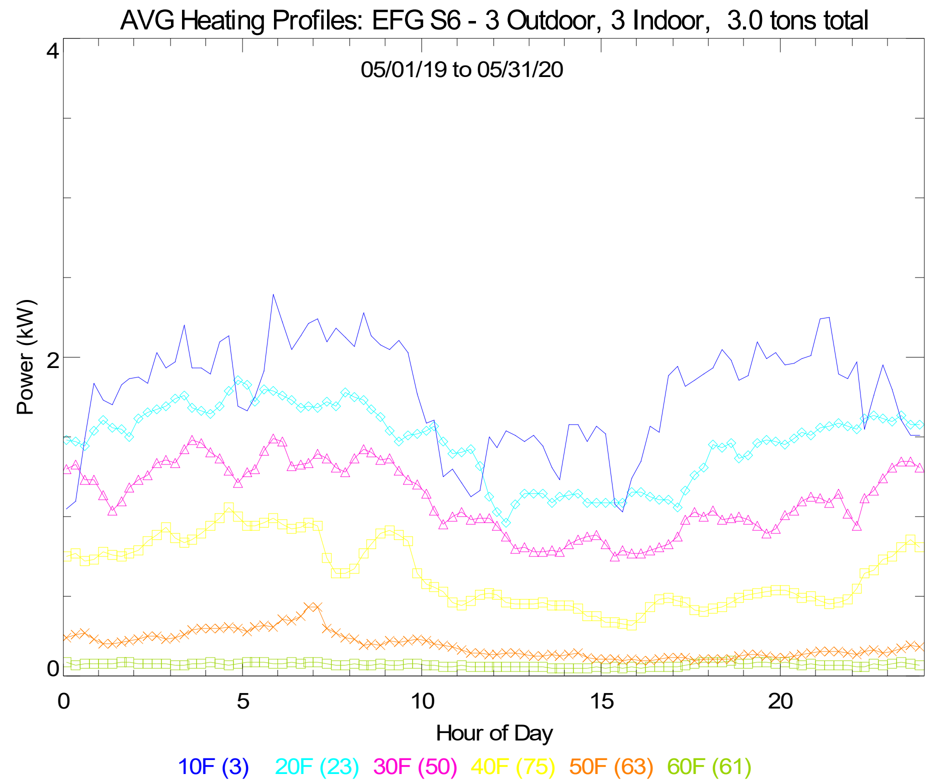


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

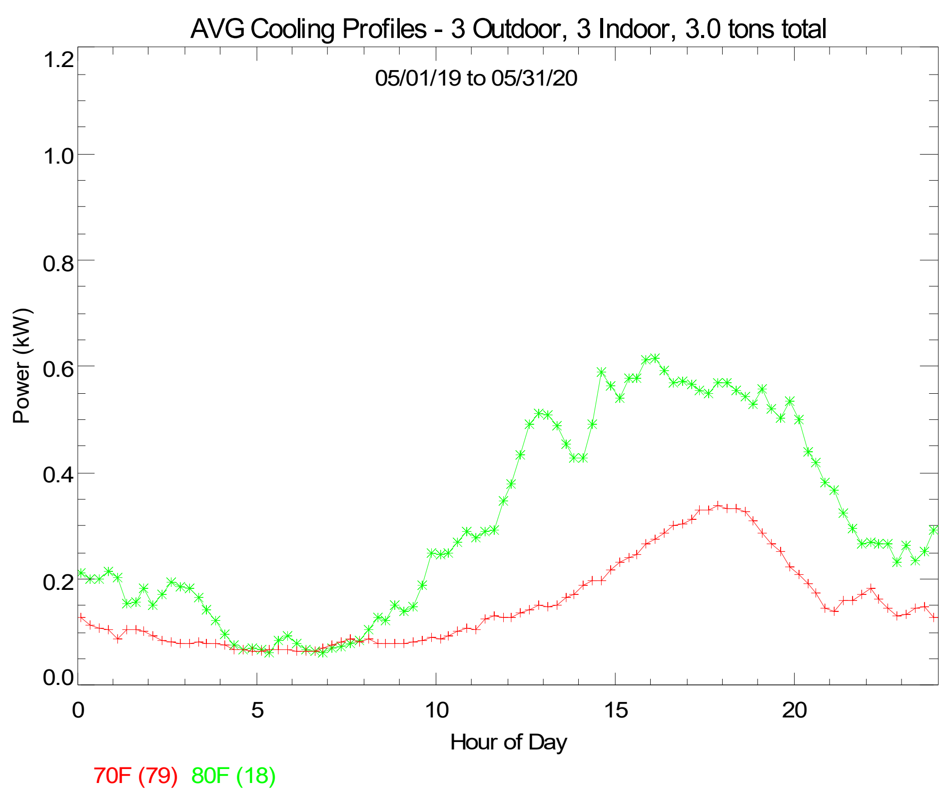


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

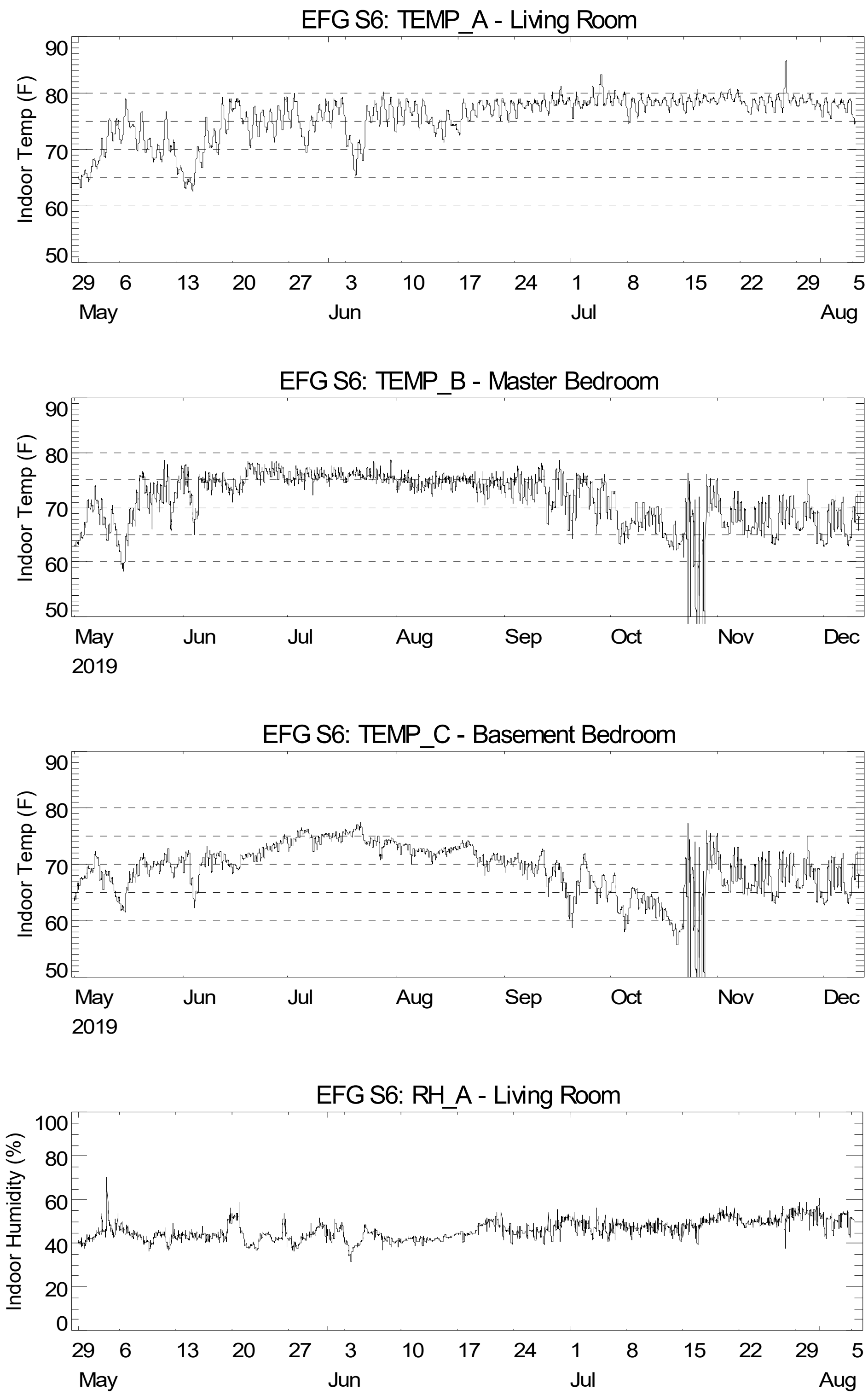


Figure 9. Space Temperatures and Humidity Levels

EFG S7 Savings Analysis

This 1752 sq ft house is in Sleepy Hollow in Westchester County. The house was originally heated by a gas boiler with hydronic baseboard. The boiler has not been used after the two ASHP units were installed in late June of 2018. Monitoring began in September 2018.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 show the power use for the individual heat pumps.

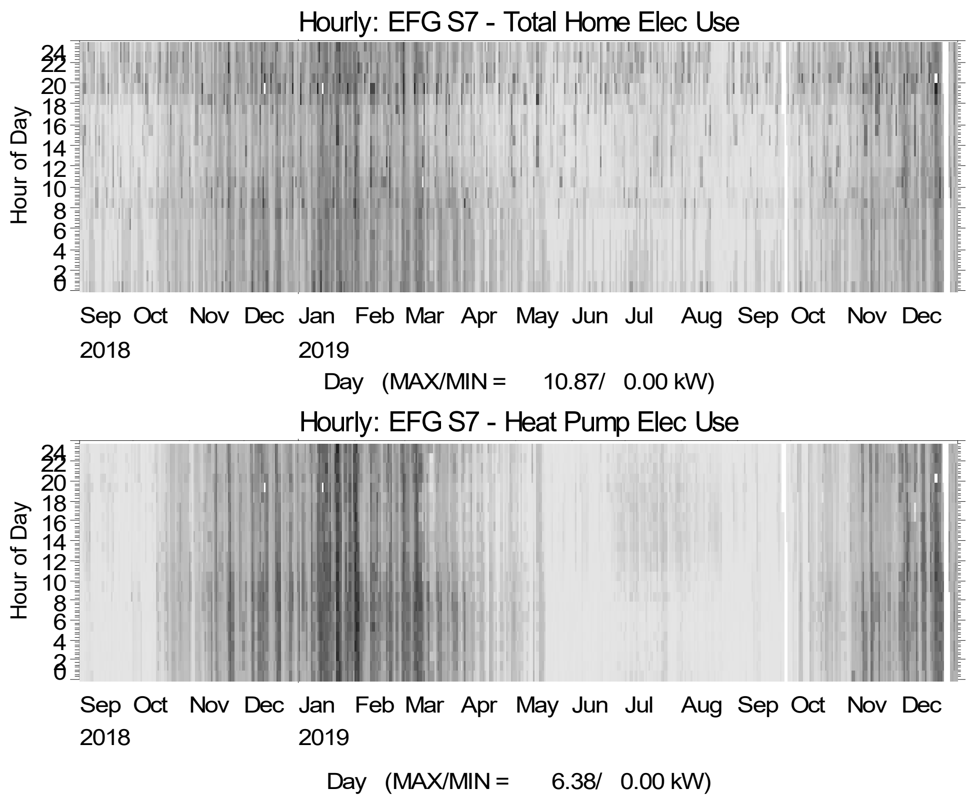


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

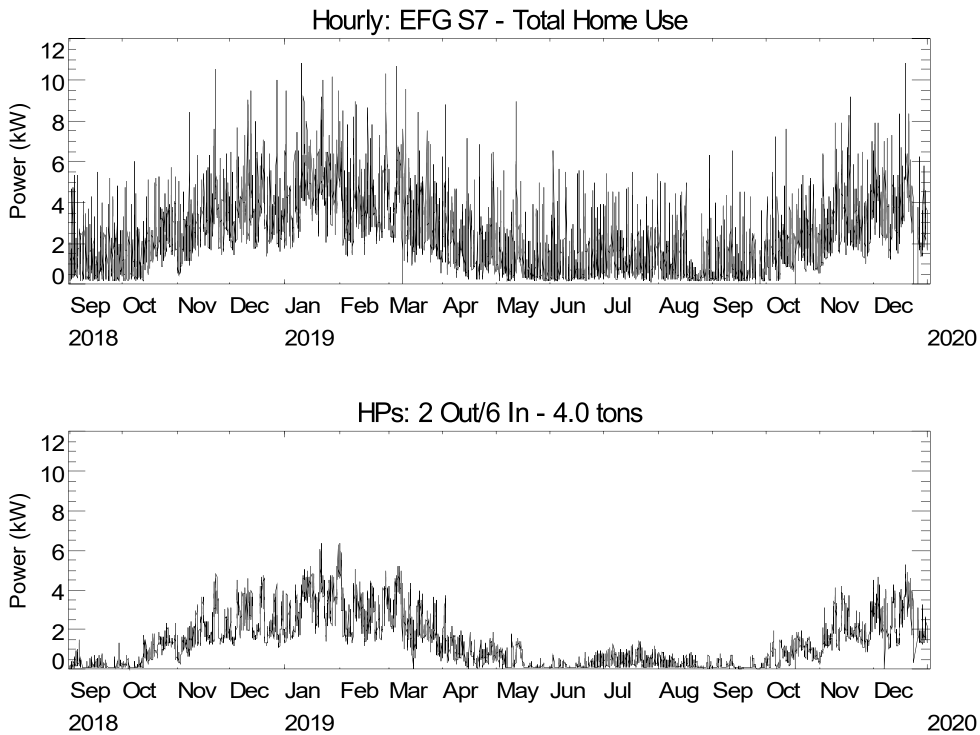


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

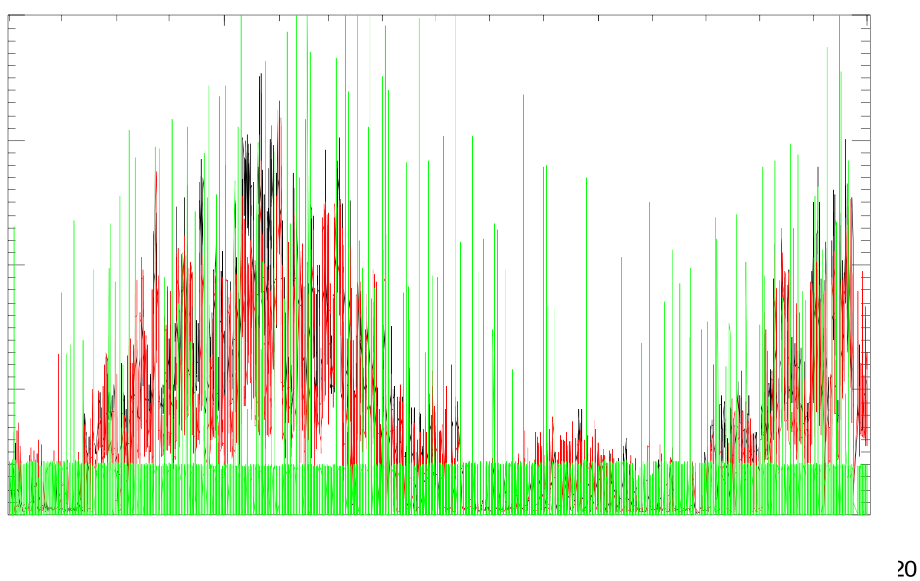


Figure 3. Power Use of Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. The power use for a heat pump water heater (HPWH) is also given in the table.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Solar (kWh)	DHW (kWh)
Sep-18	30	897.7	140.4	-	65.5
Oct-18	31	1,362.7	579.5	-	95.4
Nov-18	30	2,120.1	1,299.0	-	107.6
Dec-18	31	2,676.9	1,822.3	-	134.7
Jan-19	31	3,430.6	2,507.4	-	150.5
Feb-19	28	2,685.0	1,948.5	-	129.9
Mar-19	31	2,497.9	1,715.9	-	140.6
Apr-19	30	1,403.4	668.1	-	117.9
May-19	31	952.9	269.2	-	98.8
Jun-19	30	785.0	146.8	-	87.5
Jul-19	31	1,032.1	340.9	-	67.8
Aug-19	31	704.4	172.7	-	58.5
Sep-19	29	617.4	96.2	-	65.9
Oct-19	31	1,376.3	571.0	-	88.7
Nov-19	30	2,097.1	1,361.1	-	112.9
Dec-19	29	2,495.7	1,772.1	-	122.4
Annual	364	20,268.4	11,566.5	-	1,255.1
Htg Season	243	17,129.5	10,809.9	-	975.4
Jun-Sep	121	3,138.9	756.6	-	279.7

<u>Measured Trends</u>

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature. There is a consistent data trend, implying the occupants used the ductless heat pumps in a consistent manner. The dotted line on the plot represents to a best fit of the trend with temperature.

Figure 5 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. Off season gas use for water heating also dropped to a lower level in the post retrofit period since a HPWH was installed.

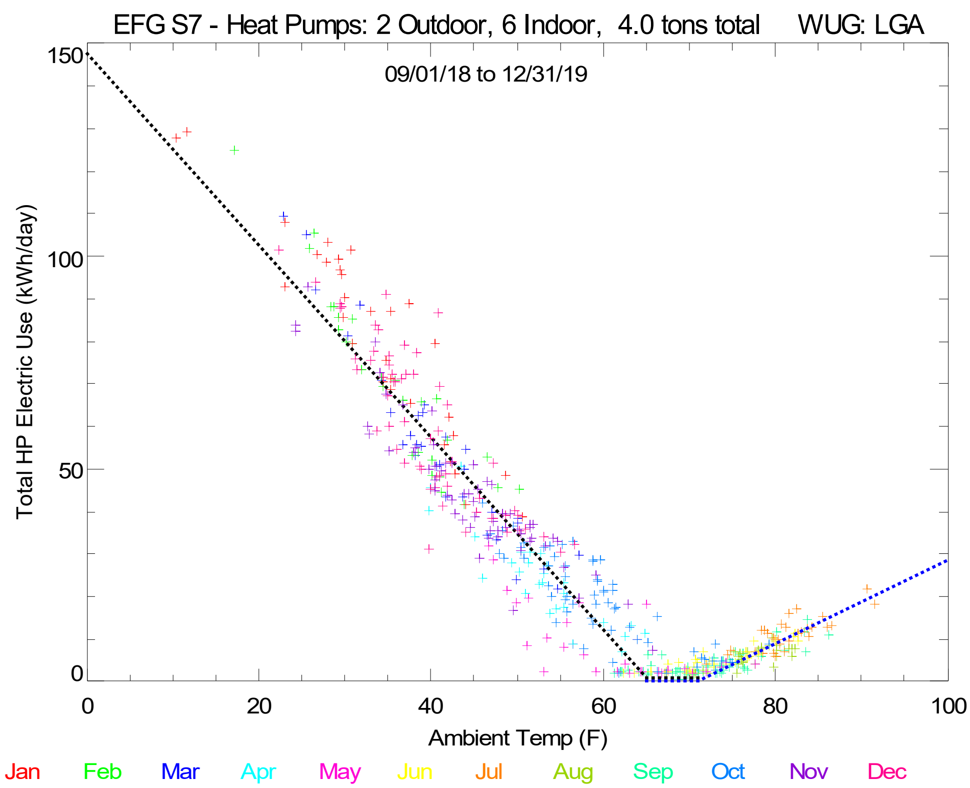


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

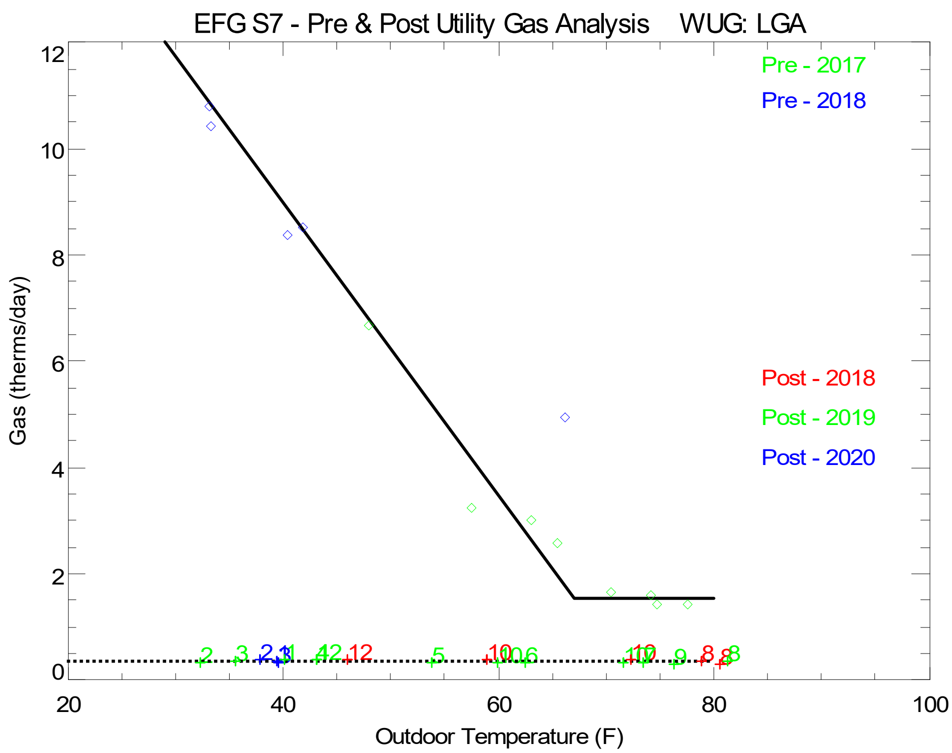


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

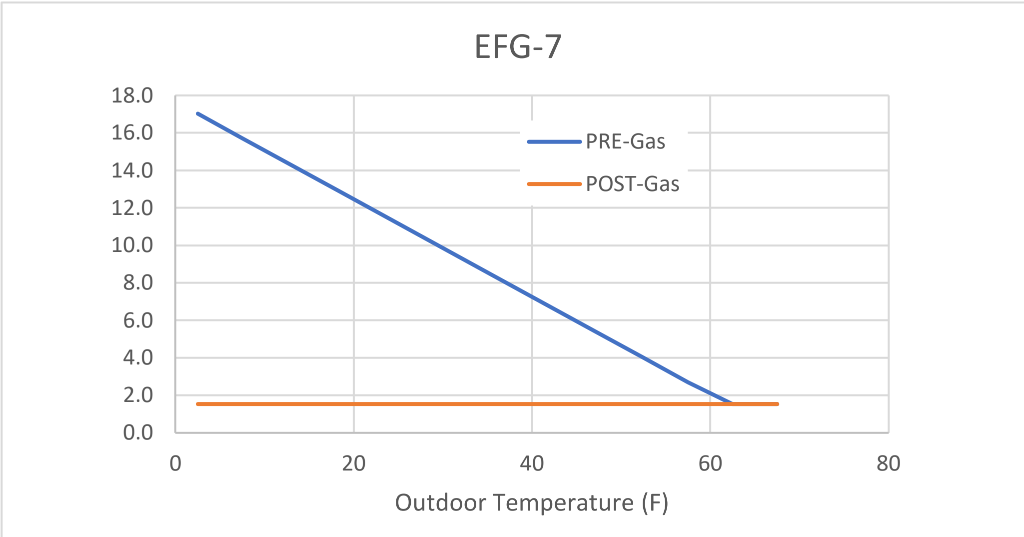
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for New York. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis. The trend line for post-retrofit gas no longer includes domestic hot water heating since a heat pump water heater (HPWH) was also installed at the time as the heat pump installation. However, the post-retrofit trend is the bin analysis was adjusted to equal 1.5 therms, in order to match the pre-retrofit base use and wash out the impact of the HPWH.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	EFG-7			WEATHER:	New_York		$ 0.200 per kWh	
FUEL:	Gas						$ 1.403 per therm	
Floor Area	1752			LOCATION:	Sleepy Hollow			

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	24.8	0.4	209.5	1.5	2.6	$ 34.8	$ 44.0	
-22.5	0	23.5	0.4	198.2	1.5	2.6	$ 33.0	$ 41.8	
-17.5	0	22.2	0.4	186.9	1.5	2.6	$ 31.2	$ 39.5	
-12.5	0	20.9	0.4	175.7	1.5	2.6	$ 29.4	$ 37.3	
-7.5	0	19.6	0.4	164.4	1.5	2.5	$ 27.5	$ 35.0	
-2.5	0	18.3	0.4	153.1	1.5	2.5	$ 25.7	$ 32.8	
2.5	0	17.0	0.4	141.9	1.5	2.5	$ 23.9	$ 30.5	
7.5	11	15.7	0.4	130.6	1.5	2.5	$ 22.0	$ 28.3	
12.5	22	14.4	0.4	119.3	1.5	2.5	$ 20.2	$ 26.0	
17.5	101	13.1	0.4	108.1	1.5	2.5	$ 18.4	$ 23.8	
22.5	167	11.8	0.4	96.8	1.5	2.5	$ 16.6	$ 21.5	
27.5	247	10.5	0.4	85.5	1.5	2.4	$ 14.7	$ 19.3	
32.5	475	9.2	0.4	74.3	1.5	2.4	$ 12.9	$ 17.0	
37.5	855	7.9	0.4	63.0	1.5	2.3	$ 11.1	$ 14.7	
42.5	708	6.6	0.4	51.7	1.5	2.3	$ 9.3	$ 12.5	
47.5	608	5.3	0.4	40.4	1.5	2.2	$ 7.4	$ 10.2	
52.5	880	4.0	0.4	29.2	1.5	2.0	$ 5.6	$ 8.0	
57.5	750	2.7	0.4	17.9	1.5	1.5	$ 3.8	$ 5.7	
62.5	814	1.5	0.4	6.6	1.5	0.0	$ 2.1	$ 3.5	
67.5	723	1.5	0.4	1.0	1.5	0.0	$ 2.1	$ 2.3	
72.5	751	1.5	0.4	1.0	1.5	0.0	$ 2.1	$ 2.3	
77.5	870	1.5	0.4	1.0	1.5	0.0	$ 2.1	$ 2.3	
82.5	569	1.5	0.4	1.0	1.5	0.0	$ 2.1	$ 2.3	
87.5	165	1.5	0.4	1.0	1.5	0.0	$ 2.1	$ 2.3	
92.5	36	1.5	0.4	1.0	1.5	0.0	$ 2.1	$ 2.3	
97.5	8	1.5	0.4	1.0	1.5	0.0	$ 2.1	$ 2.3	
102.5	0	1.5	0.4	1.0	1.5	0.0	$ 2.1	$ 2.3	



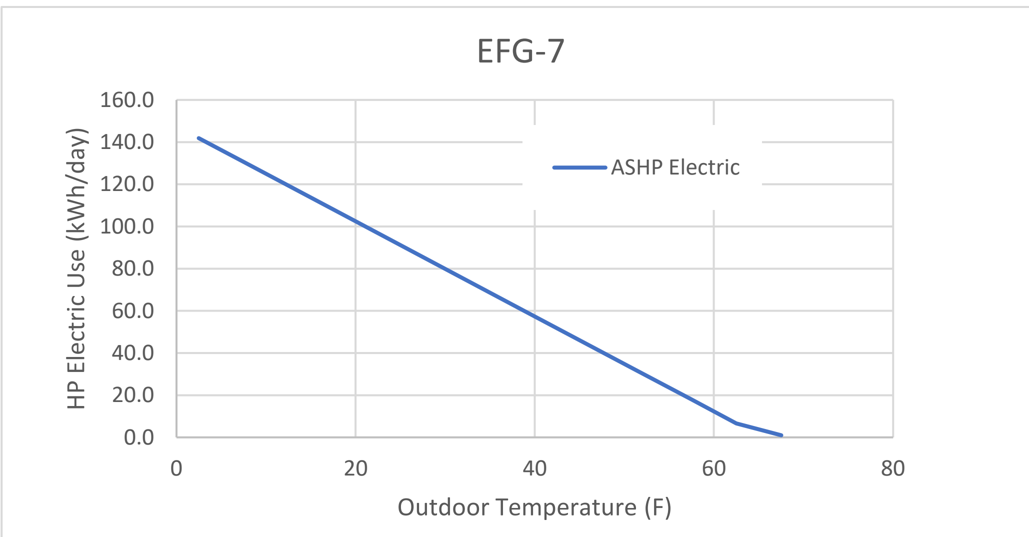


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. Since the base fuel is natural gas, there are no cost savings. The implied seasonal heating COP for the ASHPs is 2.2 in this case.

In this instance the implied COP is calculated from

$$COP = (Fuel_{pre} - Fuel_{post})*eff/(3.412xkWh_{hp}) = (983 - 0)*100*0.79 / (3.412*10325)$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	**PRE-Retrofit**	**POST-Retrofit**	**Savings**
Gas (therms/yr)	983	-	983
HP Electric (kWh/yr)		10,325	(10,325)
Total Heating Costs	$1,379	$2,065	-$686
Implied Seasonal COP			2.2

Summary Statistics	
0.56	Fuel therms per sq ft per yr
44.3	Htg MBtu per sq ft per yr
100%	Reduction in Fuel Use
10,810	Measured HP for Htg (kWh/yr)
105%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. For both the warmest (90°F) and coldest (10°F) lines, the average profile are only based on two days of data, so the profiles are very jagged.

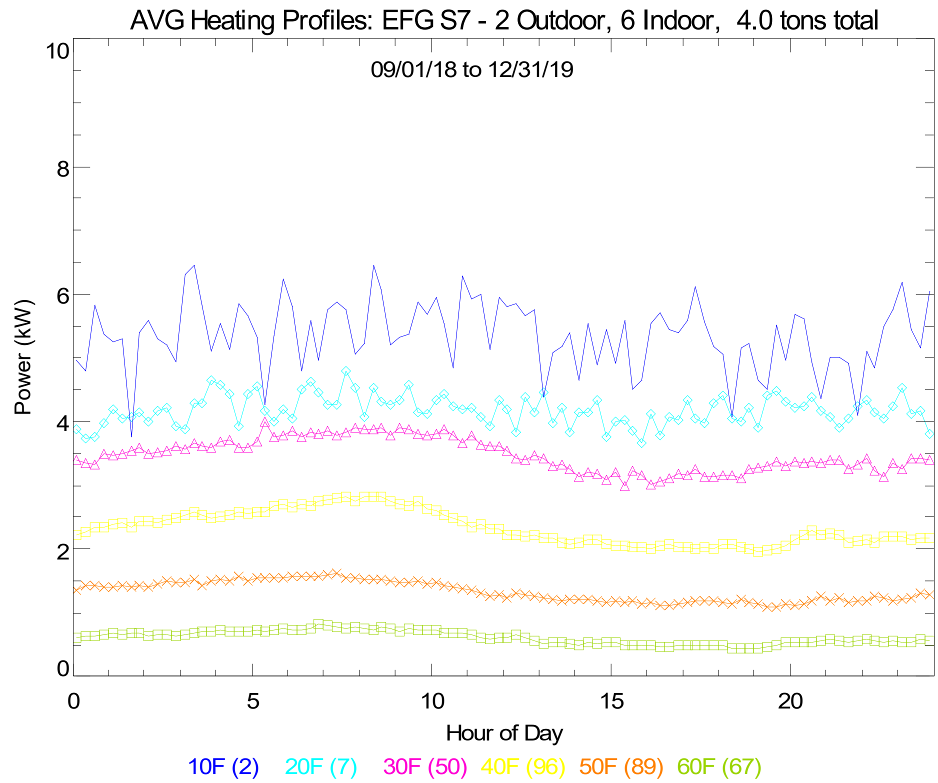


Figure 7. Heat Pump Demand Heating Profile Across the Day – Averaged for Various Outdoor Temperature Bins

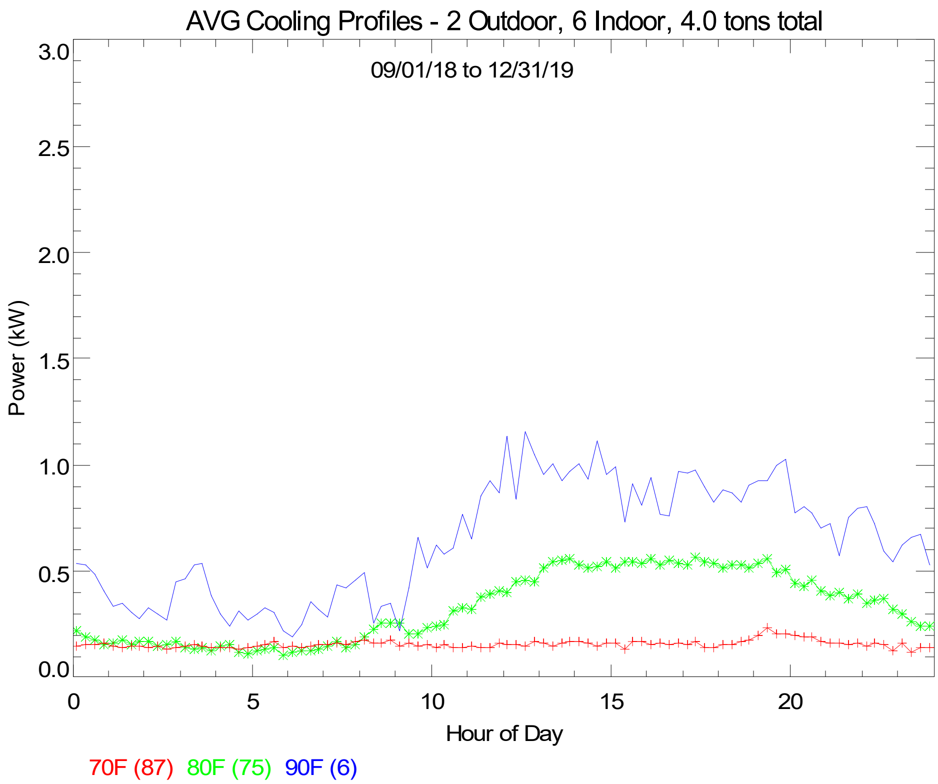


Figure 8. Heat Pump Demand Cooling Profile Across the Day – Averaged for Various Outdoor Temperature Bins

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

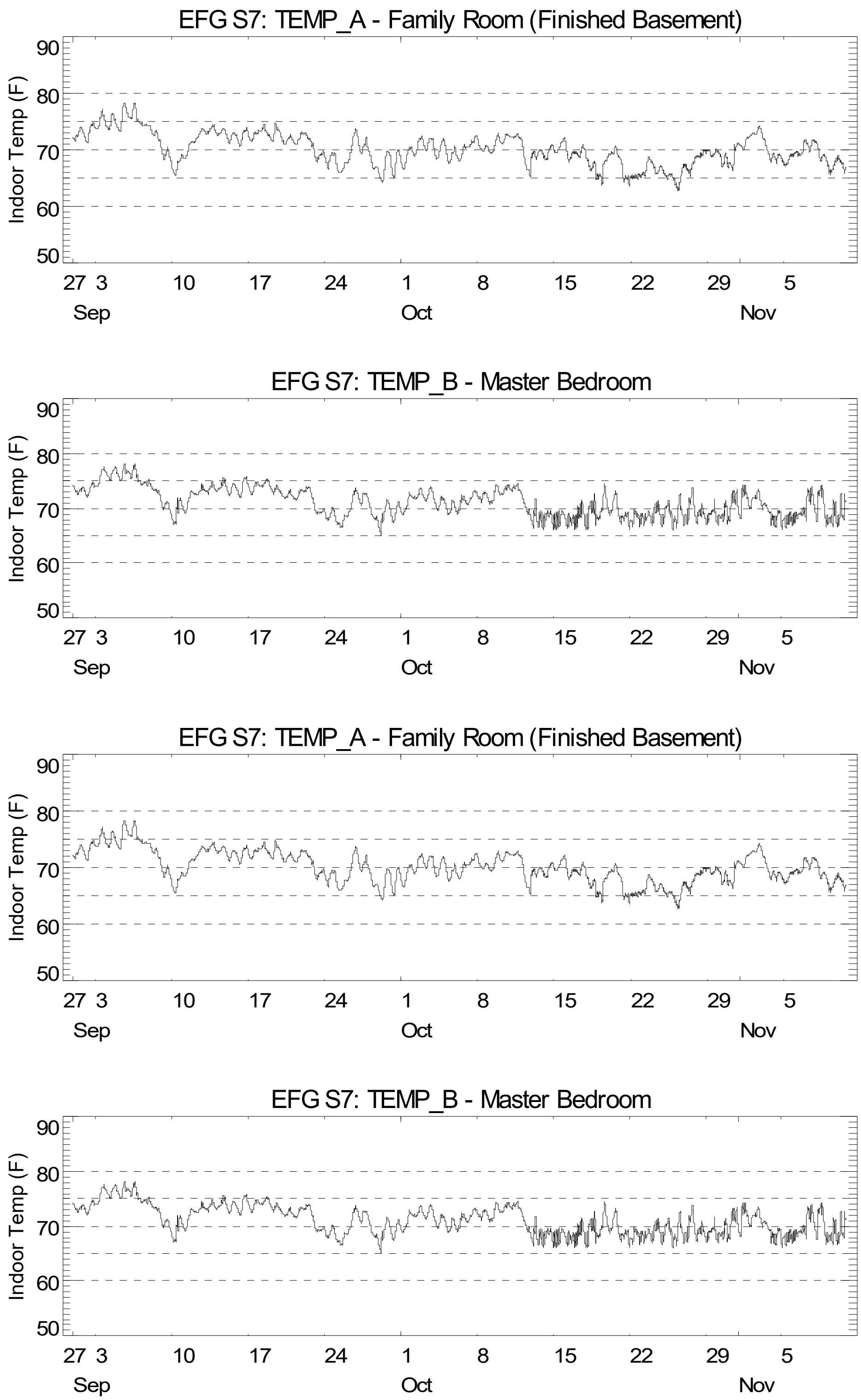


Figure 9. Space Temperatures and Humidity Levels

EFG S8

This 1,600 sq ft house is located in Coxsackie, NY near Albany. The house was originally heated by an oil boiler with hydronic baseboard. The boiler was also used for hot water in the winter. The boiler continued to provide supplemental heating after the four ASHP units (3 tons total) was installed on June 26, 2018. Monitoring began in July 2018. This unit frequently operates in cooling.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. The lower shade plot shows the change in operation where the heat pumps ran based on a daily schedule starting in January 2019. In the July 2019 after a discussion with the HVHPP staff , the pattern was changed in the 2nd heating season so that the heat pumps ran nearly all the time. Points of peak use for the house are related to a level two electric car charging station used at the end of most workdays. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use for the individual heat pumps at the site.

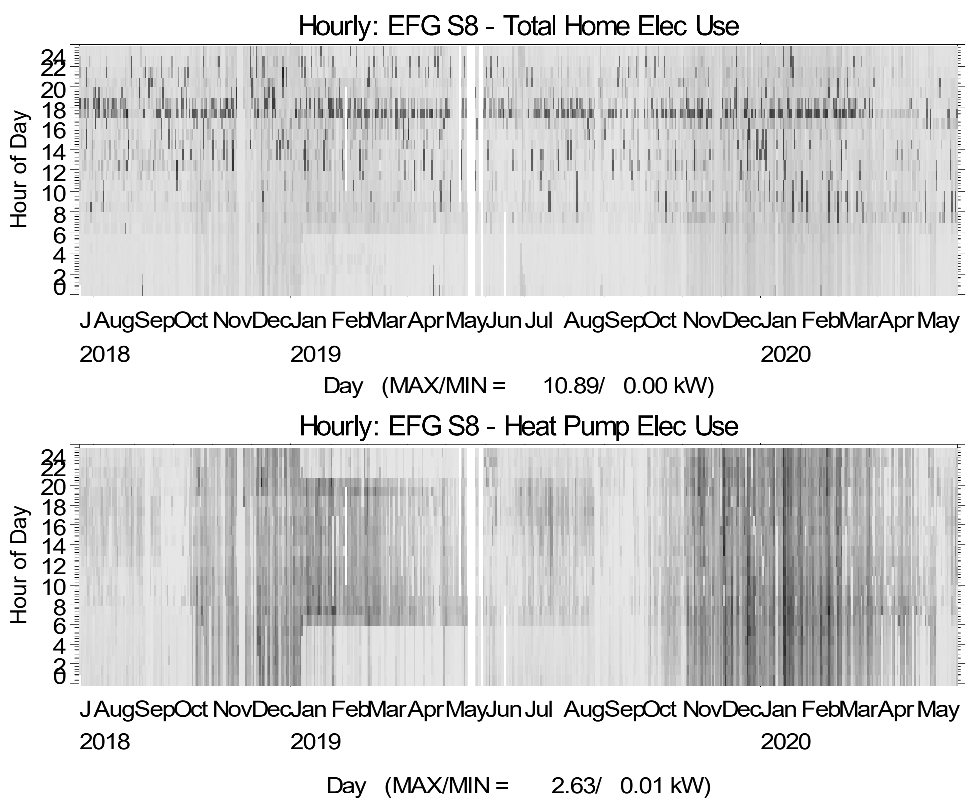
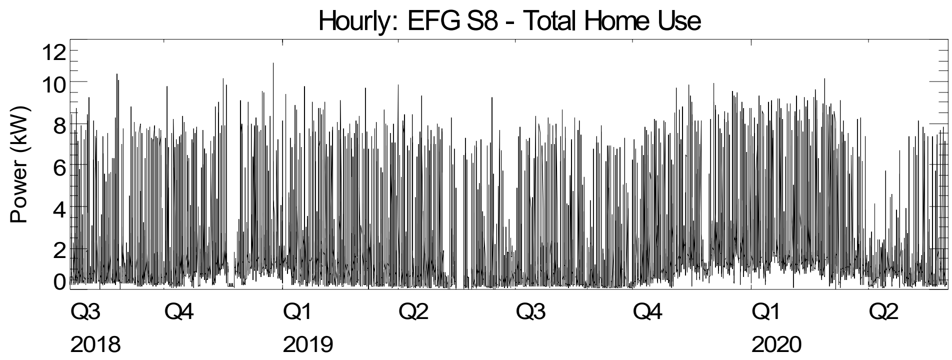


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.



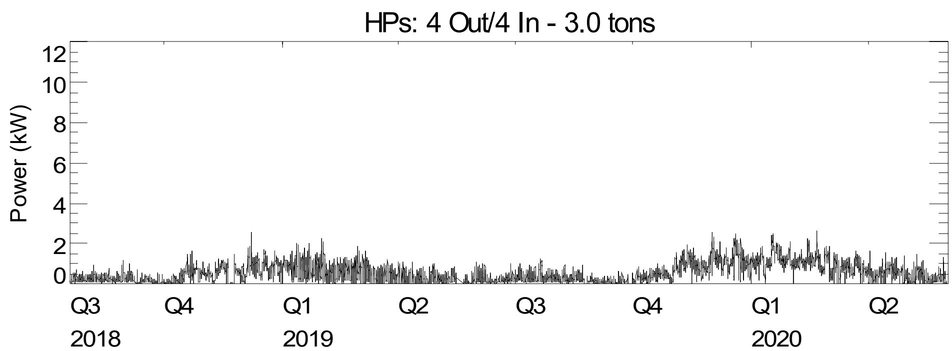


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

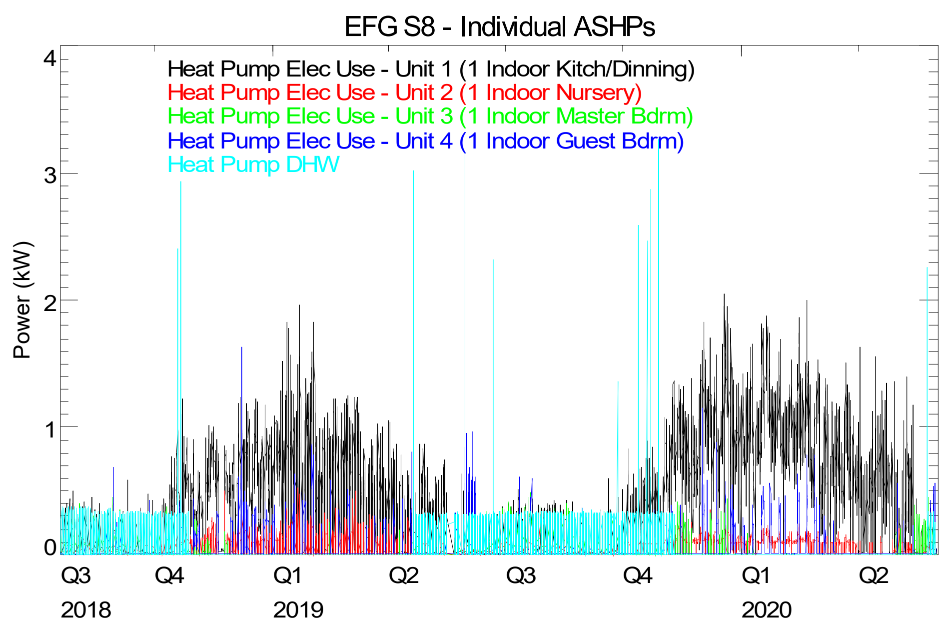


Figure 3. Power Consumption of Individual Heat Pumps (HPWH is also shown but was not included in the HP total)

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Solar (kWh)	DHW (kWh)
Jul-18	12	344.0	73.1	-	15.7
Aug-18	31	858.3	182.8	-	37.7
Sep-18	30	727.4	114.1	-	41.4
Oct-18	31	989.2	286.4	-	49.5
Nov-18	30	868.6	364.6	-	-
Dec-18	31	1,241.0	593.0	-	-
Jan-19	31	1,212.6	586.3	-	-
Feb-19	28	995.8	395.2	-	-
Mar-19	31	933.1	321.4	-	-
Apr-19	30	801.5	180.6	-	28.3
May-19	25	495.1	123.1	-	41.4
Jun-19	30	580.2	145.6	-	55.9
Jul-19	31	725.5	246.1	-	44.0
Aug-19	31	683.9	167.5	-	40.9
Sep-19	30	540.7	68.3	-	43.5
Oct-19	31	875.8	258.4	-	65.5
Nov-19	30	1,193.7	665.4	-	16.3
Dec-19	31	1,561.4	887.5	-	-
Jan-20	31	1,588.4	910.7	-	-
Feb-20	29	1,368.9	790.7	-	-
Mar-20	31	1,109.7	575.3	-	-
Apr-20	30	665.7	362.0	-	-
May-20	31	693.4	200.5	-	10.0
Annual	359	10,067.2	3,478.1	-	303.5
Htg Season	237	7,536.9	2,850.6	-	119.2
Jun-Sep	122	2,530.3	627.5	-	184.3

Measured Trends

Daily heat pump power use is shown in Figure 4 as a function of daily average outdoor temperature (from Albany Airport). There was considerable scatter in the daily energy use data, due to variations in how the occupants used the ductless heat pump in conjunction with their pre-existing boiler. The level of ASHP use was low in the first winter season but increased in the 2nd season. The dotted line on the plot represents to a best fit of the combined trend with temperature. Cooling operation was observed at this site.

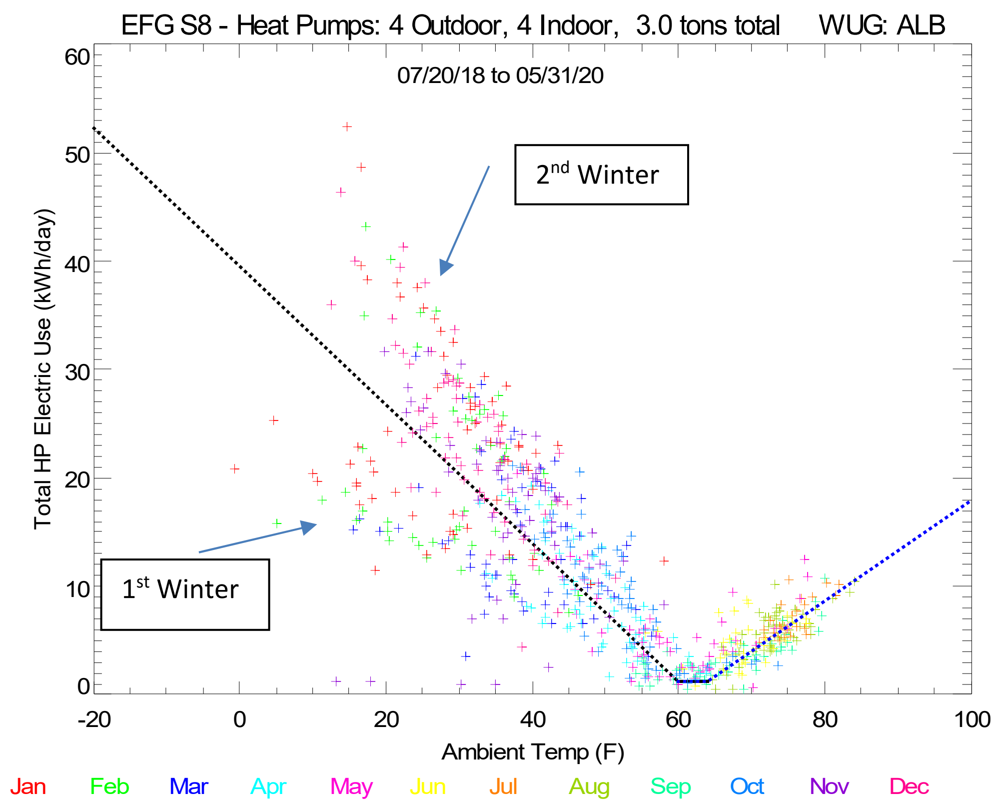


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

Figure 5 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. The load line for oil is shifted to the left in the post-retrofit period since the ASHPs are used for most (if not all) of the heating when daily temperatures averaged from 52- 60 ˚F. The boiler was used for DHW heating in the winter but the electric DHW systems were used on the summer (the electric tank was changed to a heat pump water heater in 2017). This is why the oil use trend line goes to zero in the summer.

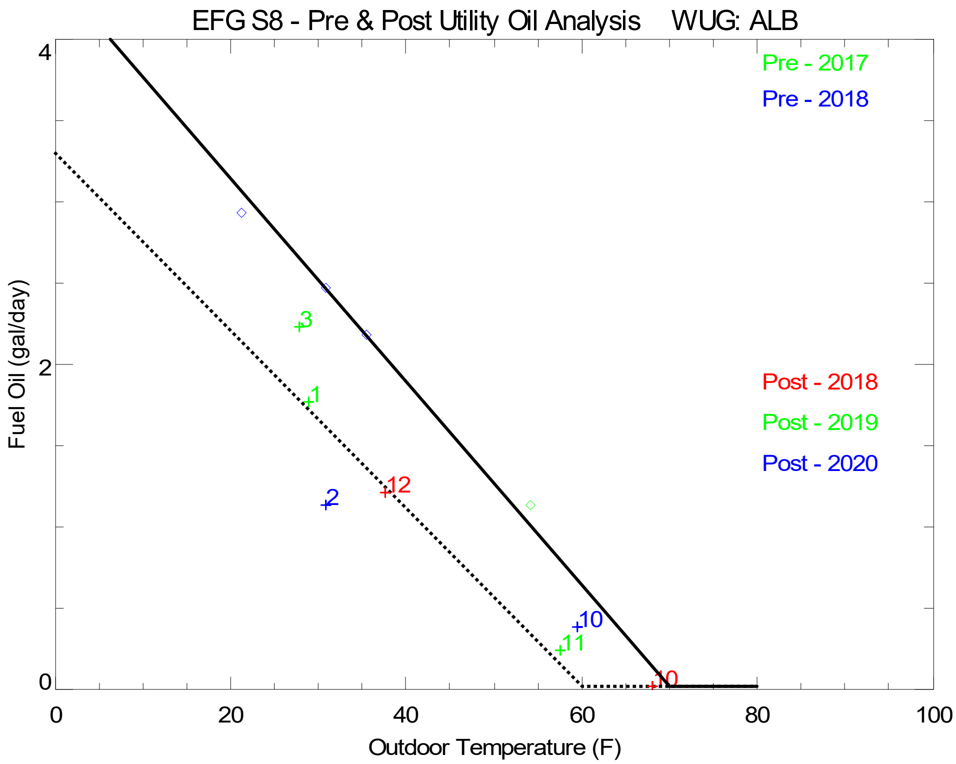


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

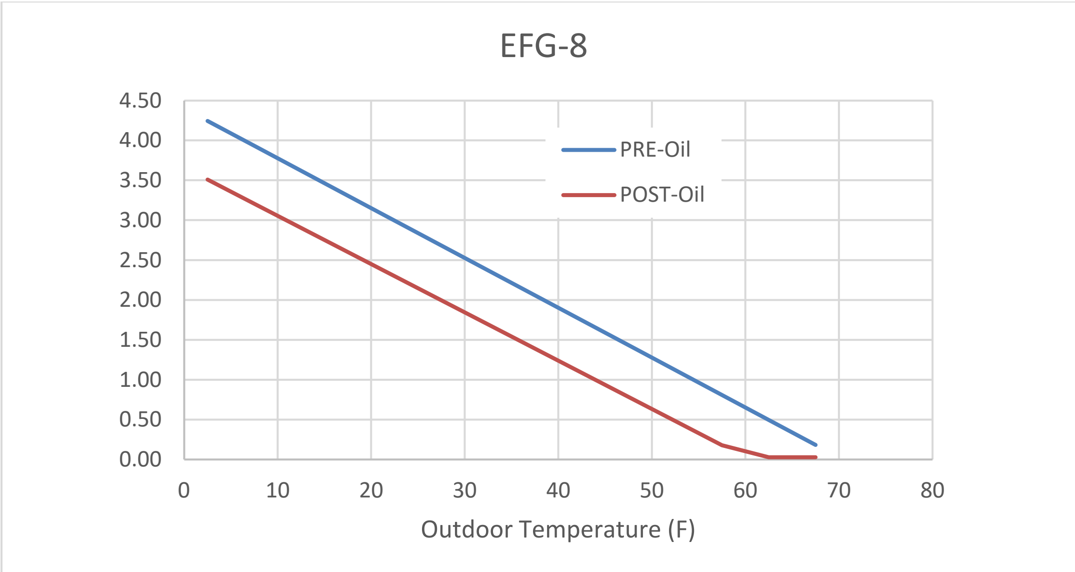
<u>Bin Analysis to Predict Seasonal Impacts</u>

The trend lines above were used in a bin analysis using typical year weather data for Albany. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	EFG-8	WEATHER:	Albany	$ 0.117 per kWh
FUEL:	Oil			$ 2.487 per gal (oil)
Floor Area	1600	LOCATION:	Coxsackie	

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	6.1	4.8	57.1	4.8	0.8	15.2	18.6	
-22.5	0	5.8	4.5	53.9	4.5	0.8	14.4	17.5	
-17.5	0	5.5	4.3	50.7	4.3	0.8	13.7	16.5	
-12.5	0	5.2	4.0	47.5	4.0	0.9	12.9	15.4	
-7.5	0	4.9	3.7	44.3	3.7	0.9	12.1	14.4	
-2.5	15	4.6	3.4	41.1	3.4	0.9	11.3	13.3	
2.5	36	4.2	3.2	37.9	3.2	1.0	10.6	12.3	
7.5	127	3.9	2.9	34.8	2.9	1.0	9.8	11.2	
12.5	206	3.6	2.6	31.6	2.6	1.1	9.0	10.2	
17.5	435	3.3	2.3	28.4	2.3	1.2	8.2	9.1	
22.5	498	3.0	2.1	25.2	2.1	1.3	7.4	8.1	
27.5	537	2.7	1.8	22.0	1.8	1.4	6.7	7.0	
32.5	654	2.4	1.5	18.8	1.5	1.5	5.9	6.0	
37.5	720	2.1	1.3	15.6	1.3	1.8	5.1	4.9	
42.5	550	1.7	1.0	12.4	1.0	2.1	4.3	3.9	
47.5	573	1.4	0.7	9.2	0.7	2.7	3.6	2.8	
52.5	723	1.1	0.4	6.0	0.4	3.9	2.8	1.8	
57.5	791	0.8	0.2	2.8	0.2	7.7	2.0	0.7	
62.5	943	0.5	0.0	1.3	0.0	12.8	1.2	0.2	
67.5	682	0.2	0.0	1.3	0.0	4.3	0.5	0.2	
72.5	497	0.0	0.0	1.3	0.0	0.0	0.1	0.2	
77.5	420	0.0	0.0	1.3	0.0	0.0	0.1	0.2	
82.5	274	0.0	0.0	1.3	0.0	0.0	0.1	0.2	
87.5	61	0.0	0.0	1.3	0.0	0.0	0.1	0.2	
92.5	13	0.0	0.0	1.3	0.0	0.0	0.1	0.2	
97.5	5	0.0	0.0	1.3	0.0	0.0	0.1	0.2	
102.5	0	0.0	0.0	1.3	0.0	0.0	0.1	0.2	



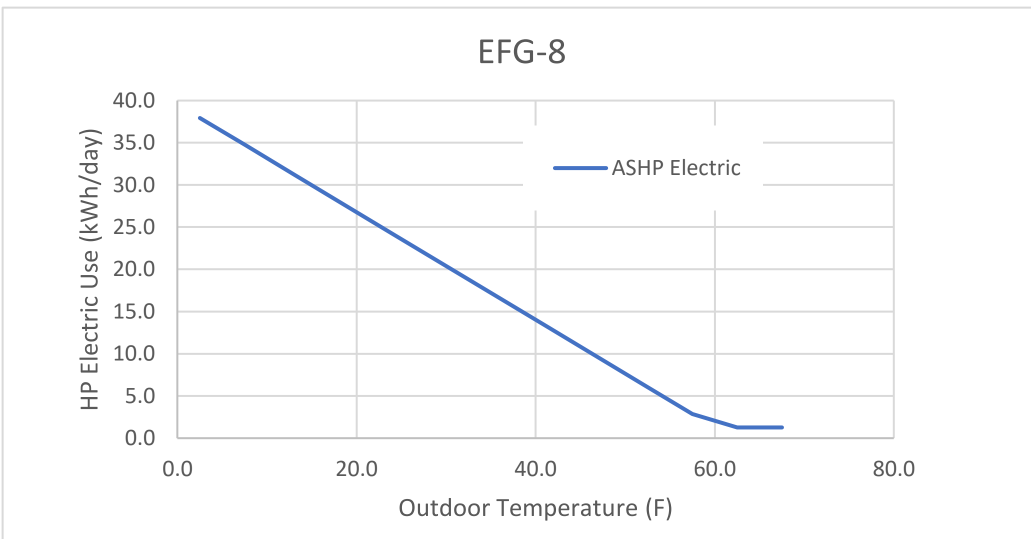


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 1.9 in this case.

In this instance the implied COP is calculated from

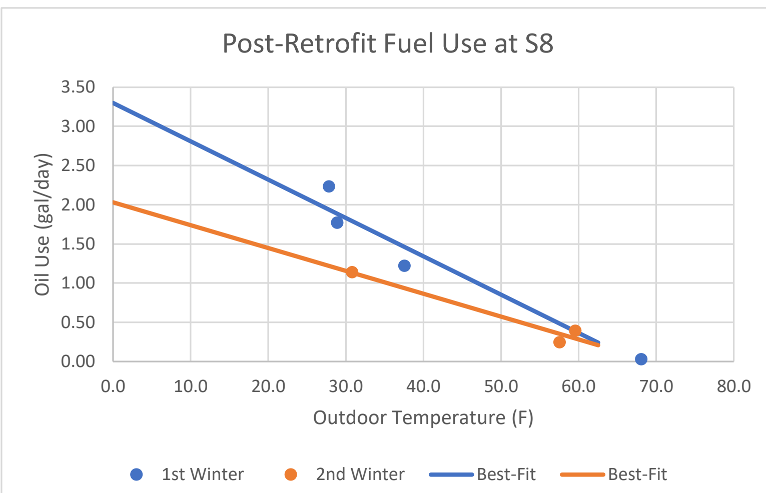
$$COP = (Fuel_{pre} - Fuel_{post})*eff/(3.412xkWh_{hp}) = (520-301)*100*0.84 / (3.412*3912)$$

Table 3. Results of Bin Analysis Showing Seasonal Results (both winters)

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Oil (gal/yr)	520	301	219
HP Electric (kWh/yr)		3,912	(3,912)
Total Heating Costs	$1,294	$1,205	$89
Implied Seasonal COP			1.9

Summary Statistics	
0.33	Fuel gal per sq ft per yr
38.0	Htg MBtu per sq ft per yr
42%	Reduction in Fuel Use
2,851	Measured HP for Htg (kWh/yr)
73%	Measured as % of Typical yr

Since there was a significant change in how the ASHP was used in the 2nd season, we repeated the analysis focusing on the 2nd winter. There was a separate oil use trend in the 2nd winter, as shown in Figure 7. Similarly, the trend for heat pump power use was also different (see Figure 8).



	Ending Date	Temp (F)	1st Winter	2nd Winter
1st Winter	10/29/2018	68.1	0.03	
	12/5/2018	37.6	1.22	
	1/24/2019	28.9	1.77	
	3/16/2019	27.8	2.23	
2nd Winter	11/27/2019	57.6		0.24
	2/27/2020	30.8		1.14
	10/21/2020	59.6		0.39

Figure 7. Trend of Post-Retrofit Fuel Use vs Outdoor Temperature for First and Second Winter Seasons

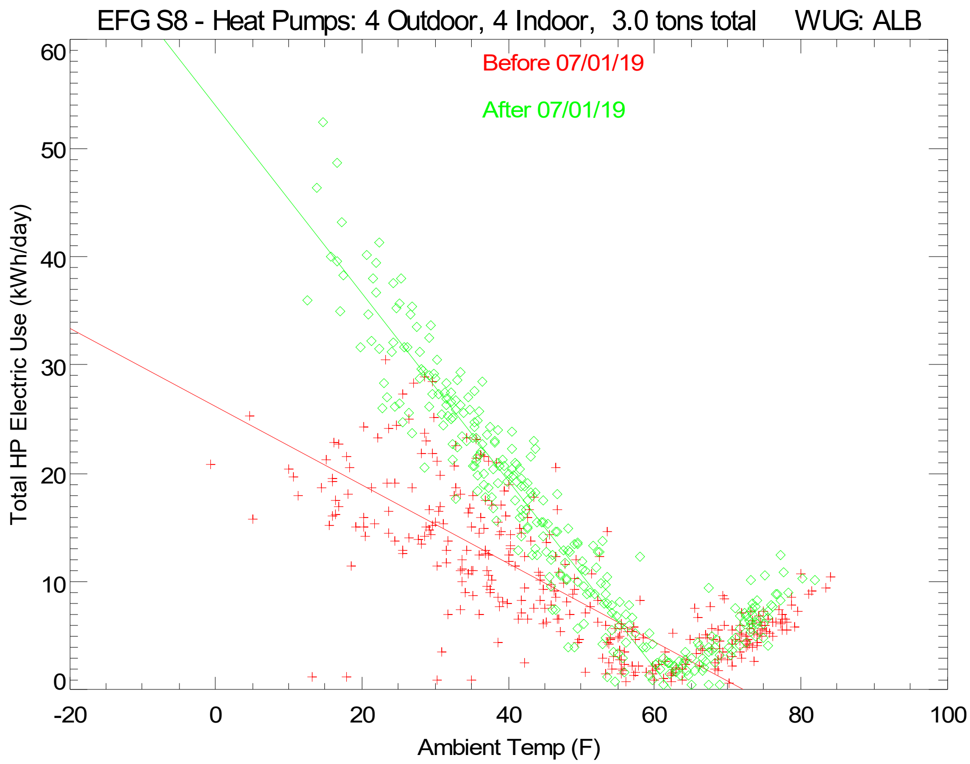


Figure 8. Post-Retrofit Heat Pump Electric Use vs. Outdoor Temperature for First and Second Winter Seasons

Table 4 shows the analysis results focusing on the second winter. The implied heating COP stayed the same, however the fuel savings changed from 219 to 286 gallons/yr and ASHP electric use for heating changed from 3,912 to 5243 kWh/yr. The percentage of fuel reduction changed from 42% to 61%.

Table 4. Results of Bin Analysis Showing Seasonal Results for the 2nd Winter

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Oil (gal/yr)	467	181	286
HP Electric (kWh/yr)		5,243	(5,243)
Total Heating Costs	$1,161	$1,062	$100
Implied Seasonal COP			1.9

Summary Statistics	
0.29	Fuel gal per sq ft per yr
34.1	Htg MBtu per sq ft per yr
61%	Reduction in Fuel Use
4,650	Measured HP for Htg (kWh/yr)
89%	Measured as % of Typical yr

Table 5 shows the results for just the first winter. In this case the fuel oil savings are only 156 gallons/yr and the seasonal COP was 1.7. The percentage fuel reduction was 33%. These results that the half hour of instruction or guidance offered to the homeowner in July 2019 caused the fuel savings from the using the heat pump to nearly double from 33% to 61%. Clearly homeowner training is a key aspect of ensuring heat pump retrofits reach their full energy saving potential.

Table 5. Results of Bin Analysis Showing Seasonal Results for the 1st Winter

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Oil (gal/yr)	467	311	156
HP Electric (kWh/yr)		3,220	(3,220)
Total Heating Costs	$1,161	$1,150	$11
Implied Seasonal COP			1.7

Summary Statistics	
0.29	Fuel gal per sq ft per yr
34.1	Htg MBtu per sq ft per yr
33%	Reduction in Fuel Use
4,650	Measured HP for Htg (kWh/yr)
144%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 9 and Figure 10 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 10 shows the temperature bins associated with cooling operation.

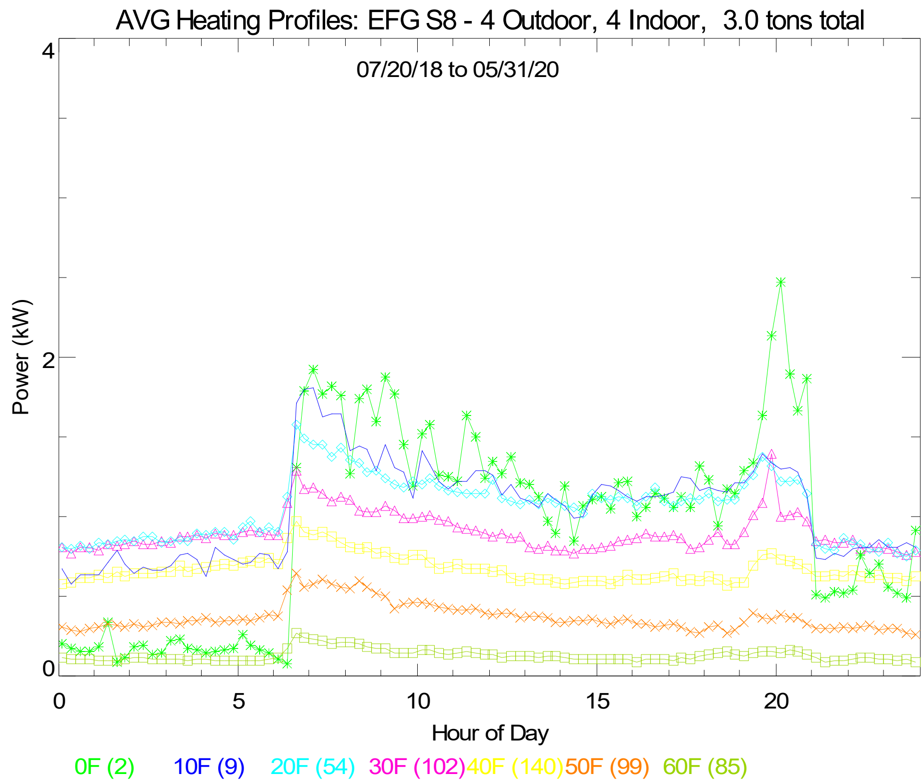


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

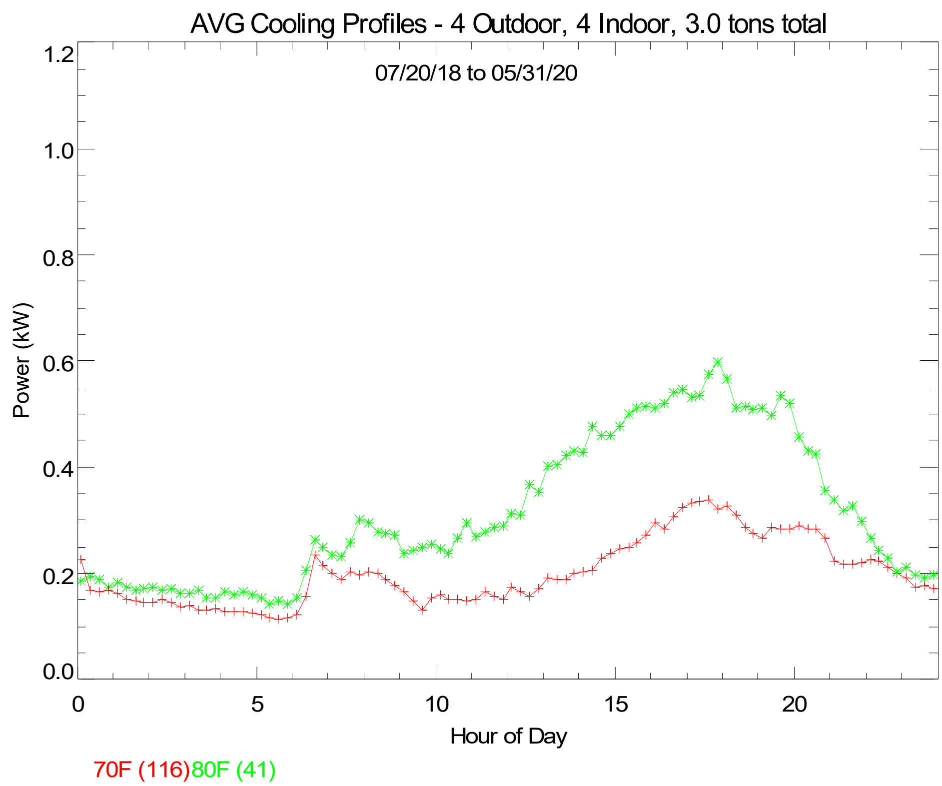


Figure 10. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 11.

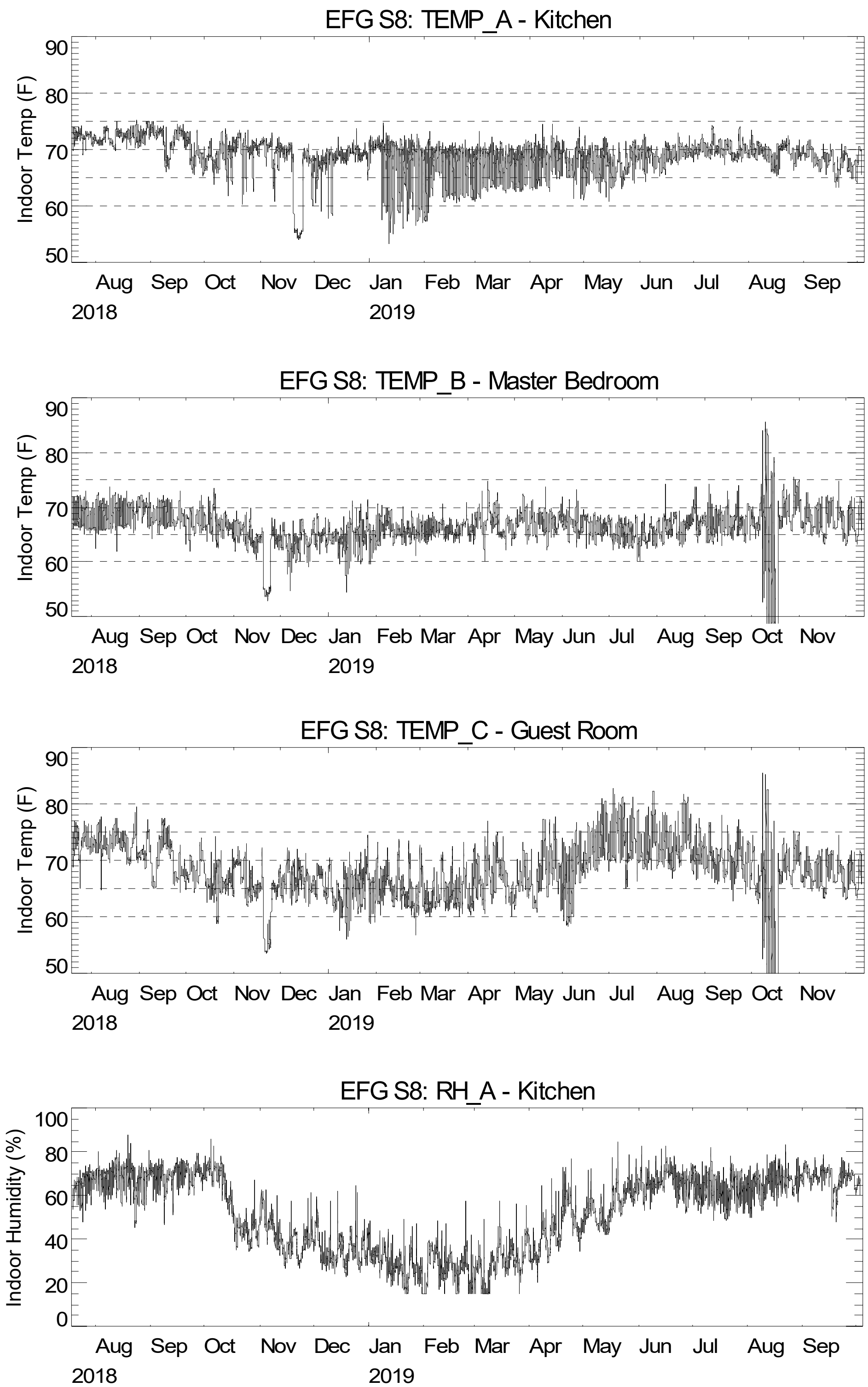


Figure 11. Space Temperatures and Humidity Levels

EFG S9 Savings Analysis

This 1800 sq ft house is in New Paltz near Newburgh. The house was originally heated by a propane furnace. The furnace was also used for supplemental heating after the two ASHPs were installed. ASHP was installed in mid 2018. Monitoring began in July 2018. These ASHP units also operate in cooling.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. There is some evidence that heat pumps use setback in the heating mode. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 4 shows the power use for the individual heat pumps.

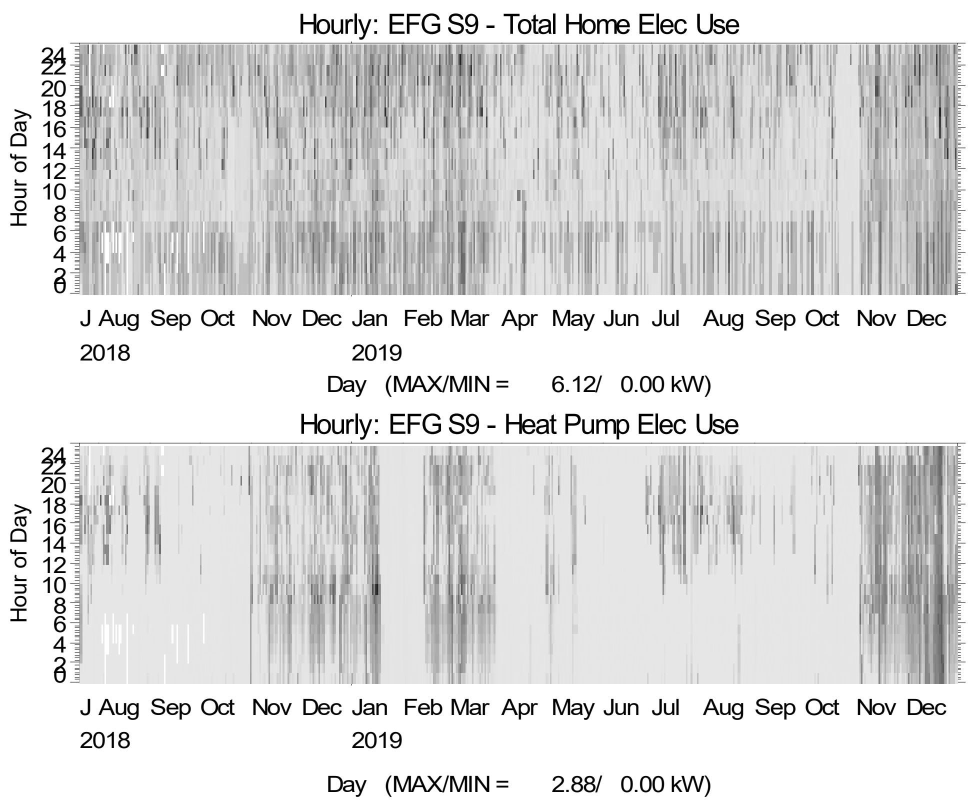


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

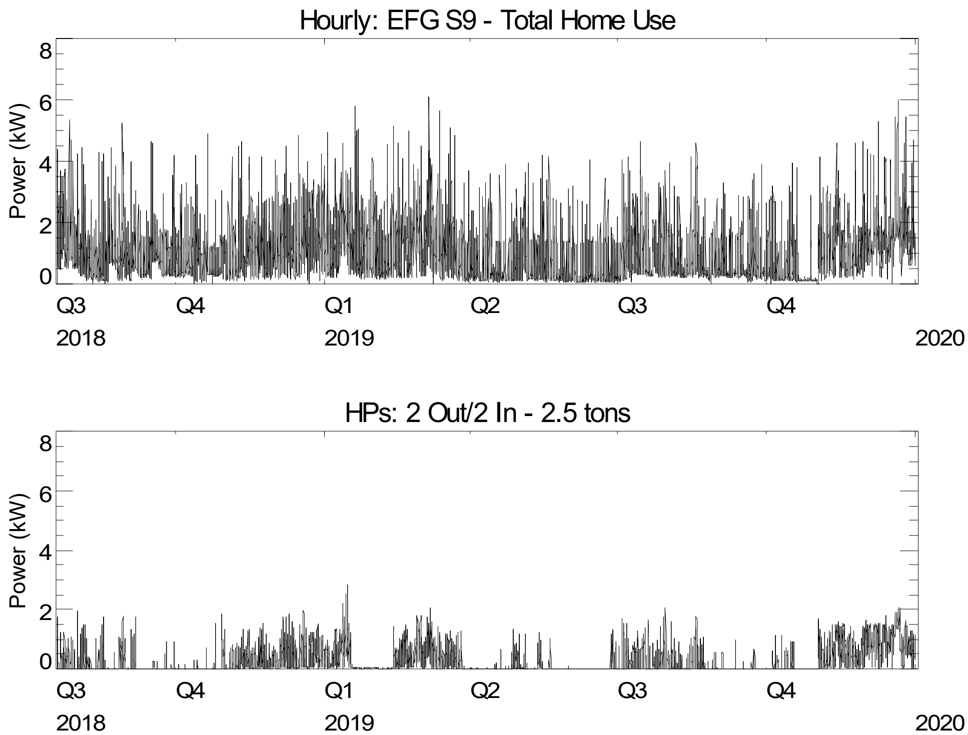


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

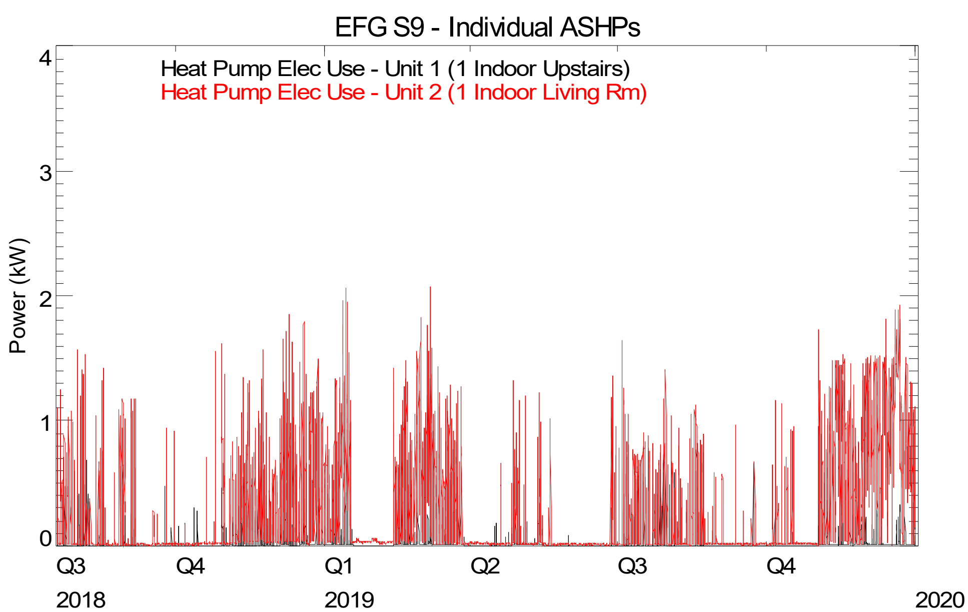


Figure 3. Power Use for Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pumps over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)
Jul-18	12	463.2	51.0
Aug-18	31	773.4	92.8
Sep-18	30	735.5	47.1
Oct-18	31	670.3	51.7
Nov-18	30	825.3	212.9
Dec-18	31	1,096.0	349.4
Jan-19	31	1,112.3	256.9
Feb-19	28	935.7	235.7
Mar-19	31	955.6	324.0
Apr-19	30	444.9	43.5
May-19	31	594.5	48.7
Jun-19	30	410.1	23.4
Jul-19	31	767.0	180.1
Aug-19	31	639.4	87.6
Sep-19	30	537.7	23.4
Oct-19	31	398.5	39.3
Nov-19	30	927.2	442.1
Dec-19	31	1,321.2	729.4
Annual	365	8,988.8	1,837.3
Htg Season	243	6,634.6	1,522.8
Jun-Sep	122	2,354.2	314.5

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature (from Albany Airport). There was considerable scatter in the daily energy use data, possibly due to daily variations in how the occupants used the ductless heat pump. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy in the summer is also apparent at this site.

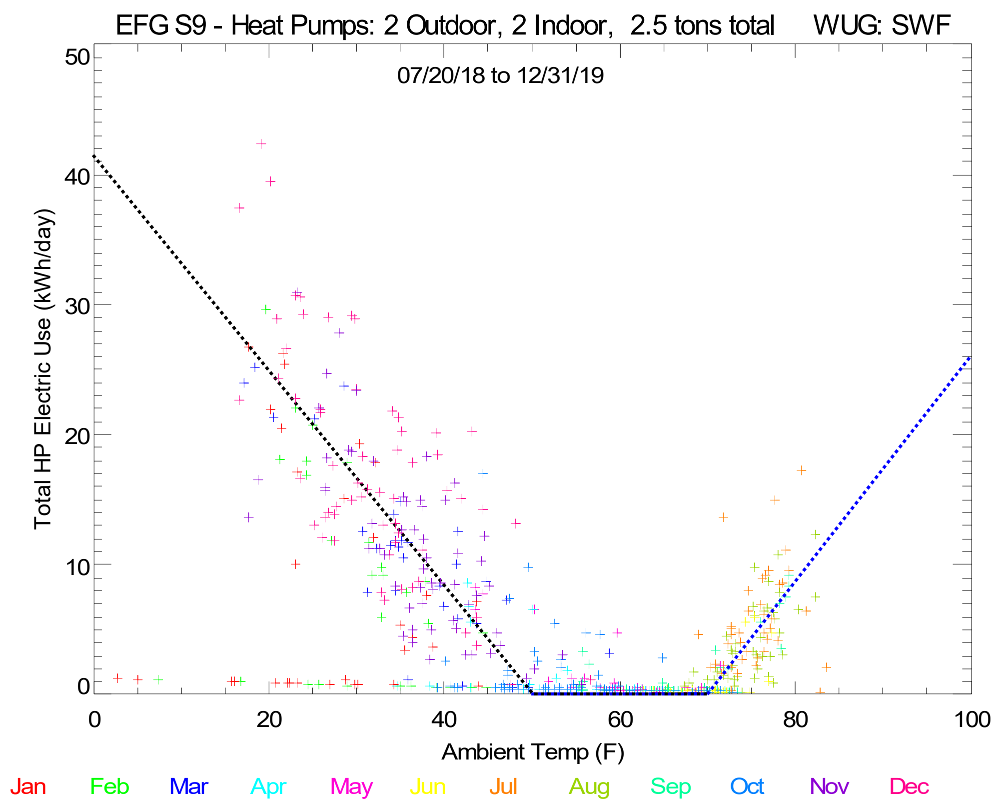


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced some of the fuel oil use by the boiler. Figure 5 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period.

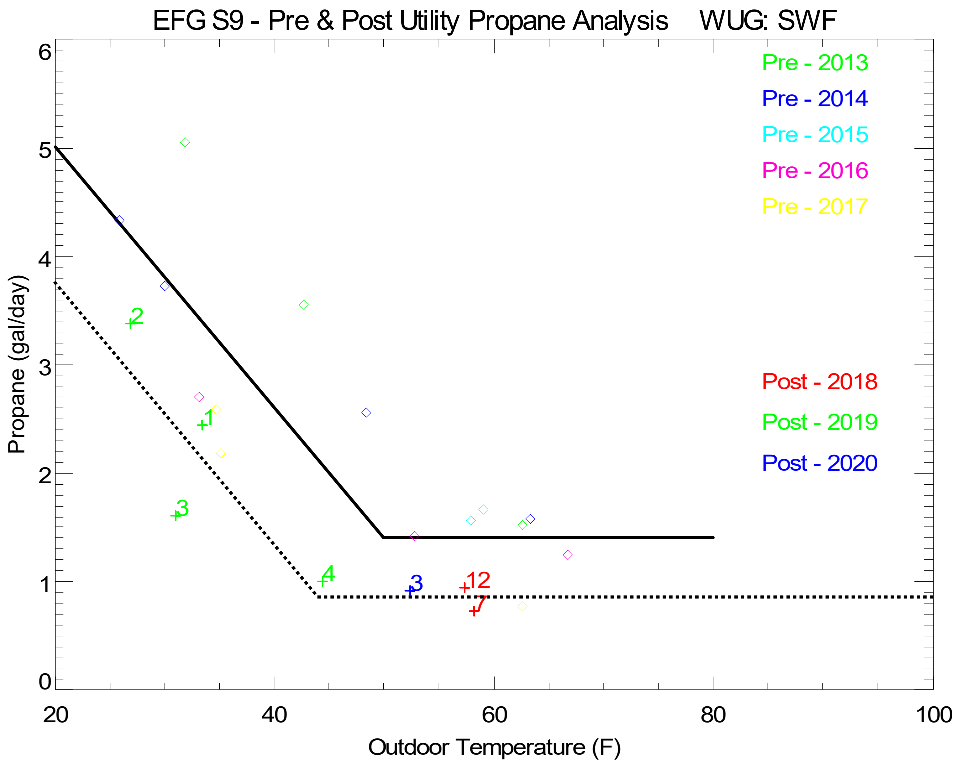


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

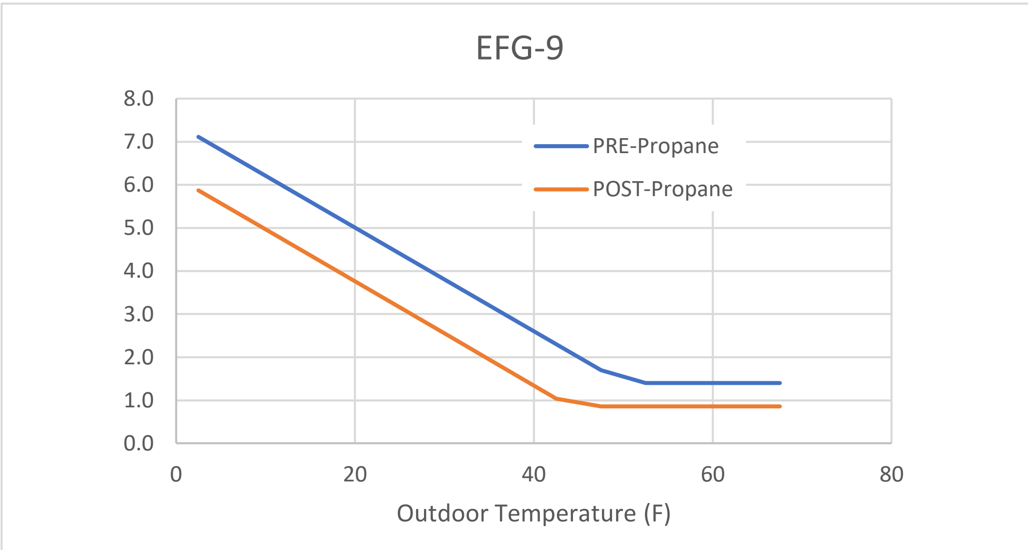
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Newburgh. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	**EFG-9**	WEATHER:	**Newburgh**	$ 0.150	per kWh
FUEL:	**Propane**			$ 2.440	per gal (propane)
Floor Area	1800	LOCATION:	New Paltz		

Temp Bin	Hours	FUEL PRE-Propane (gal/day)	FUEL POST-Propane (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Propane (gal/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Propane adjustment factor
-27.5	0	10.7	9.5	64.2	9.5	0.4	$ 26.2	$ 32.8	
-22.5	0	10.1	8.9	60.0	8.9	0.4	$ 24.7	$ 30.7	
-17.5	0	9.5	8.3	55.9	8.3	0.5	$ 23.2	$ 28.6	
-12.5	0	8.9	7.7	51.8	7.7	0.5	$ 21.8	$ 26.5	
-7.5	1	8.3	7.1	47.6	7.1	0.5	$ 20.3	$ 24.4	
-2.5	13	7.7	6.5	43.5	6.5	0.6	$ 18.8	$ 22.3	
2.5	36	7.1	5.9	39.3	5.9	0.7	$ 17.4	$ 20.2	
7.5	45	6.5	5.3	35.2	5.3	0.7	$ 15.9	$ 18.1	
12.5	113	5.9	4.7	31.1	4.7	0.8	$ 14.4	$ 16.0	
17.5	222	5.3	4.1	26.9	4.1	1.0	$ 13.0	$ 13.9	
22.5	367	4.7	3.5	22.8	3.5	1.1	$ 11.5	$ 11.9	
27.5	373	4.1	2.9	18.6	2.9	1.4	$ 10.0	$ 9.8	
32.5	764	3.5	2.2	14.5	2.2	1.8	$ 8.6	$ 7.7	
37.5	814	2.9	1.6	10.4	1.6	2.5	$ 7.1	$ 5.6	
42.5	727	2.3	1.0	6.2	1.0	4.2	$ 5.6	$ 3.5	
47.5	668	1.7	0.9	2.1	0.9	8.4	$ 4.1	$ 2.4	
52.5	480	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
57.5	748	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
62.5	831	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
67.5	902	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
72.5	538	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
77.5	603	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
82.5	358	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
87.5	134	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
92.5	23	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
97.5	1	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	
102.5	0	1.4	0.9	0.0	0.9	#######	$ 3.4	$ 2.1	



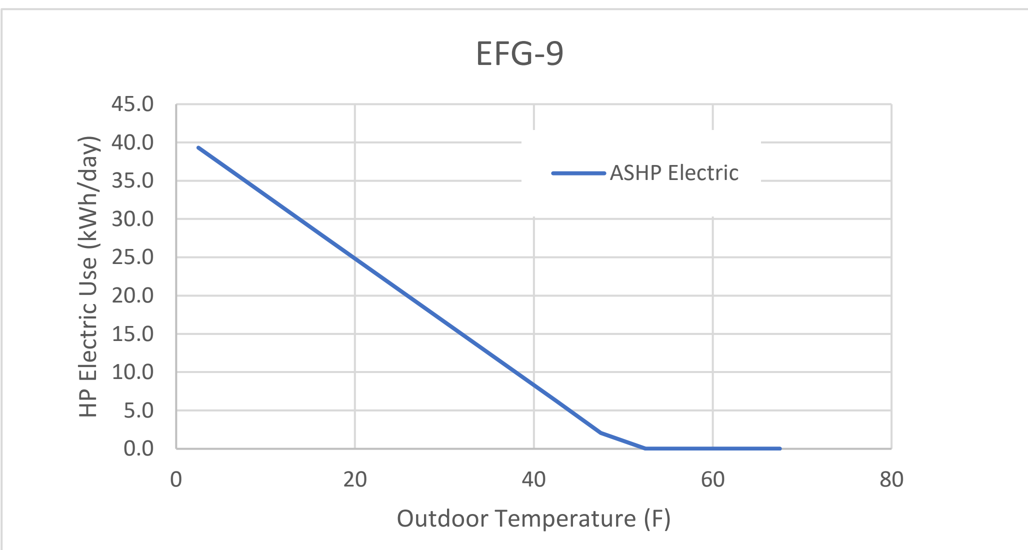


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 1.0 in this case, which is not valid. The main issue appears to be that that the propane delivery dates were only given to nearest month, making it impossible to accurately estimate the heating fuel use trend.

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	**PRE-Retrofit**	**POST-Retrofit**	**Savings**
Propane (gal/yr)	326	214	112
HP Electric (kWh/yr)		2,241	(2,241)
Total Heating Costs	$795	$858	-$63
Implied Seasonal COP			1.0

Summary Statistics	
0.18	Fuel gal per sq ft per yr
12.8	Htg MBtu per sq ft per yr
34%	Reduction in Fuel Use
1,523	Measured HP for Htg (kWh/yr)
68%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

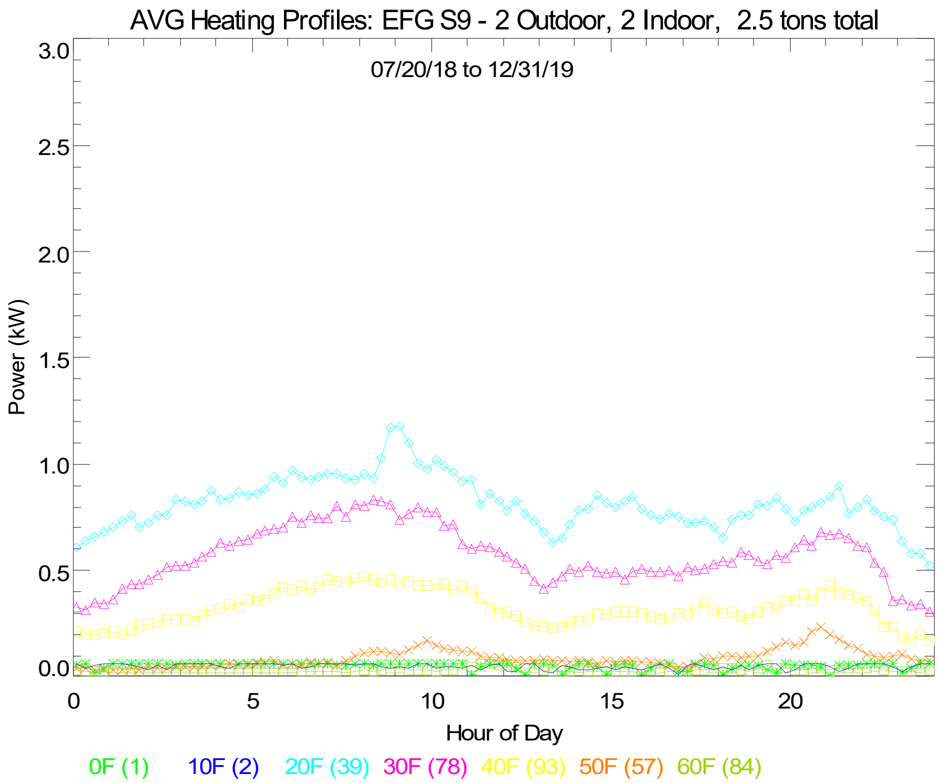


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

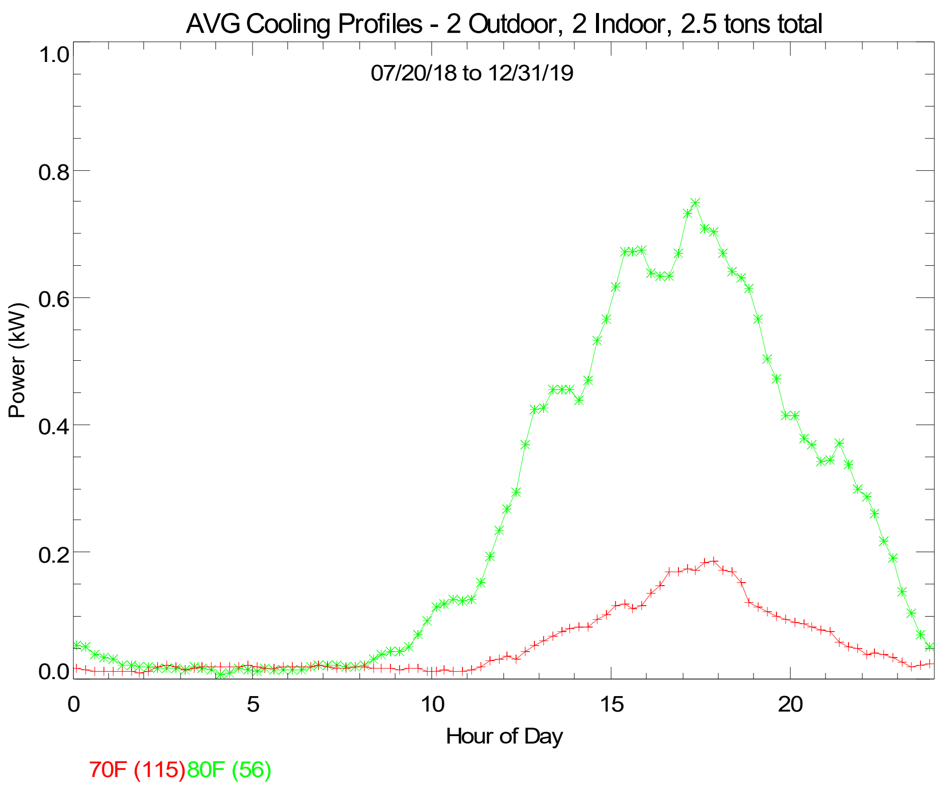


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

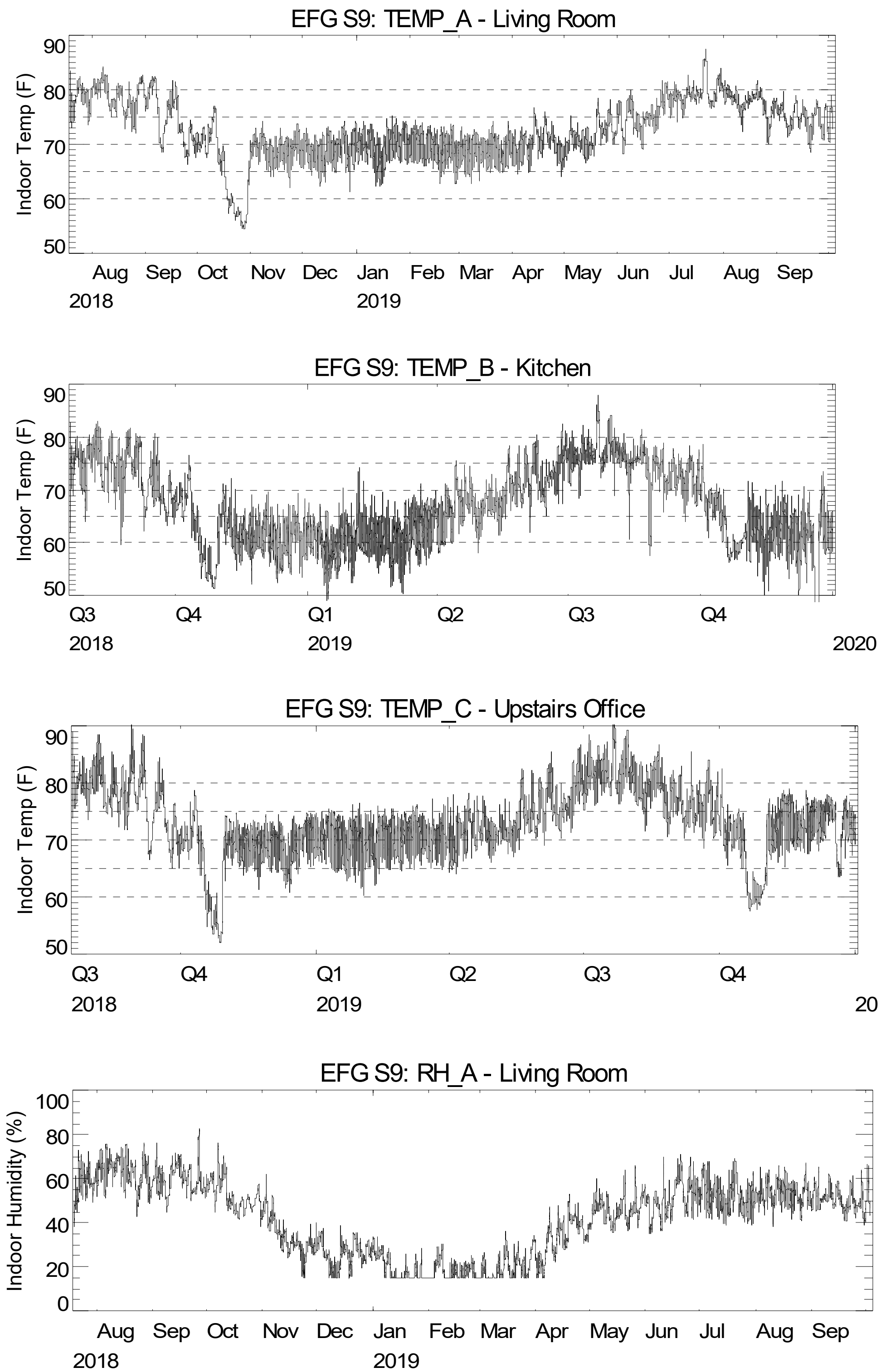


Figure 9. Space Temperatures and Humidity Levels

EFG S10 Savings Analysis

This 2233 sq ft house is in Stone Ridge near Newburgh. The house was originally heated by an oil boiler. The boiler was not used after the six ASHPs were installed (5.3 tons total). The last two ASHPs were installed in mid 2018. Unlike S5, we did have pre-retrofit fuel use dating back before all the HPs units were installed. Therefore, we were able to assess the impact of all the heat pumps. Monitoring began in October 2018. These units also operate in cooling.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. There is some evidence that heat pumps use setback in the heating mode. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use for the individual heat pumps.

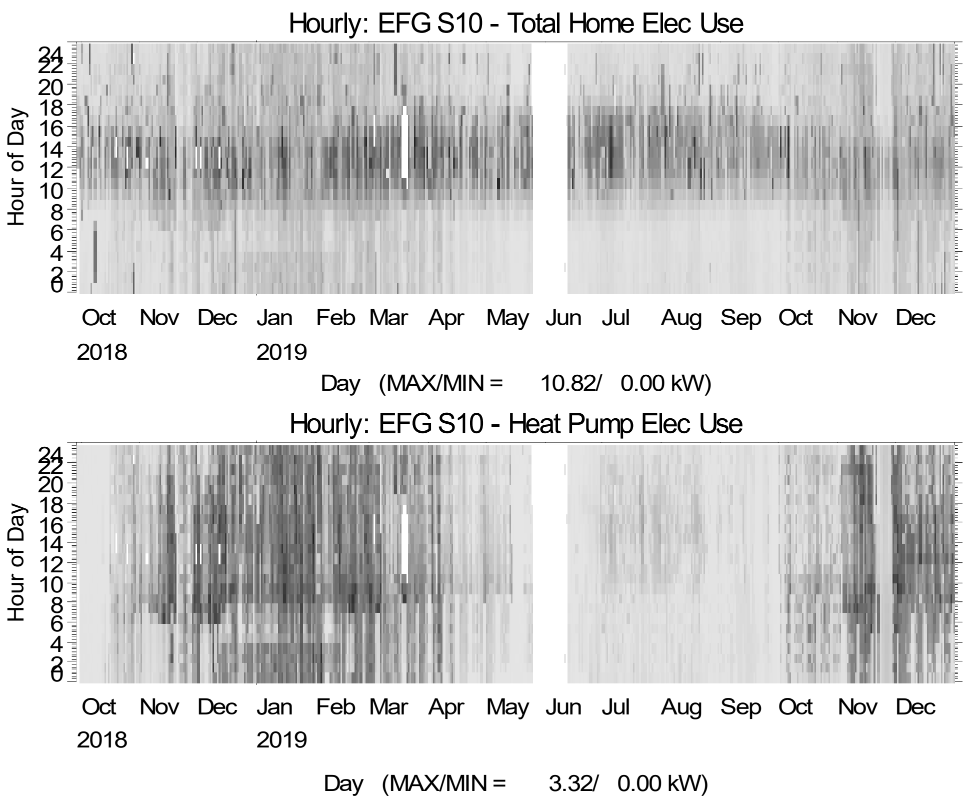


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

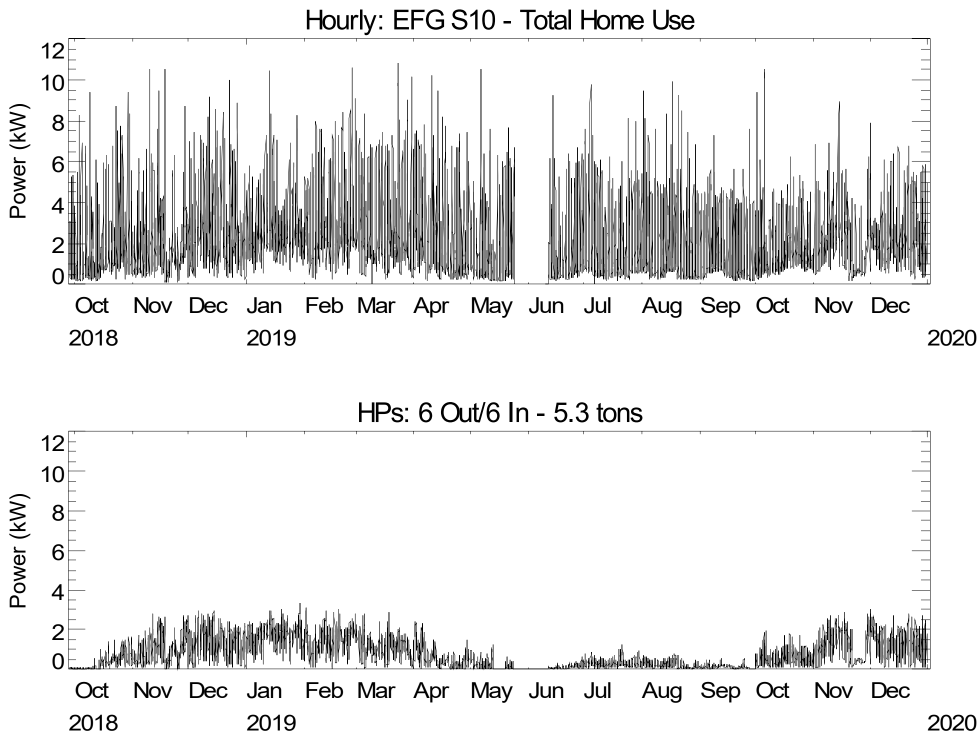


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

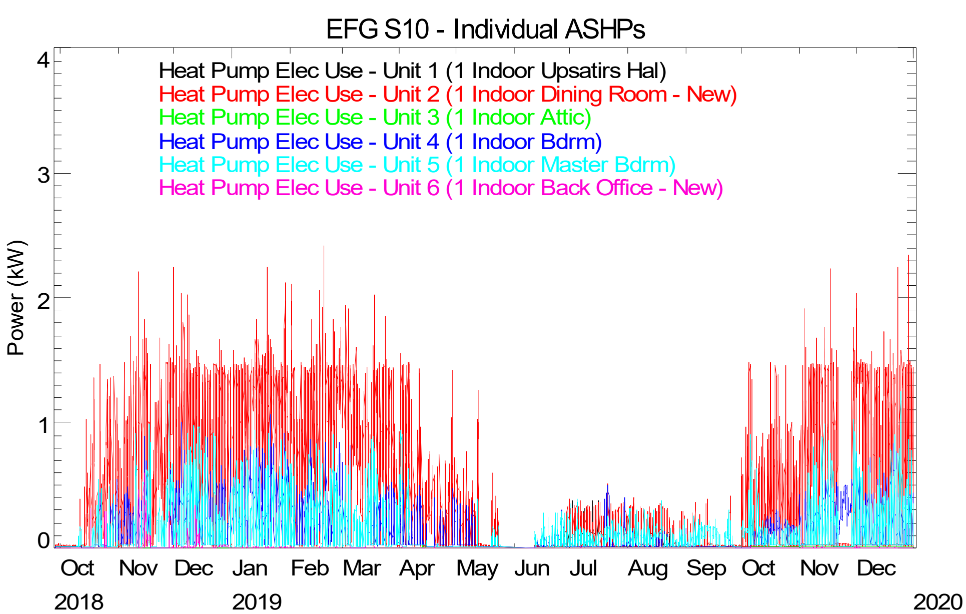


Figure 3. Power Use for the Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)
Sep-18	3	95.3	3.2
Oct-18	31	1,355.9	236.3
Nov-18	30	1,384.1	679.8
Dec-18	31	1,916.7	1,004.9
Jan-19	31	2,033.0	1,283.0
Feb-19	28	1,907.9	994.8
Mar-19	31	2,091.9	776.4
Apr-19	30	1,517.3	394.8
May-19	24	946.1	116.4
Jun-19	22	825.2	58.7
Jul-19	31	1,483.0	214.0
Aug-19	31	1,428.5	153.2
Sep-19	30	1,119.2	89.3
Oct-19	31	1,283.6	373.0
Nov-19	30	1,509.1	800.6
Dec-19	31	1,732.8	965.9
Annual	350	18,061.5	6,259.1
Htg Season	236	13,205.6	5,743.9
Jun-Sep	114	4,855.9	515.2

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature (from Newburgh). There was considerable scatter in the daily energy use data, possibly due to variations in how the occupants used the ductless heat pumps. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy use in the summer for cooling is also apparent at this site.

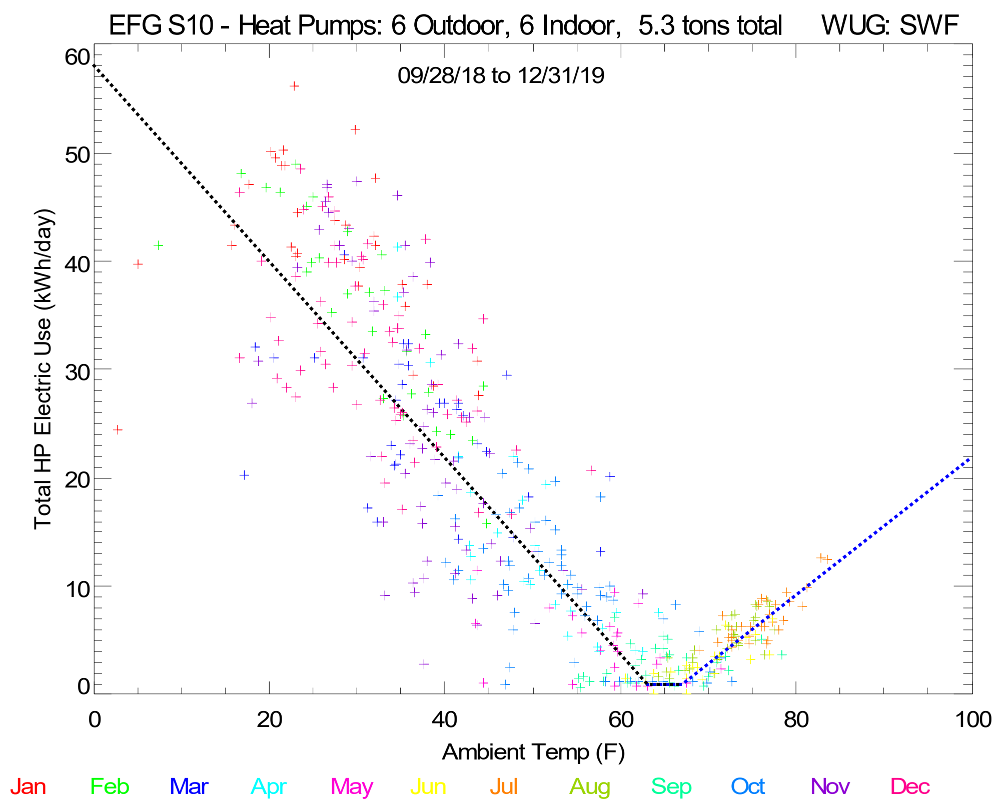


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced all of the fuel oil use by the boiler. Figure 5 compares the trend of monthly fuel use with temperature for both the pre-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period (in this case before the first ASHP units were installed in June 2013). There was no post-retrofit fuel oil use.

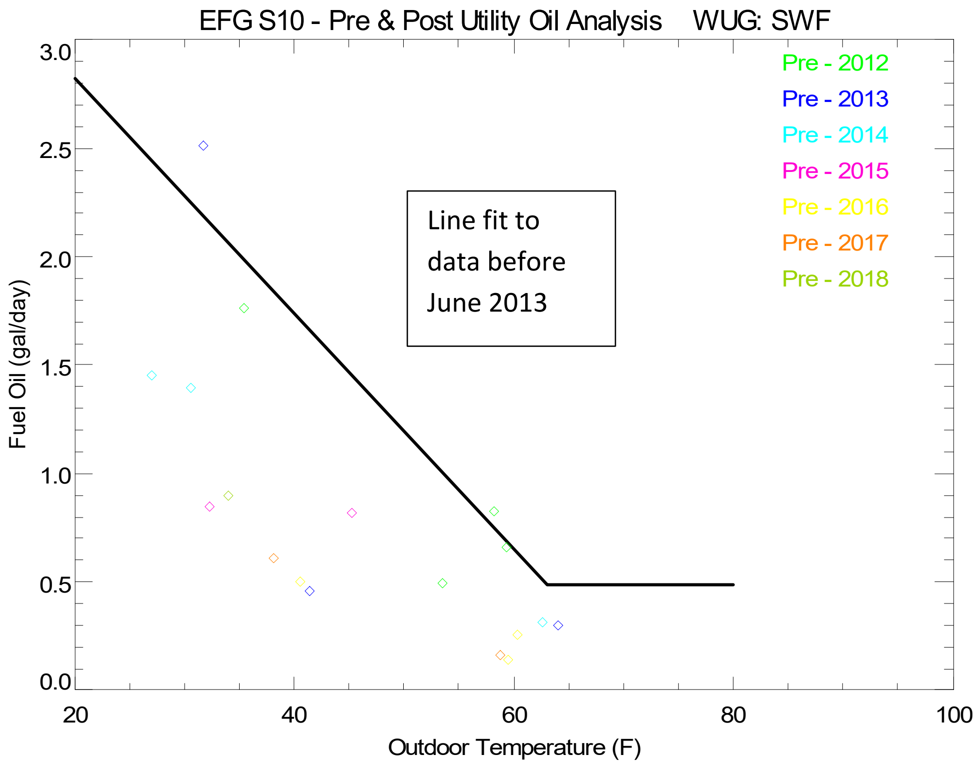


Figure 5. Analysis of Monthly Utility Bills with Temperature, Pre-Retrofit Trend of Fuel Use

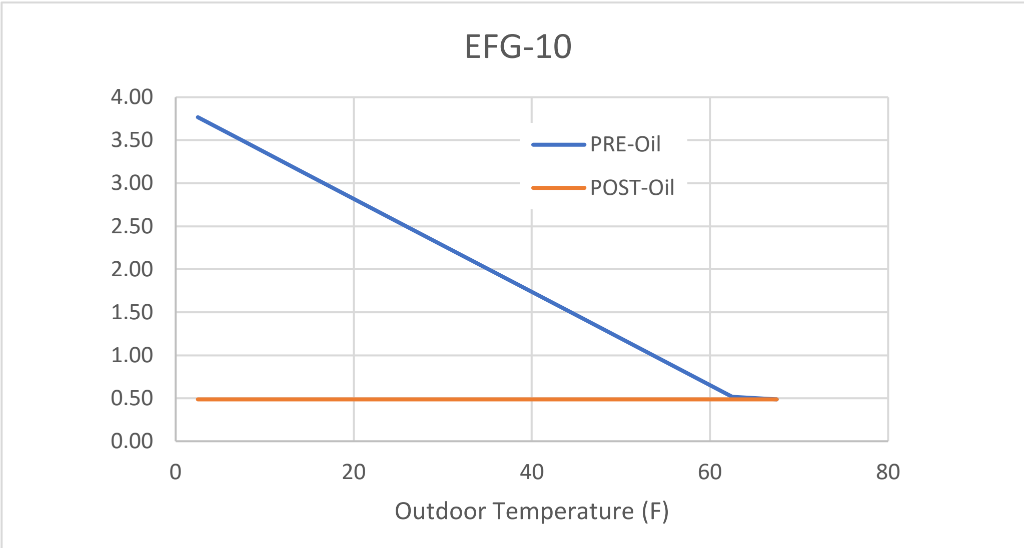
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis. In this case the post-retrofit fuel use in the bin analysis was set to match the pre-retrofit base load fuel use.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	EFG-10				WEATHER:	Newburgh		$ 0.150	per kWh
FUEL:	Oil							$ 2.686	per gal (oil)
Floor Area	2233				LOCATION:	Stone Ridge			

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	5.39	0.00	82.88	0.49	2.0	$ 14.5	$ 13.7	0.091
-22.5	0	5.12	0.00	78.36	0.49	2.0	$ 13.8	$ 13.1	0.096
-17.5	0	4.85	0.00	73.83	0.49	2.0	$ 13.0	$ 12.4	0.101
-12.5	0	4.58	0.00	69.31	0.49	2.0	$ 12.3	$ 11.7	0.107
-7.5	1	4.31	0.00	64.79	0.49	2.0	$ 11.6	$ 11.0	0.114
-2.5	13	4.04	0.00	60.26	0.49	2.0	$ 10.9	$ 10.4	0.121
2.5	36	3.77	0.00	55.74	0.49	2.0	$ 10.1	$ 9.7	0.130
7.5	45	3.50	0.00	51.21	0.49	2.0	$ 9.4	$ 9.0	0.140
12.5	113	3.23	0.00	46.69	0.49	2.0	$ 8.7	$ 8.3	0.152
17.5	222	2.96	0.00	42.17	0.49	2.0	$ 7.9	$ 7.6	0.166
22.5	367	2.68	0.00	37.64	0.49	2.0	$ 7.2	$ 7.0	0.183
27.5	373	2.41	0.00	33.12	0.49	2.0	$ 6.5	$ 6.3	0.203
32.5	764	2.14	0.00	28.60	0.49	2.0	$ 5.8	$ 5.6	0.229
37.5	814	1.87	0.00	24.07	0.49	2.0	$ 5.0	$ 4.9	0.262
42.5	727	1.60	0.00	19.55	0.49	1.9	$ 4.3	$ 4.2	0.306
47.5	668	1.33	0.00	15.02	0.49	1.9	$ 3.6	$ 3.6	0.368
52.5	480	1.06	0.00	10.50	0.49	1.9	$ 2.8	$ 2.9	0.463
57.5	748	0.79	0.00	5.98	0.49	1.7	$ 2.1	$ 2.2	0.622
62.5	831	0.52	0.00	1.45	0.49	0.6	$ 1.4	$ 1.5	0.948
67.5	902	0.49	0.00	1.00	0.49	0.0	$ 1.3	$ 1.5	1
72.5	538	0.49	0.00	1.00	0.49	0.0	$ 1.3	$ 1.5	1
77.5	603	0.49	0.00	1.00	0.49	0.0	$ 1.3	$ 1.5	1
82.5	358	0.49	0.00	1.00	0.49	0.0	$ 1.3	$ 1.5	1
87.5	134	0.49	0.00	1.00	0.49	0.0	$ 1.3	$ 1.5	1
92.5	23	0.49	0.00	1.00	0.49	0.0	$ 1.3	$ 1.5	1
97.5	1	0.49	0.00	1.00	0.49	0.0	$ 1.3	$ 1.5	1
102.5	0	0.49	0.00	1.00	0.49	0.0	$ 1.3	$ 1.5	1



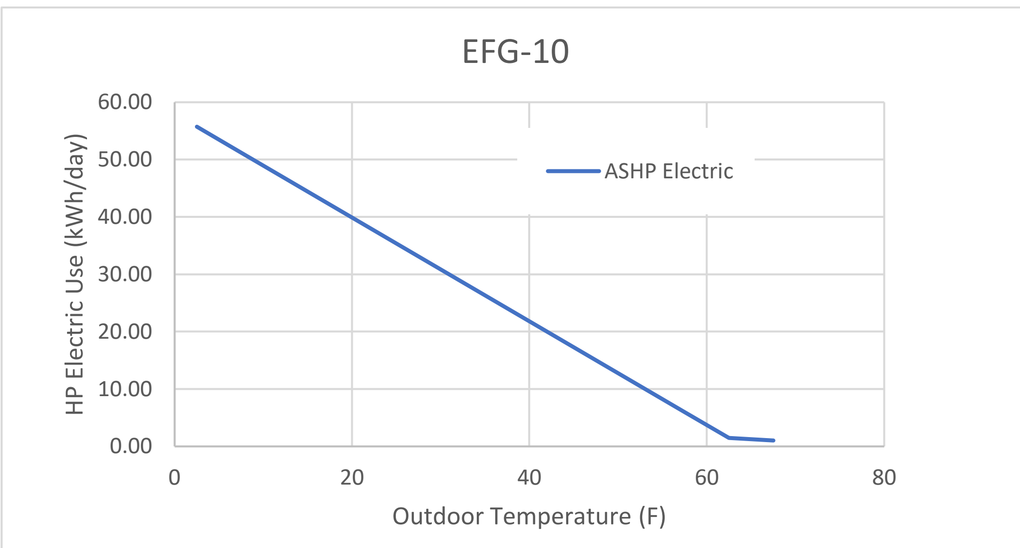


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 1.9 in this case.

In this instance the implied COP is calculated from

$$COP = (Fuel_{pre} - Fuel_{post})*eff/(3.412xkWh_{hp}) = (290-0)*139*0.84 / (3.412*5136)$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Oil (gal/yr)	290	0	290
HP Electric (kWh/yr)		5,136	(5,136)
Total Heating Costs	$ 779	$ 770	$ 8
Implied Seasonal COP			1.9

Summary Statistics	
0.13	Fuel gal per sq ft per yr
15.2	Htg MBtu per sq ft per yr
100%	Reduction in Fuel Use
5,743	Measured HP for Htg (kWh/yr)
112%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation. The lines corresponding to the 0˚F and 10˚F profiles are fairly jagged in this case since the average profile is only based on 1 and 2 days.

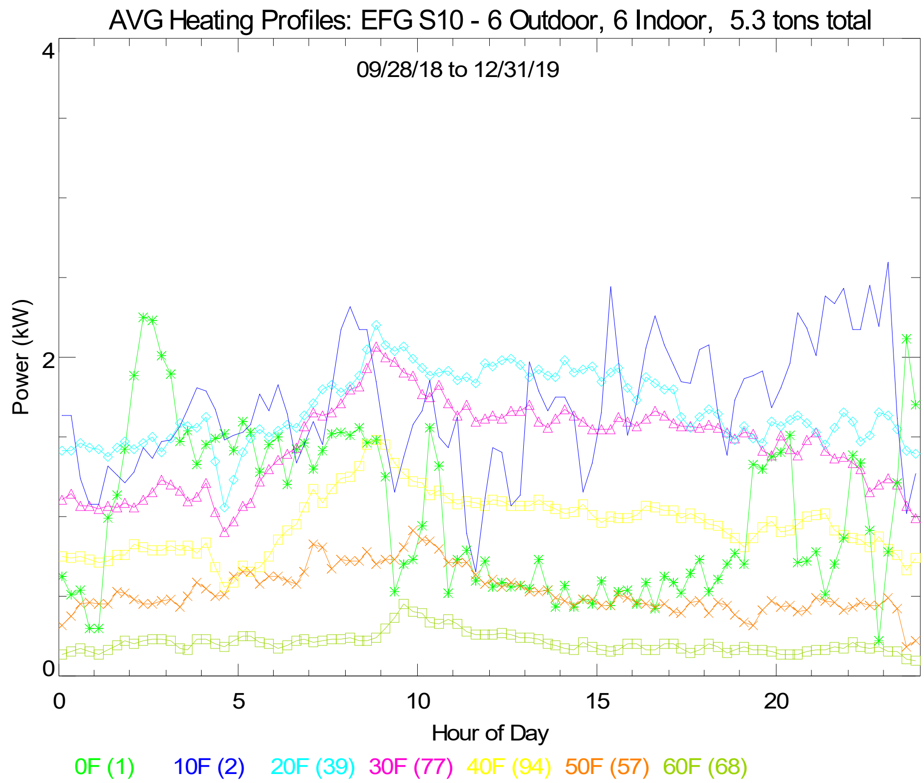


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

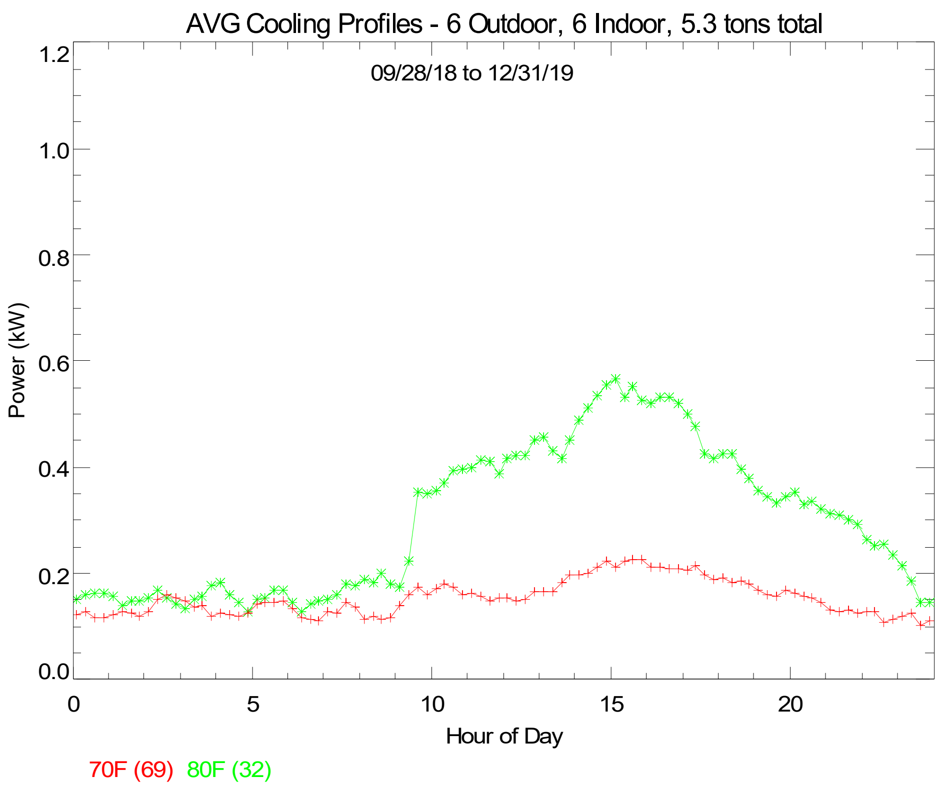


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

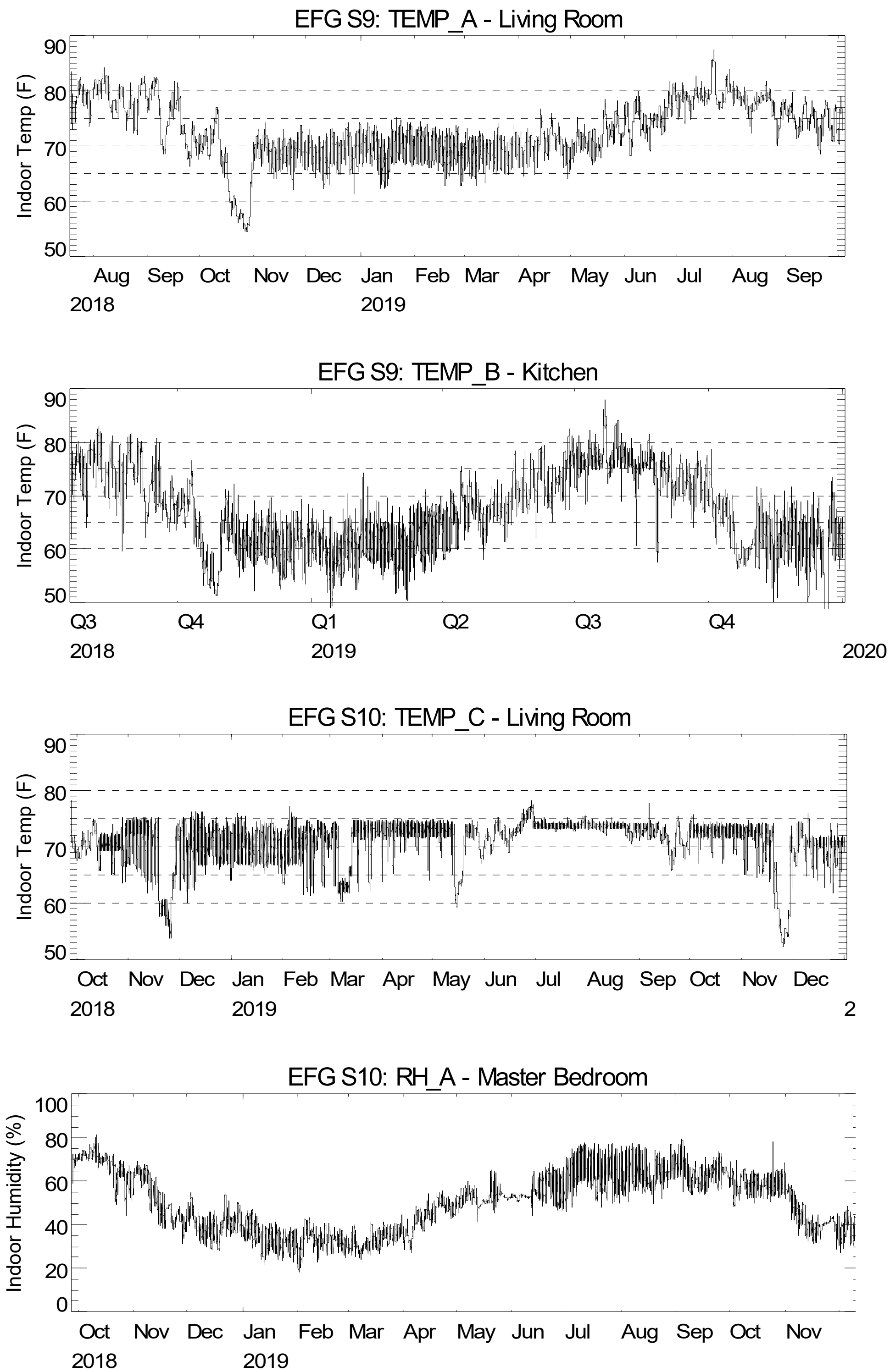


Figure 9. Space Temperatures and Humidity Levels

EFG S11 Savings Analysis

This 1249 sq ft house is located in New Paltz, NY near Newburgh. The house was originally heated by baseboard electric heat. The electric baseboard was monitored in the post-retrofit period, but none was used for supplemental heating after the five ASHP units were installed. The ASHPs were installed in September 2018. Monitoring began in February 2019. These units also ran in the summer to provide cooling.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 4 shows the power use for each individual heat pump.

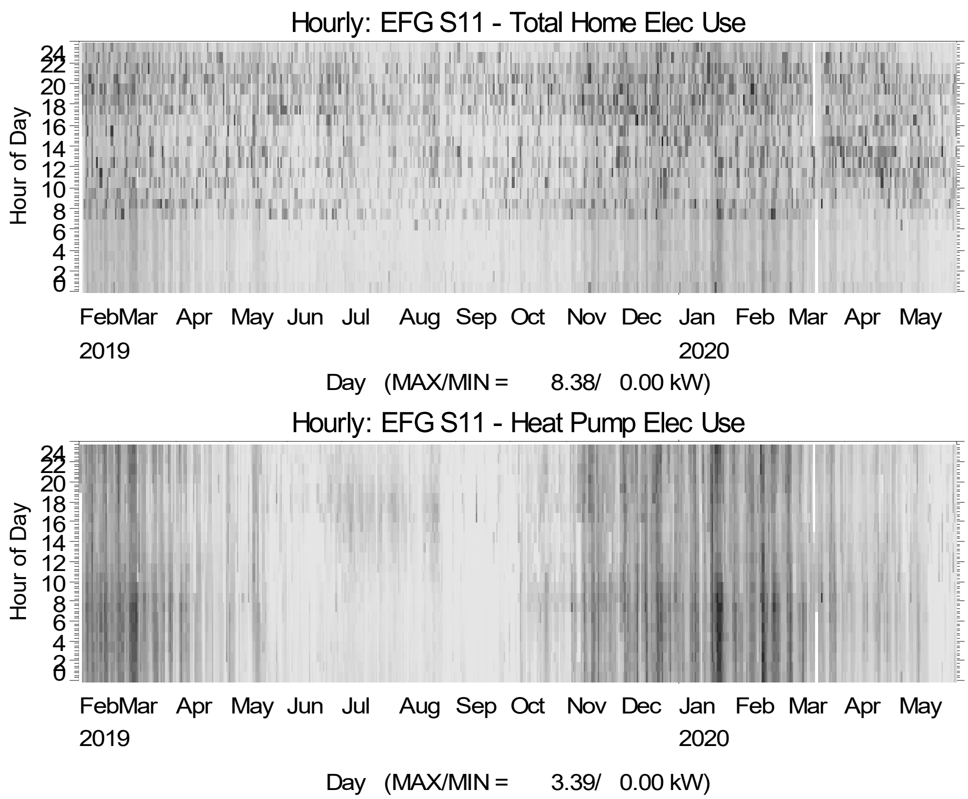


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

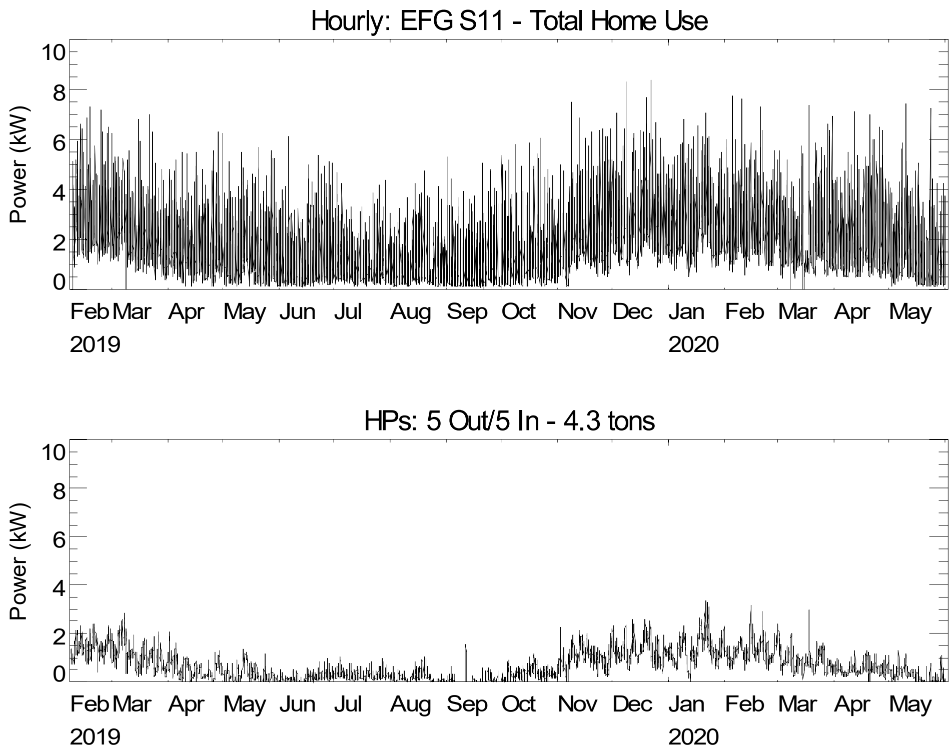


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

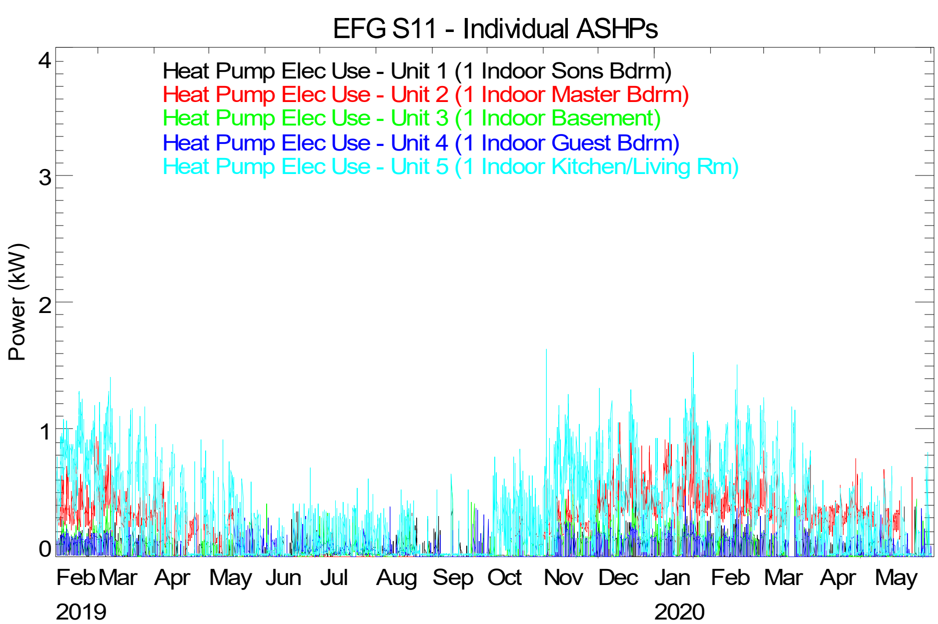


Figure 3. Power Use for Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. It also includes the resistance electric heaters that were monitored (but the use was zero).

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)
Feb-19	22	1,256.6	755.5	-
Mar-19	31	1,501.4	811.7	-
Apr-19	30	1,034.7	368.9	-
May-19	31	978.7	206.9	-
Jun-19	30	760.6	113.9	-
Jul-19	31	697.9	205.2	-
Aug-19	31	684.6	123.0	-
Sep-19	30	622.8	45.2	-
Oct-19	31	871.4	231.4	-
Nov-19	30	1,419.7	705.7	-
Dec-19	31	1,834.5	978.5	-
Jan-20	31	1,788.4	1,013.1	-
Feb-20	29	1,602.8	917.1	-
Mar-20	31	1,338.6	619.7	-
Apr-20	30	1,301.2	380.3	-
May-20	31	933.0	173.8	-
Annual	366	13,901.2	5,540.0	-
Htg Season	244	11,135.3	5,052.7	-
Jun-Sep	122	2,765.9	487.3	-

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature. There is moderate scatter in the data, indicating that the occupants used the ductless heat pumps in a fairly consistent manner. The dotted line on the plot represents to a best fit of the trend with temperature.

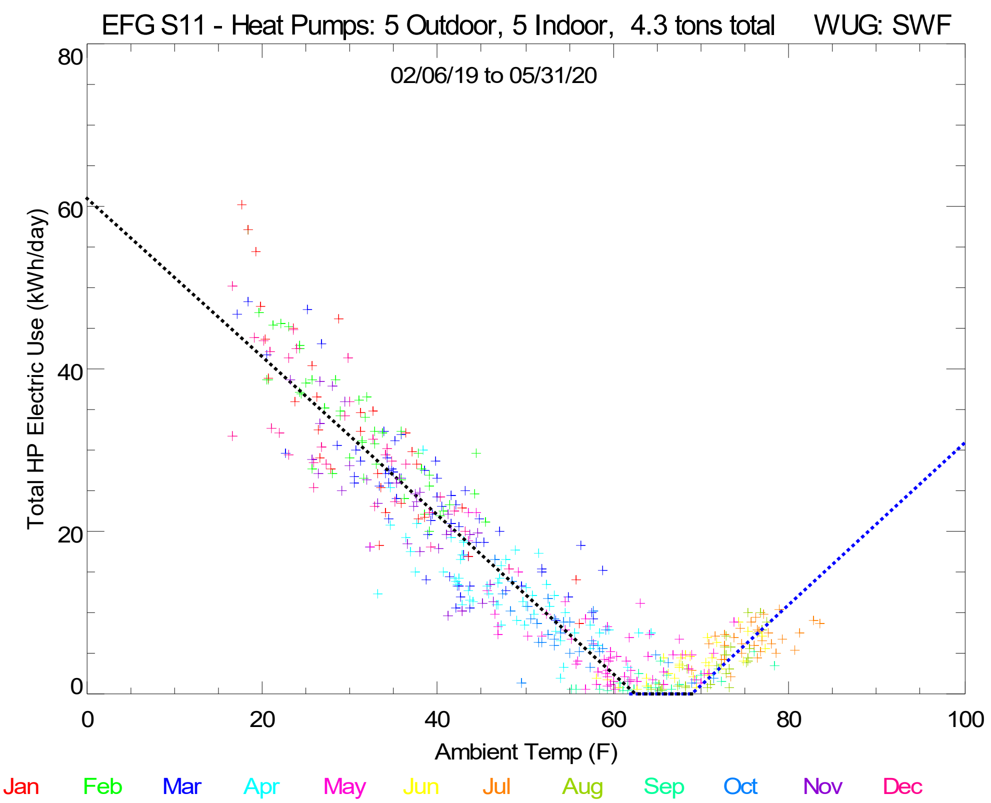


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced baseboard electric heat use. Figure 5 compares the trend of monthly electric for the total house with temperature for both the pre- and post-retrofit periods. The solid line represents the overall electric use trend in the pre-retrofit period. The dotted line represents the electric use trend in the post-retrofit period. Since the post-retrofit trend of total electric use was weak, we used the trend of daily total house electric use from the measured data (rather than the monthly utility data) to discern the post retrofit trend (Figure 6).

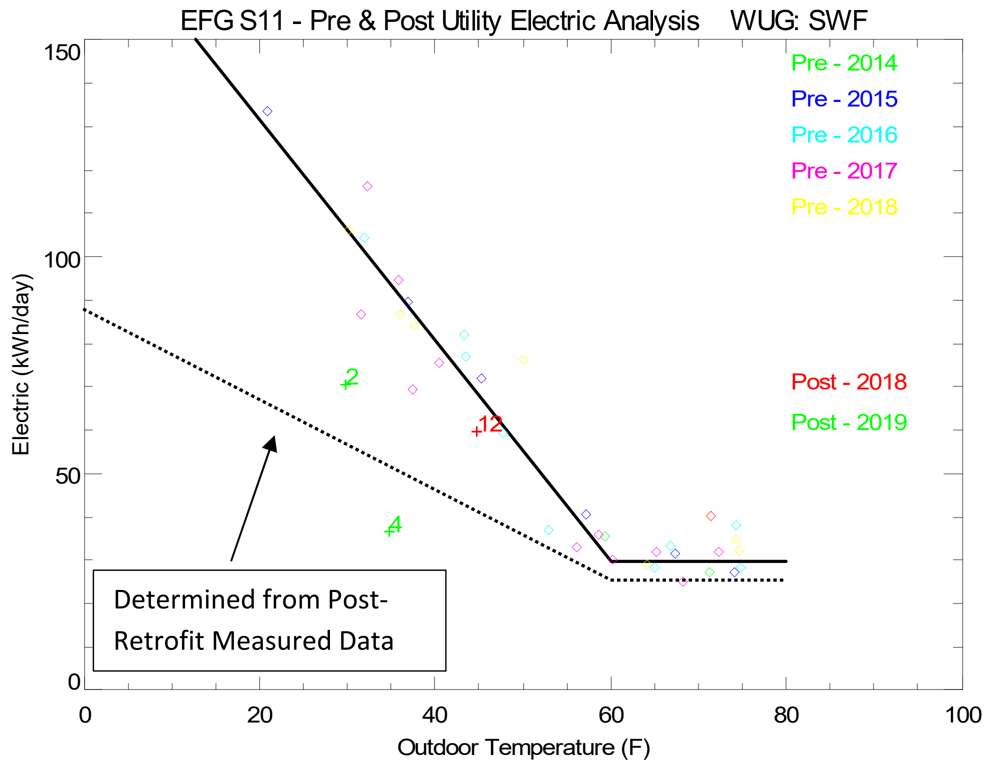


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Electric Use (the number shown by each post-retrofit data point indicates the month)

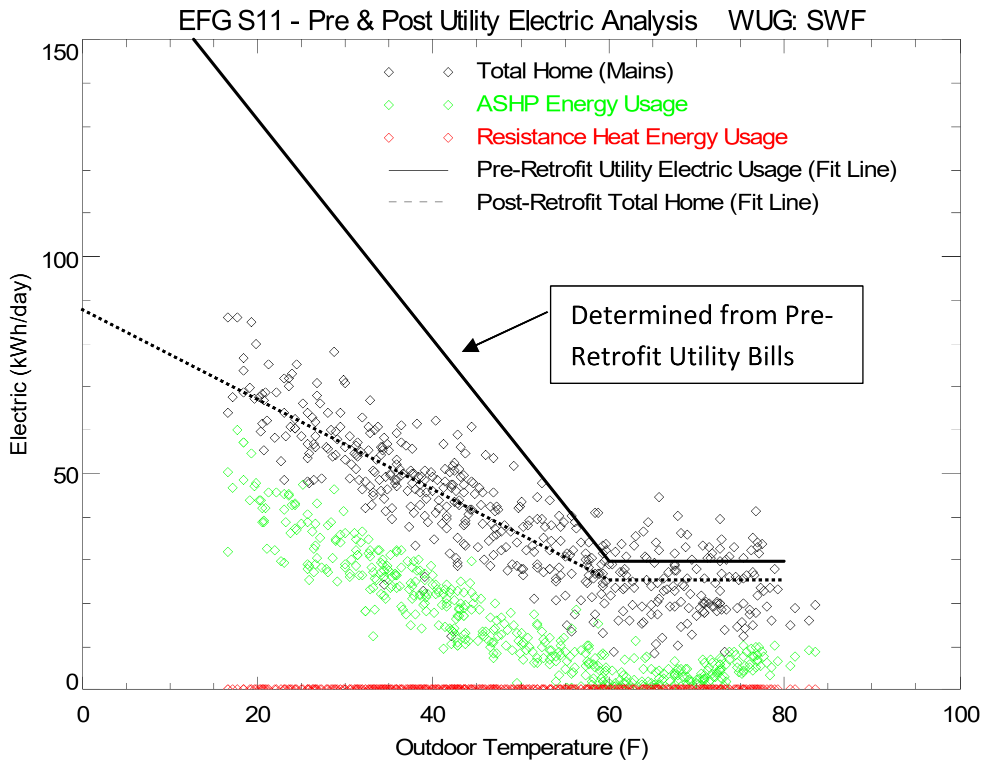


Figure 6. Analysis of Total House Energy Use versus Outdoor Temperature in the Post-Retrofit Period (ASHP and Resistance heat also shown)

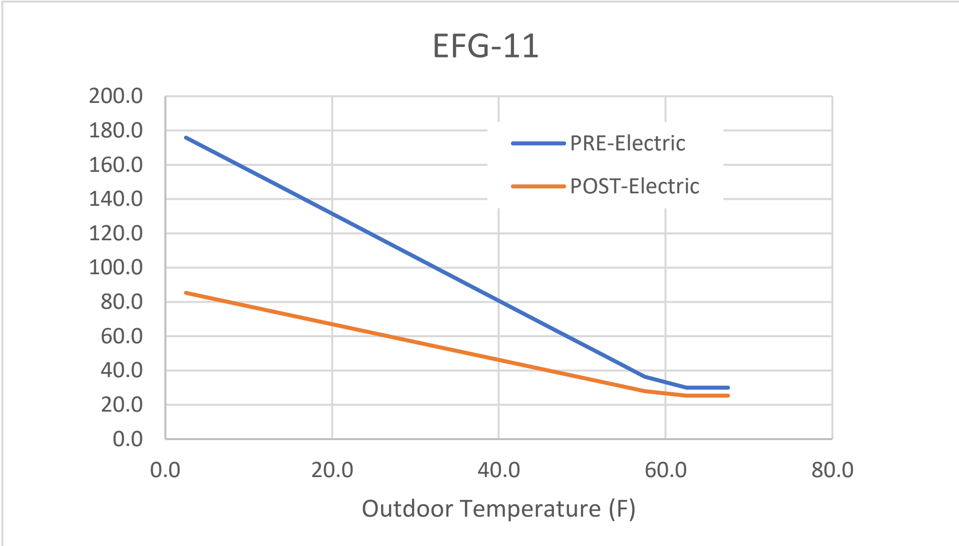
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Newburgh. Table 2 shows the details of bin analysis and Figure 7 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	**EFG-11**	WEATHER:	**Newburgh**	$ 0.150	per kWh
FUEL:	**Electric**			$ 0.150	per kWh
Floor Area	1249	LOCATION:	New Paltz		

Temp Bin	Hours	FUEL PRE-Electric (kWh/day)	FUEL POST-Electric (kWh/day)	ASHP Electric (kWh/day)	Adjusted POST-Electric (kWh/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Electric adjustment factor
-27.5	0	252.1	116.4	87.8	116.4	2.5	37.8	30.6	
-22.5	0	239.4	111.2	83.0	111.2	2.5	35.9	29.1	
-17.5	0	226.7	106.0	78.1	106.0	2.5	34.0	27.6	
-12.5	0	214.0	100.8	73.2	100.8	2.5	32.1	26.1	
-7.5	1	201.3	95.6	68.3	95.6	2.5	30.2	24.6	
-2.5	13	188.6	90.4	63.4	90.4	2.5	28.3	23.1	
2.5	36	175.9	85.2	58.6	85.2	2.5	26.4	21.6	
7.5	45	163.2	80.0	53.7	80.0	2.6	24.5	20.1	
12.5	113	150.5	74.8	48.8	74.8	2.6	22.6	18.5	
17.5	222	137.8	69.6	43.9	69.6	2.6	20.7	17.0	
22.5	367	125.1	64.4	39.0	64.4	2.6	18.8	15.5	
27.5	373	112.4	59.2	34.2	59.2	2.6	16.9	14.0	
32.5	764	99.7	54.0	29.3	54.0	2.6	15.0	12.5	
37.5	814	87.0	48.8	24.4	48.8	2.6	13.1	11.0	
42.5	727	74.3	43.6	19.5	43.6	2.6	11.2	9.5	
47.5	668	61.6	38.4	14.6	38.4	2.6	9.2	8.0	
52.5	480	48.9	33.2	9.8	33.2	2.6	7.3	6.4	
57.5	748	36.2	28.0	4.9	28.0	2.7	5.4	4.9	
62.5	831	29.9	25.4	0.0	25.4		4.5	3.8	
67.5	902	29.9	25.4	0.0	25.4		4.5	3.8	
72.5	538	29.9	25.4	0.0	25.4		4.5	3.8	
77.5	603	29.9	25.4	0.0	25.4		4.5	3.8	
82.5	358	29.9	25.4	0.0	25.4		4.5	3.8	
87.5	134	29.9	25.4	0.0	25.4		4.5	3.8	
92.5	23	29.9	25.4	0.0	25.4		4.5	3.8	
97.5	1	29.9	25.4	0.0	25.4		4.5	3.8	
102.5	0	29.9	25.4	0.0	25.4		4.5	3.8	



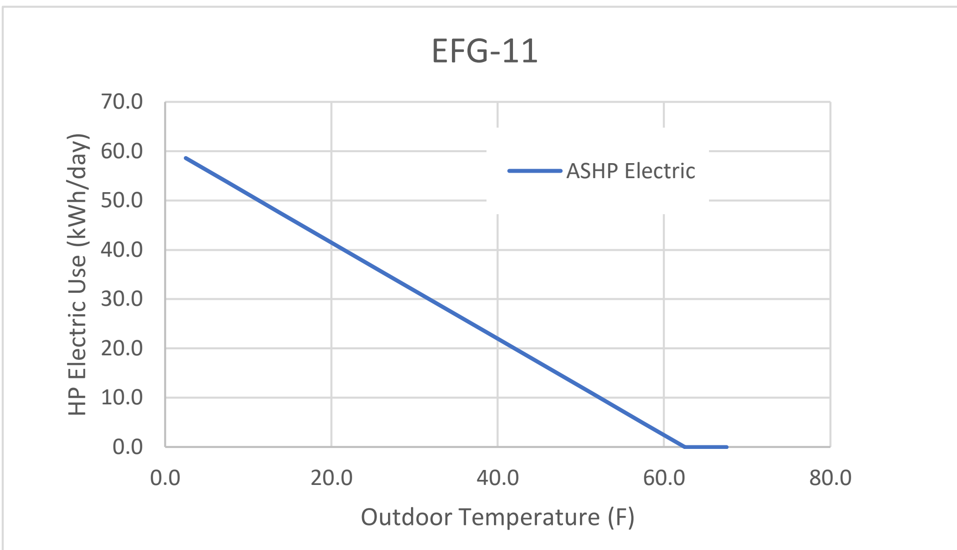


Figure 7. Trends of (Pre and Post Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. Since the base fuel is electric, the savings calculation only considers the pre- and post-retrofit electric use. The implied seasonal heating COP is 2.3, using both electric savings and heat pump energy use which is shown on the bottom of the table.

In this instance the implied COP is calculated from

$$COP = (kWh_{pre} - kWh_{post} + kWh_{hp})/kW_{hp} = (11835 - 4849 + 5095) / 5095$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Total Heat (kWh/yr)	11,835	4,849	6,986
		-	-
Total Heating Costs	$1,775.23	$727.35	$1,047.88
Implied Seasonal COP			2.4
HP Electric (kWh/yr)			5,095

Summary Statistics	
9.48	Fuel kWh per sq ft per yr
32.3	Htg MBtu per sq ft per yr
59%	Reduction in Fuel Use
5,052	Measured HP for Htg (kWh/yr)
99%	Measured as % of Typical yr

Table 4 indicates resistance heating use in the post-retrofit period and the savings in result of installing the heat pump. An implied COP including resistance heating is provided. The implied COP was slightly lower with this approach using the measured resistance heating power.

Table 4. Results of Bin Analysis Showing Seasonal Impact to Resistant Heating Use

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Resistance (kWh/yr)	11,835	-	11,835
ASHP (kWh/yr)		5,095	(5,095)
Total Heat (kWh/yr)	11,835	5,095	6,740
Total Heating Costs	$1,775	$764	$1,011
Implied ASHP COP			2.32
Overall COP Including Resistance			2.32

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 9 shows the temperature bins associated with cooling operation.

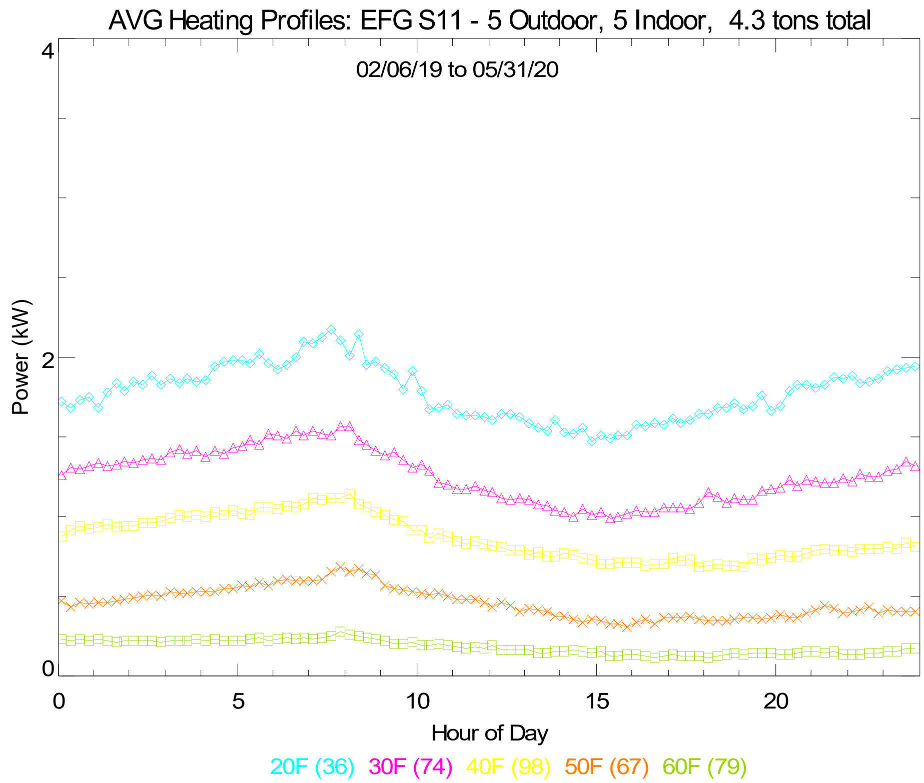


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

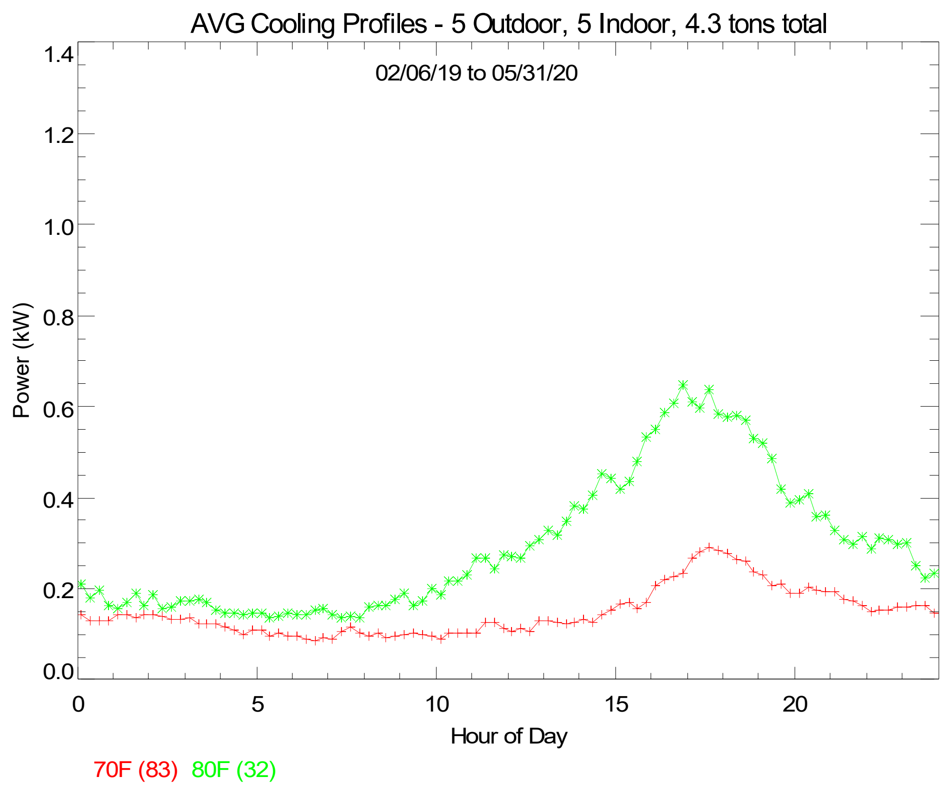


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10. The summertime temperatures are only partially controlled indicating very little cooling. The high RH is the summer reflects the lack of cooling and/or poor dehumidification.

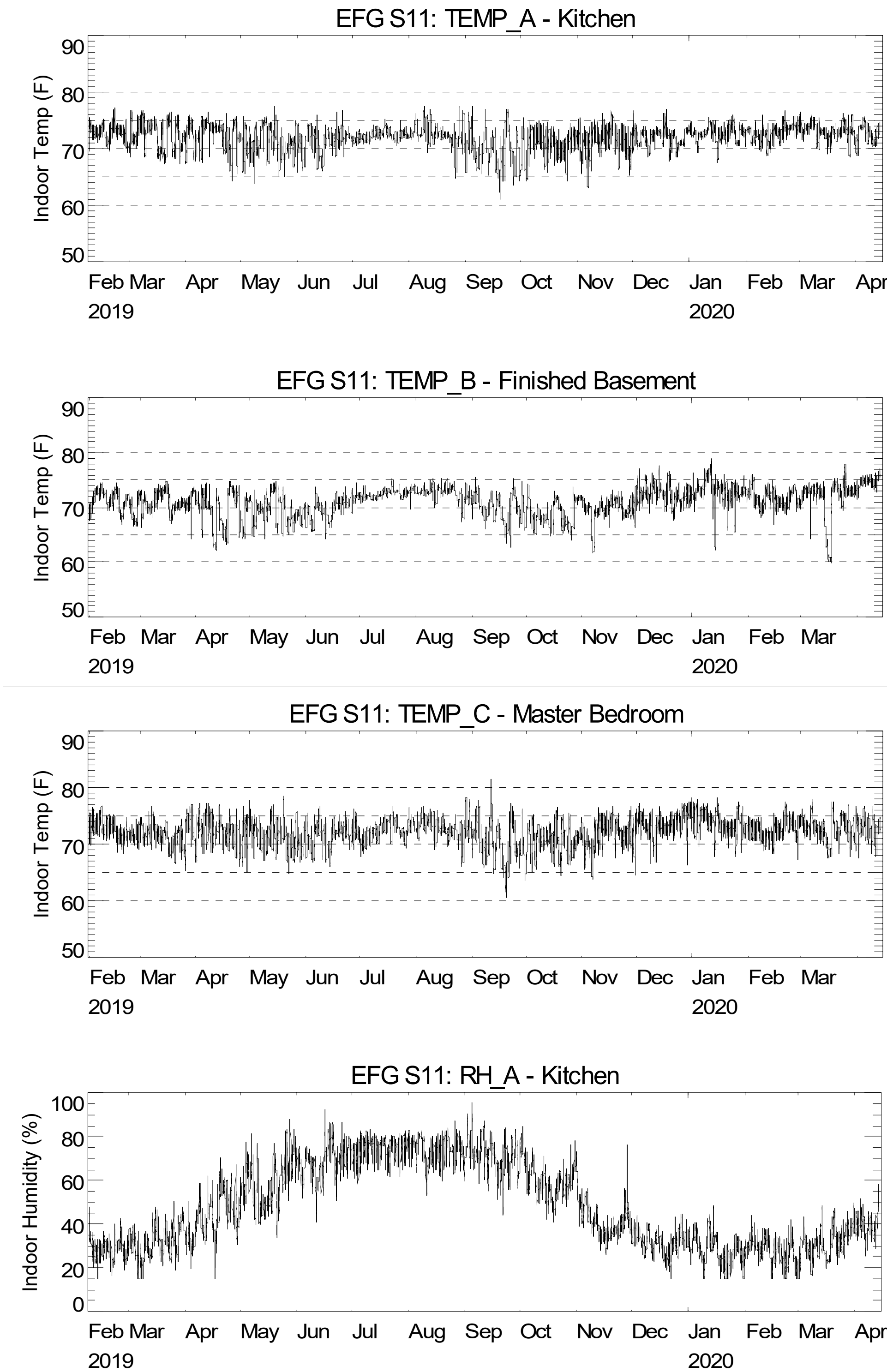


Figure 10. Space Temperatures and Humidity Levels

EFG S12 Savings Analysis

This 1500 sq ft house is in Shady, NY near Newburgh. The house was originally heated by an oil boiler and the occupants burned one cord of word per year. The boiler was not used after the ASHP was installed. ASHP was installed on in August 2018. Monitoring began in November 2018. This unit also operated in cooling.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. There is some evidence that heat pumps use setback in the heating mode. Figure 2 shows the power use for the house and heat pumps across the monitoring period.

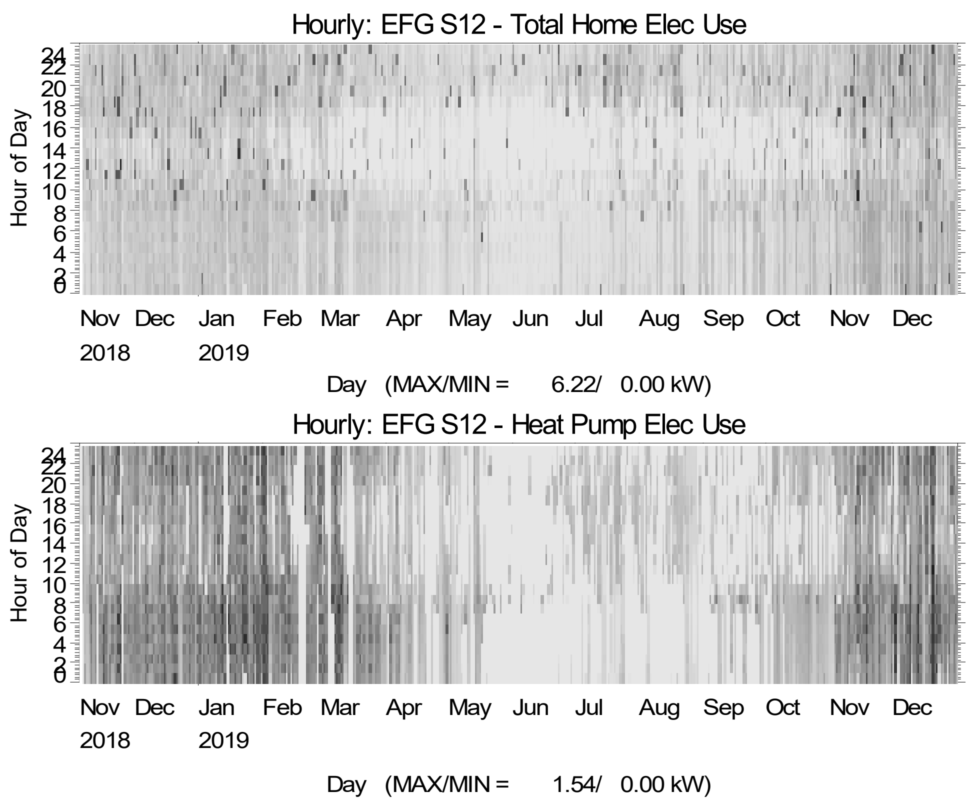
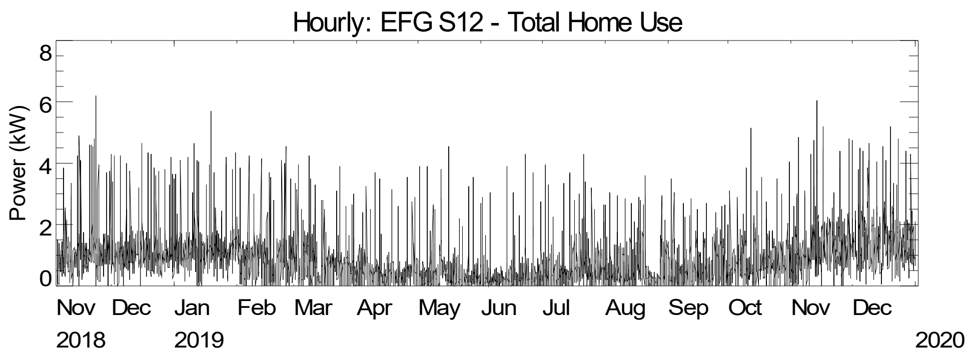


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.



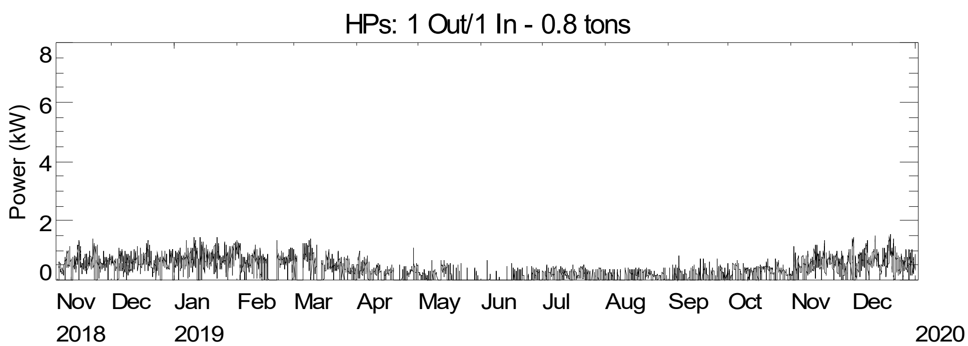


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)
Nov-18	27	656.7	331.2
Dec-18	31	818.8	444.0
Jan-19	31	878.8	513.2
Feb-19	28	590.2	349.1
Mar-19	31	515.5	322.6
Apr-19	30	317.2	168.3
May-19	31	282.6	78.8
Jun-19	30	214.1	28.5
Jul-19	31	411.1	102.8
Aug-19	31	387.2	75.5
Sep-19	30	432.4	73.8
Oct-19	31	555.2	186.9
Nov-19	30	895.4	371.5
Dec-19	31	1,054.1	461.0
Annual	365	6,533.8	2,732.0
Htg Season	243	5,089.0	2,451.4
Jun-Sep	122	1,444.8	280.6

Measured Trends

Daily heat pump power use is shown in Figure 3 as function of daily average outdoor temperature (from Newburgh). There was some scatter in the daily energy use data, possibly indicating variations in how the occupants used the ductless heat pump. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy use in the summer for cooling is also apparent at this site.

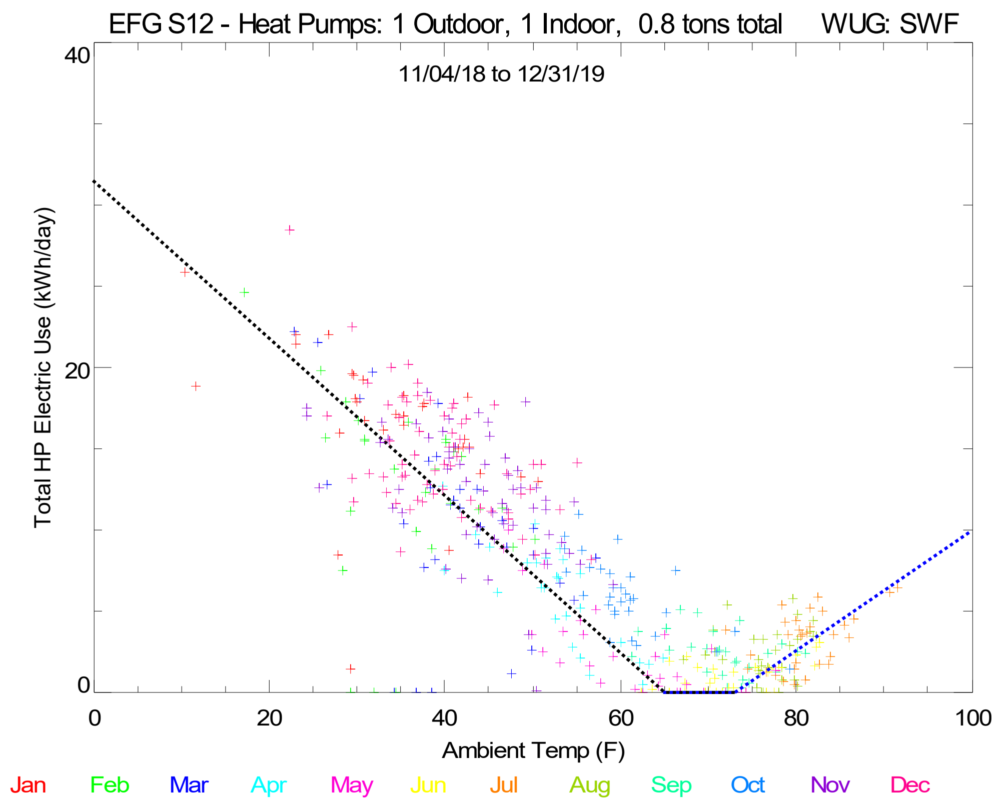


Figure 3. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced all of the fuel oil use for space heating by the boiler. Figure 4 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. Only a limited amount of post-retrofit data was available to confirm the fuel use trend in this period.

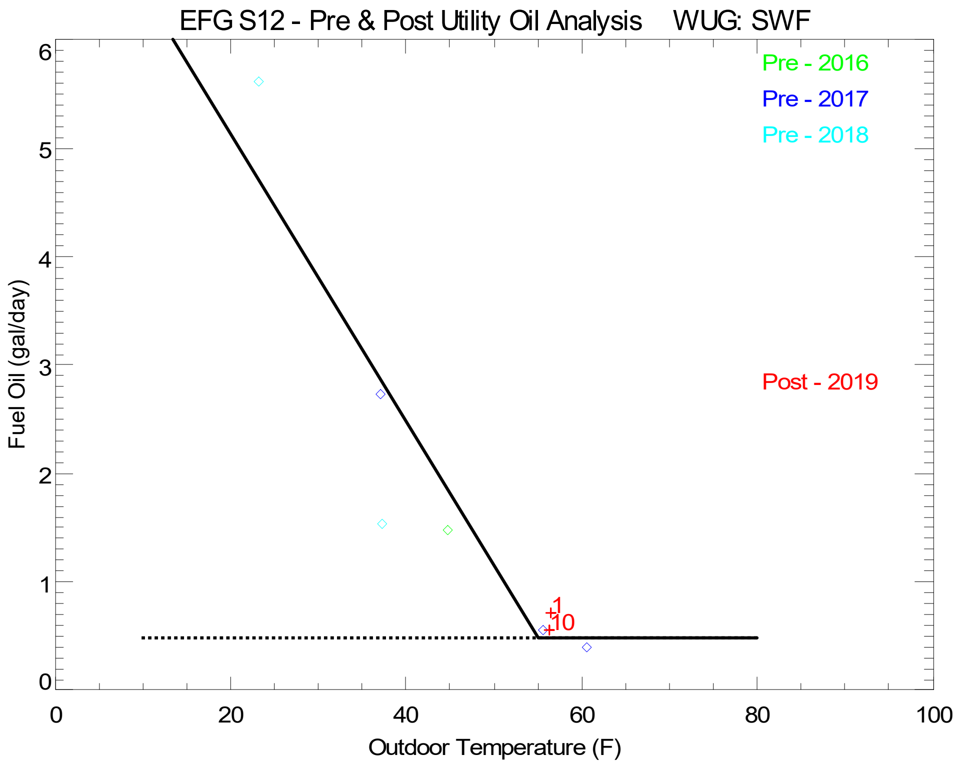


Figure 4. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

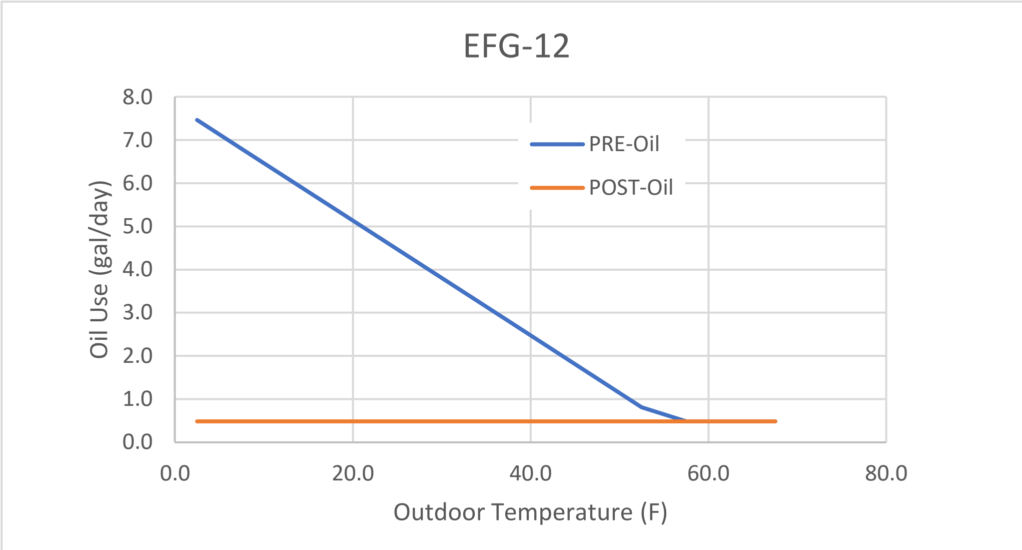
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data. Table 2 shows the details of bin analysis and Figure 5 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	EFG-12				WEATHER:	Newburgh		$ 0.150	per kWh
FUEL:	Oil							$ 2.686	per gal (oil)
Floor Area	1500				LOCATION:	Shady			

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	11.5	0.5	44.8	0.5	8.4	30.8	8.0	
-22.5	0	10.8	0.5	42.4	0.5	8.3	29.0	7.6	
-17.5	0	10.1	0.5	40.0	0.5	8.3	27.2	7.3	
-12.5	0	9.5	0.5	37.6	0.5	8.2	25.4	6.9	
-7.5	1	8.8	0.5	35.1	0.5	8.1	23.6	6.6	
-2.5	13	8.1	0.5	32.7	0.5	8.0	21.8	6.2	
2.5	36	7.5	0.5	30.3	0.5	7.9	20.0	5.8	
7.5	45	6.8	0.5	27.9	0.5	7.8	18.3	5.5	
12.5	113	6.1	0.5	25.4	0.5	7.6	16.5	5.1	
17.5	222	5.5	0.5	23.0	0.5	7.4	14.7	4.7	
22.5	367	4.8	0.5	20.6	0.5	7.2	12.9	4.4	
27.5	373	4.1	0.5	18.2	0.5	6.9	11.1	4.0	
32.5	764	3.5	0.5	15.8	0.5	6.5	9.3	3.7	
37.5	814	2.8	0.5	13.3	0.5	6.0	7.5	3.3	
42.5	727	2.1	0.5	10.9	0.5	5.2	5.8	2.9	
47.5	668	1.5	0.5	8.5	0.5	4.0	4.0	2.6	
52.5	480	0.8	0.5	6.1	0.5	1.9	2.2	2.2	
57.5	748	0.5	0.5	3.6	0.5	0.0	1.3	1.8	
62.5	831	0.5	0.5	1.2	0.5	0.0	1.3	1.5	
67.5	902	0.5	0.5	0.0	0.5	0.0	1.3	1.3	
72.5	538	0.5	0.5	0.0	0.5	0.0	1.3	1.3	
77.5	603	0.5	0.5	0.0	0.5	0.0	1.3	1.3	
82.5	358	0.5	0.5	0.0	0.5	0.0	1.3	1.3	
87.5	134	0.5	0.5	0.0	0.5	0.0	1.3	1.3	
92.5	23	0.5	0.5	0.0	0.5	0.0	1.3	1.3	
97.5	1	0.5	0.5	0.0	0.5	0.0	1.3	1.3	
102.5	0	0.5	0.5	0.0	0.5	0.0	1.3	1.3	



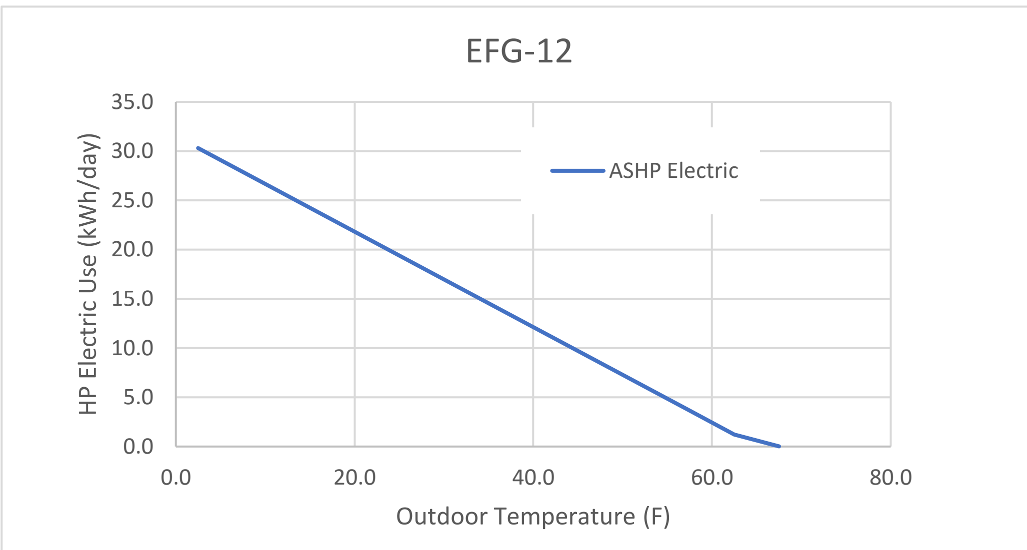


Figure 5. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis using Newburgh weather data. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP is very high (and the COPs at colder temperature bins in Table 2 are impossibly high). Changes in the site's wood use between the pre- and post-retrofit period seems to have confounded this analysis, despite the owner stating they would try to maintain consistent stove use. One possible explanation is that the site stopped using oil and at same time used more wood in the post retrofit period (i.e., wood use increased from 1 cord of wood per year to 2-3 cords per year in the post-retrofit period).

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	**PRE-Retrofit**	**POST-Retrofit**	**Savings**
Oil (gal/yr)	482	-	482
HP Electric (kWh/yr)		2,843	(2,843)
Total Heating Costs	$1,293	$426	$867
Implied Seasonal COP			5.8

Summary Statistics	
0.32	Fuel gal per sq ft per yr
37.5	Htg MBtu per sq ft per yr
100%	Reduction in Fuel Use
2,451	Measured HP for Htg (kWh/yr)
86%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 6 and Figure 7 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 7 shows the temperature bins associated with cooling operation.

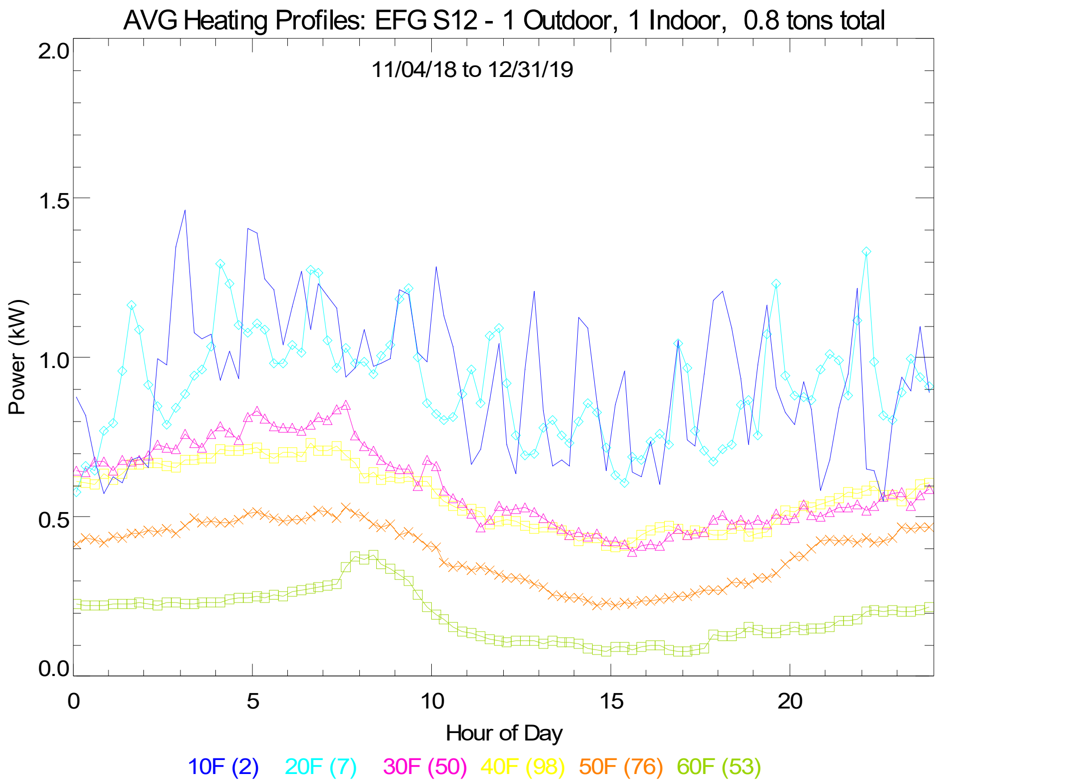


Figure 6. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

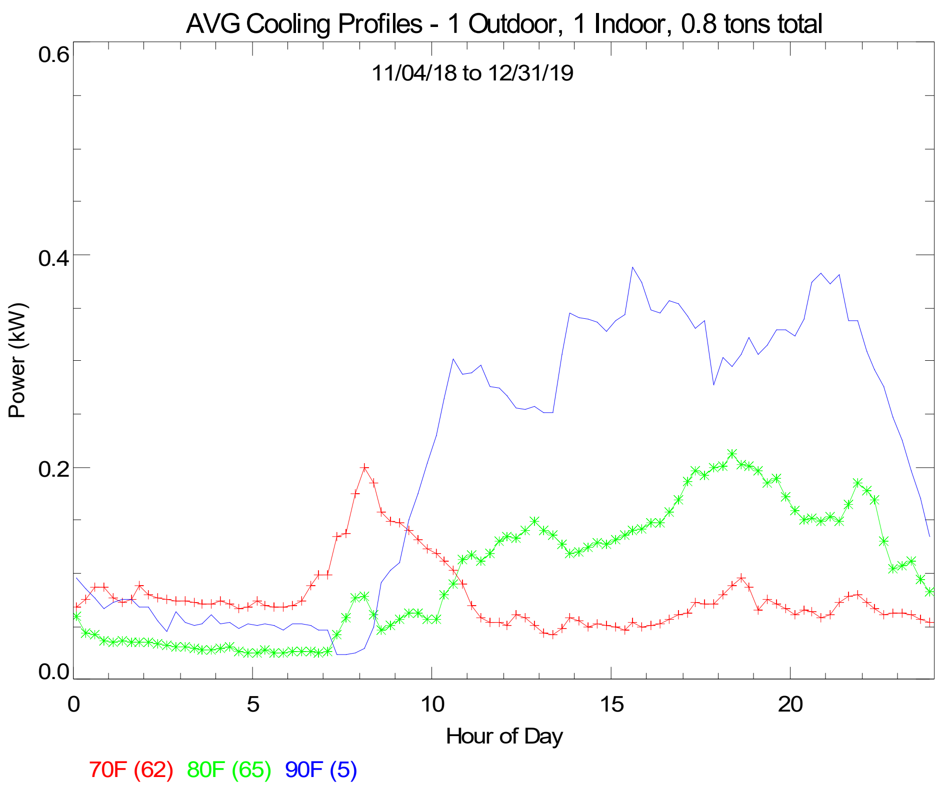


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 8.

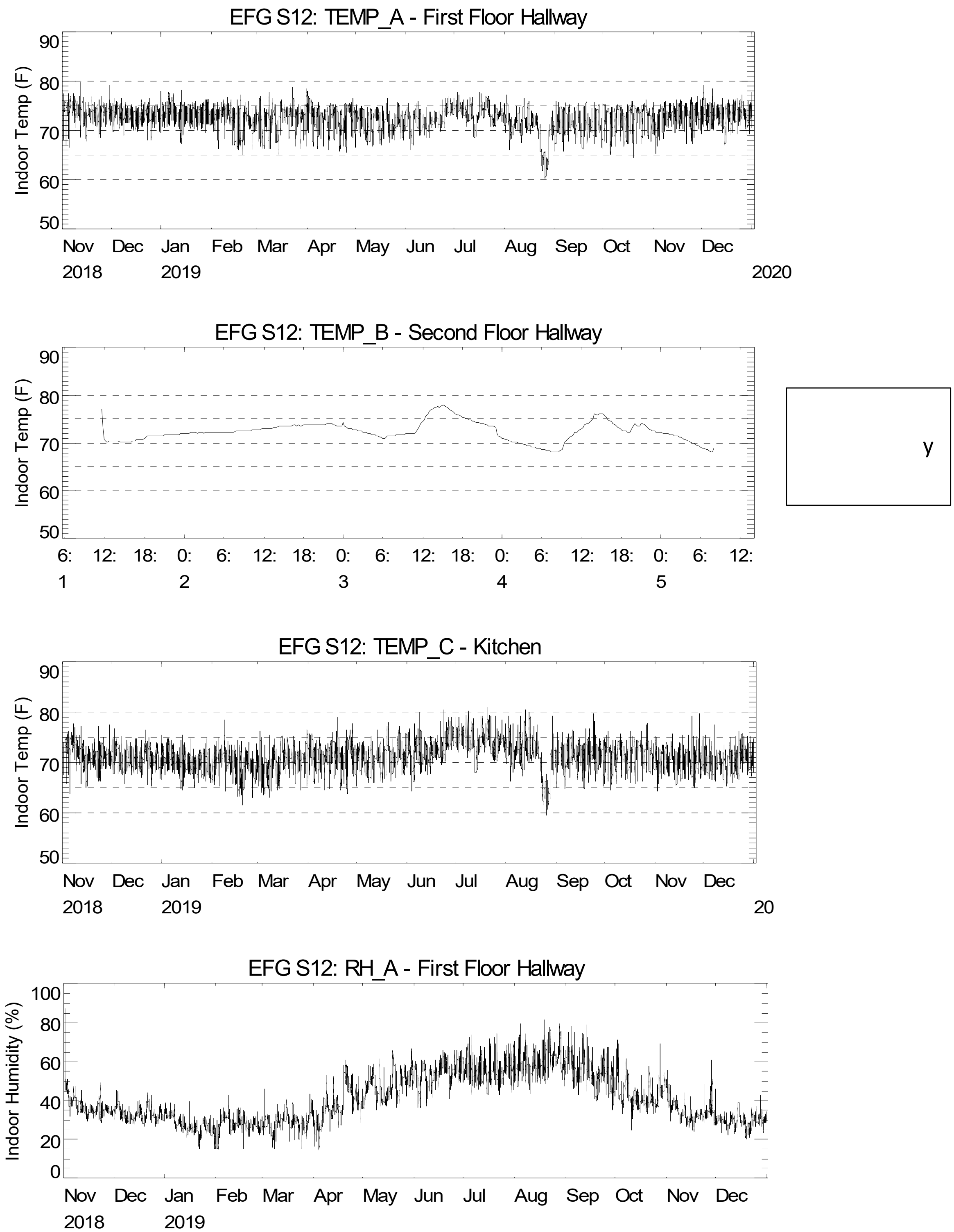


Figure 8. Space Temperatures and Humidity Levels

EFG S13 Savings Analysis

This 1,950 sq ft house is located in West Hurley, NY near Newburgh. The house was originally heated by an oil boiler with hydronic baseboard. The boiler was also used for supplemental heating and some hot water heating after the three ASHP units (3.5 tons total) were installed in September of 2018. Monitoring began in October 2018.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. Work conducted on the electrical panel resulted in monitoring being turned off as shown by the white areas in April and May 2019. Points of peak use in the morning and evening for total house are related to a level two electric car charging station.

Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use for the individual heat pumps.

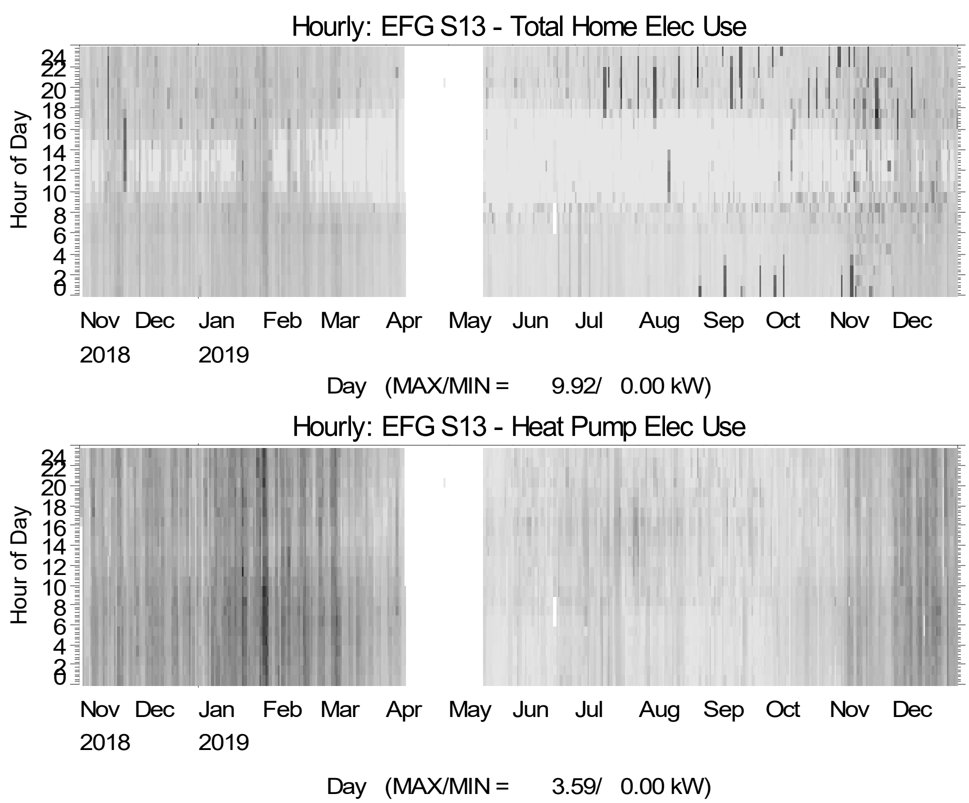


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

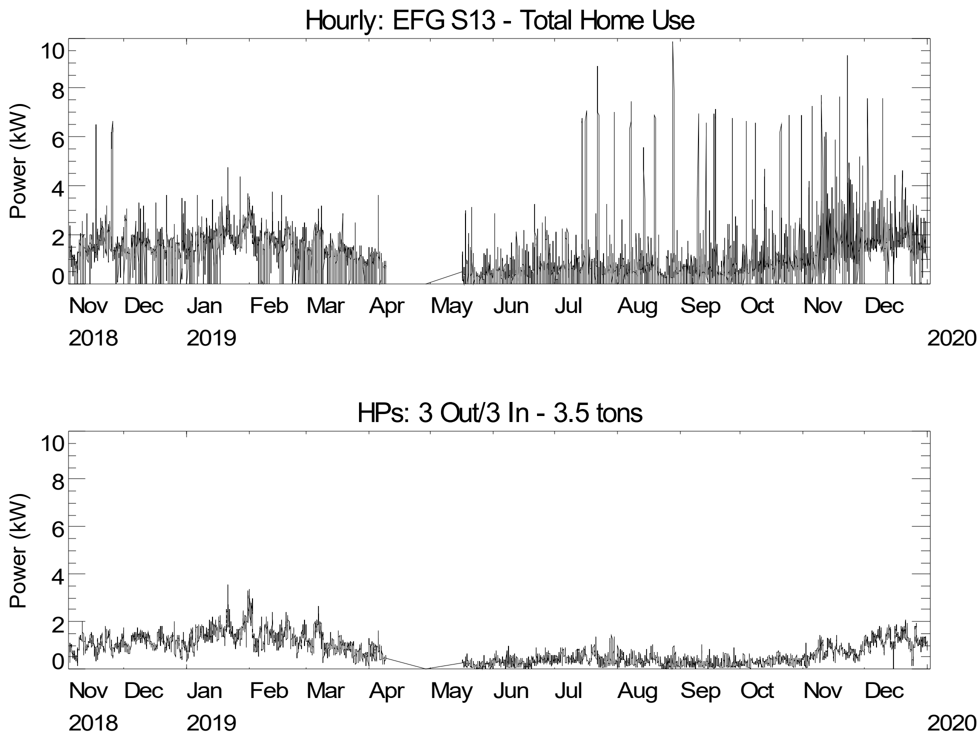


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

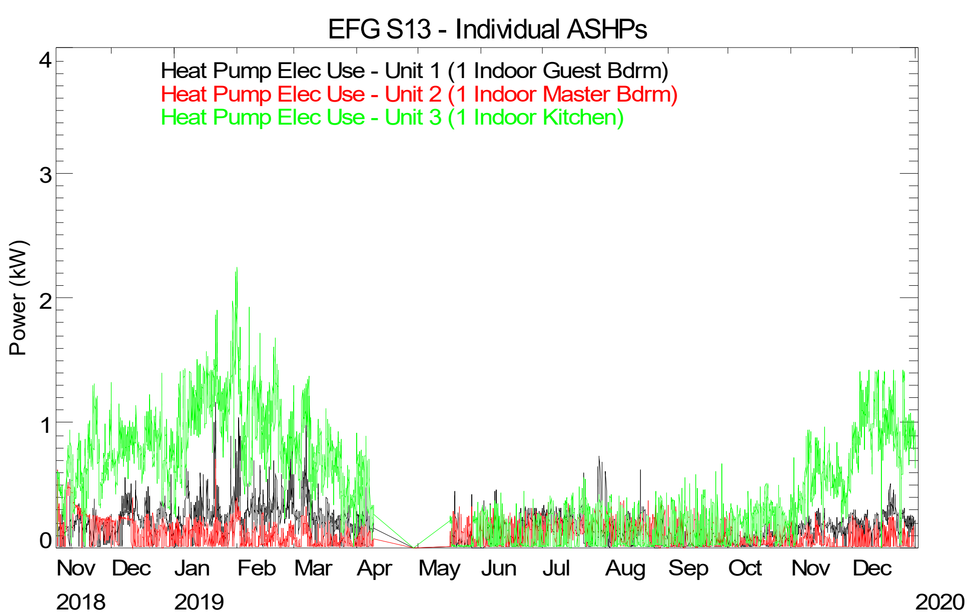


Figure 3. Power Use for Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)
Nov-18	27	1,006.7	642.0	-
Dec-18	31	1,100.6	866.5	-
Jan-19	31	1,351.8	1,139.3	-
Feb-19	28	1,090.1	962.0	-
Mar-19	31	757.1	733.8	-
Apr-19	12	149.0	142.5	-
May-19	31	295.2	69.3	-
Jun-19	30	348.6	224.7	-
Jul-19	31	530.5	354.4	-
Aug-19	31	467.1	244.8	-
Sep-19	30	491.6	178.2	-
Oct-19	31	672.7	248.5	-
Nov-19	30	1,162.8	523.7	-
Dec-19	31	1,337.4	926.1	-
Annual	347	8,653.9	5,747.3	-
Htg Season	225	6,816.1	4,745.2	-
Jun-Sep	122	1,837.8	1,002.1	-

Note: April 2019 had a loss of data.

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature (from Newburgh). There was some scatter in the daily energy use data, possibly indicating variations in how the occupants used the ductless heat pump. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy use fo cooling in the summer is also apparent at this site.

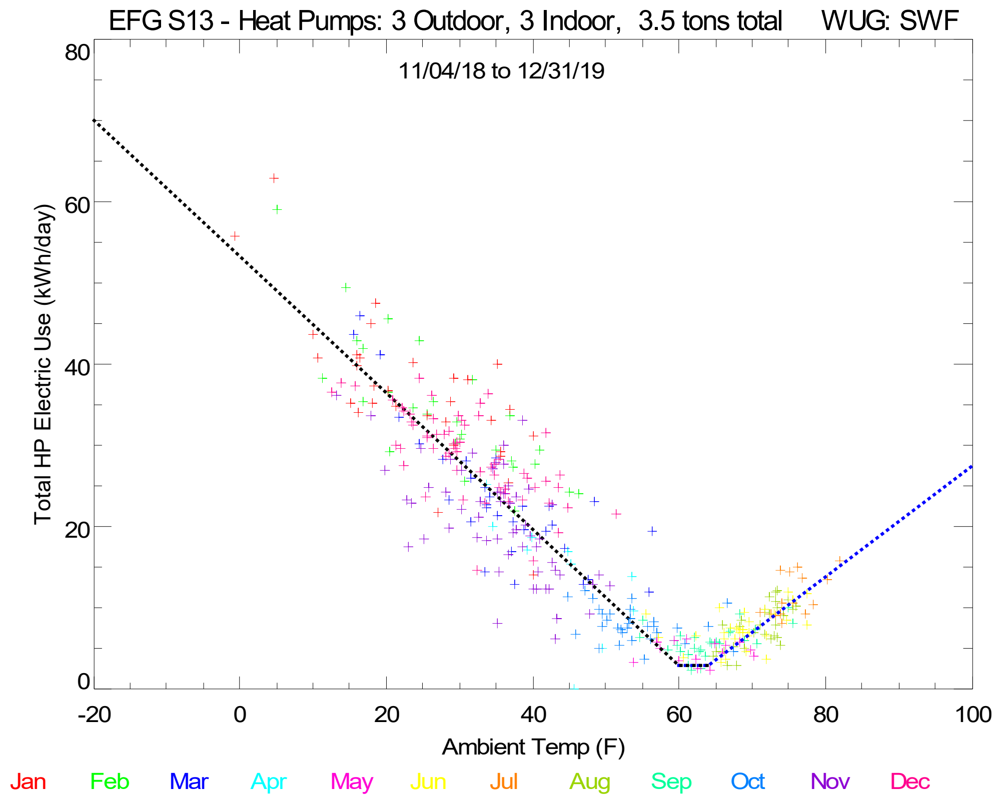


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced some of the fuel oil use by the boiler. Figure 5 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. A limited amount of post-retrofit data was available to confirm the fuel use trend in this period.

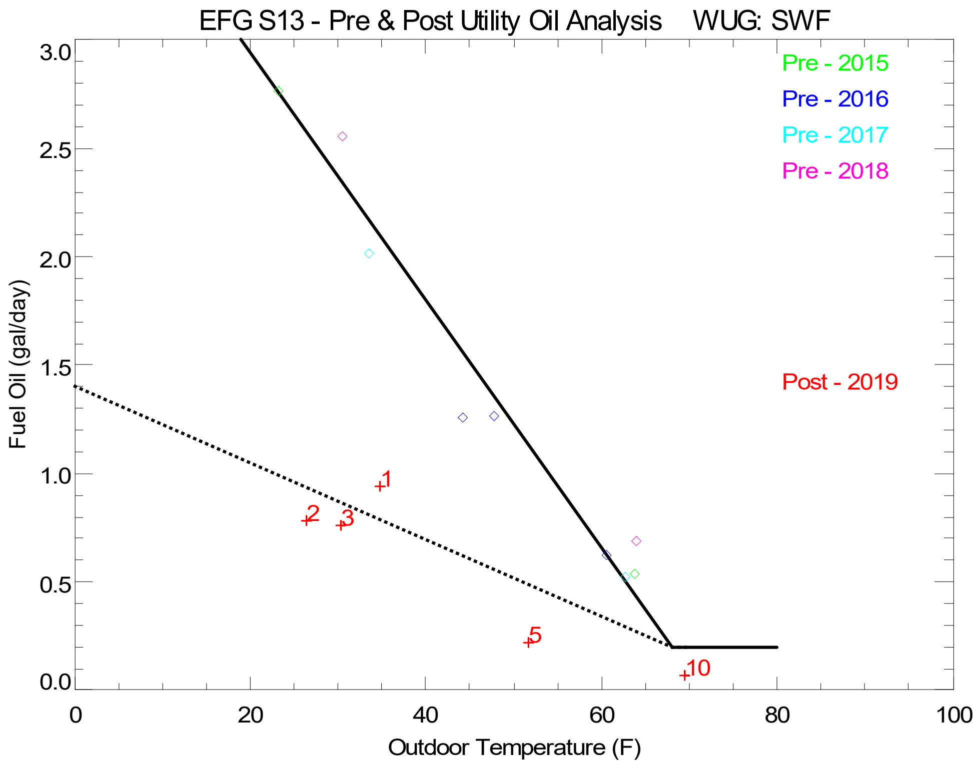


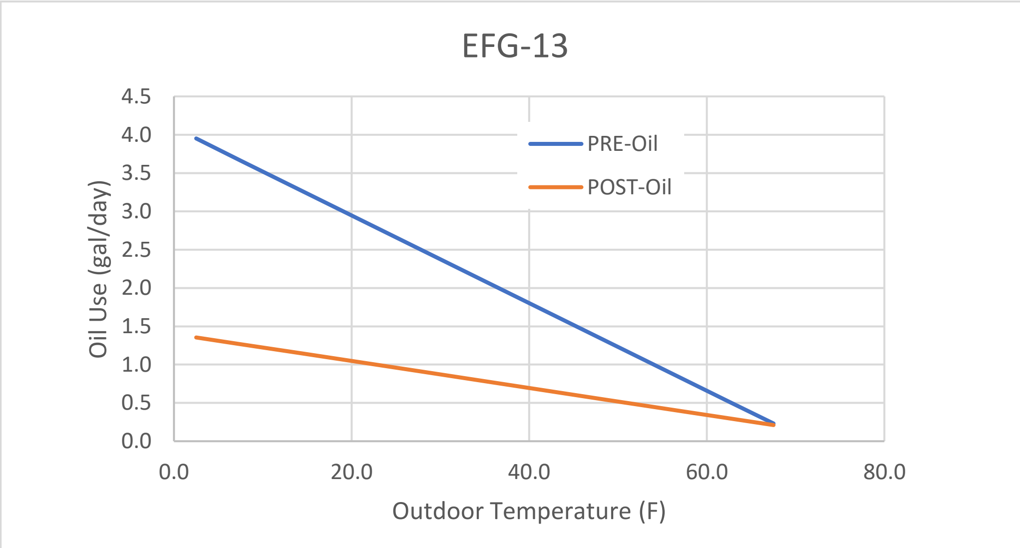
Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Newburgh. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	**EFG-13**				WEATHER:	**Newburgh**		$ 0.150	per kWh
FUEL:	**Oil**							$ 2.686	per gal (oil)
Floor Area	1950				LOCATION:	West Hurley			
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	5.7	1.9	76.3	1.9	1.7	15.2	16.5	
-22.5	0	5.4	1.8	72.1	1.8	1.7	14.5	15.6	
-17.5	0	5.1	1.7	67.9	1.7	1.7	13.7	14.8	
-12.5	0	4.8	1.6	63.7	1.6	1.7	12.9	13.9	
-7.5	1	4.5	1.5	59.5	1.5	1.7	12.1	13.0	
-2.5	13	4.2	1.4	55.3	1.4	1.7	11.4	12.2	
2.5	36	4.0	1.4	51.2	1.4	1.7	10.6	11.3	
7.5	45	3.7	1.3	47.0	1.3	1.7	9.8	10.5	
12.5	113	3.4	1.2	42.8	1.2	1.8	9.1	9.6	
17.5	222	3.1	1.1	38.6	1.1	1.8	8.3	8.7	
22.5	367	2.8	1.0	34.4	1.0	1.8	7.5	7.9	
27.5	373	2.5	0.9	30.2	0.9	1.8	6.8	7.0	
32.5	764	2.2	0.8	26.0	0.8	1.8	6.0	6.1	
37.5	814	1.9	0.7	21.8	0.7	1.9	5.2	5.3	
42.5	727	1.7	0.7	17.7	0.7	2.0	4.5	4.4	
47.5	668	1.4	0.6	13.5	0.6	2.1	3.7	3.5	
52.5	480	1.1	0.5	9.3	0.5	2.3	2.9	2.7	
57.5	748	0.8	0.4	5.1	0.4	2.8	2.2	1.8	
62.5	831	0.5	0.3	3.0	0.3	2.5	1.4	1.2	
67.5	902	0.2	0.2	3.0	0.2	0.2	0.6	1.0	
72.5	538	0.2	0.2	3.0	0.2	0.0	0.5	1.0	
77.5	603	0.2	0.2	3.0	0.2	0.0	0.5	1.0	
82.5	358	0.2	0.2	3.0	0.2	0.0	0.5	1.0	
87.5	134	0.2	0.2	3.0	0.2	0.0	0.5	1.0	
92.5	23	0.2	0.2	3.0	0.2	0.0	0.5	1.0	
97.5	1	0.2	0.2	3.0	0.2	0.0	0.5	1.0	
102.5	0	0.2	0.2	3.0	0.2	0.0	0.5	1.0	



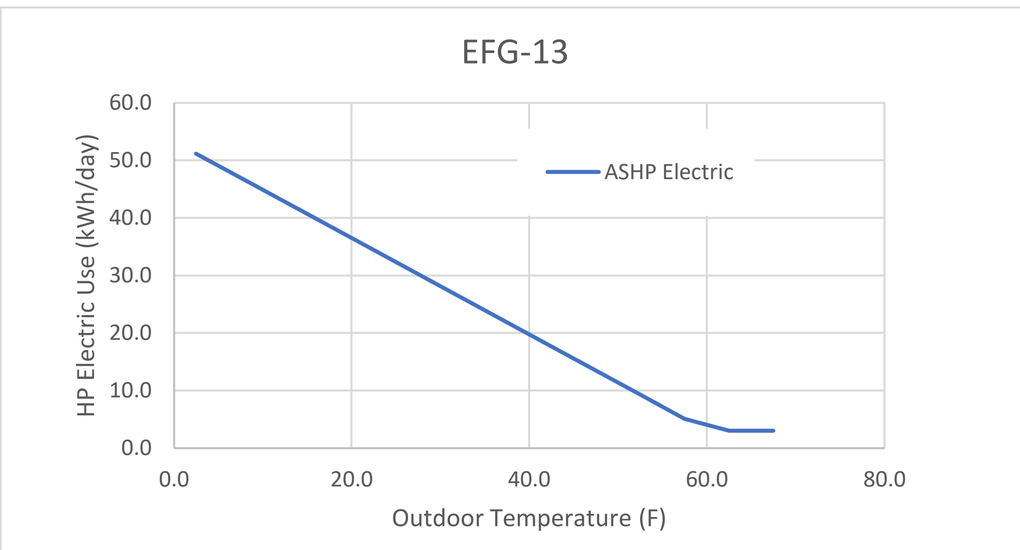


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 1.9 in this case.

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	**PRE-Retrofit**	**POST-Retrofit**	**Savings**
Oil (gal/yr)	381	118	264
HP Electric (kWh/yr)		4,791	(4,791)
Total Heating Costs	$1,024	$1,034	-$10
Implied Seasonal COP			1.9

Summary Statistics	
0.20	Fuel gal per sq ft per yr
22.8	Htg MBtu per sq ft per yr
69%	Reduction in Fuel Use
4,745	Measured HP for Htg (kWh/yr)
99%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

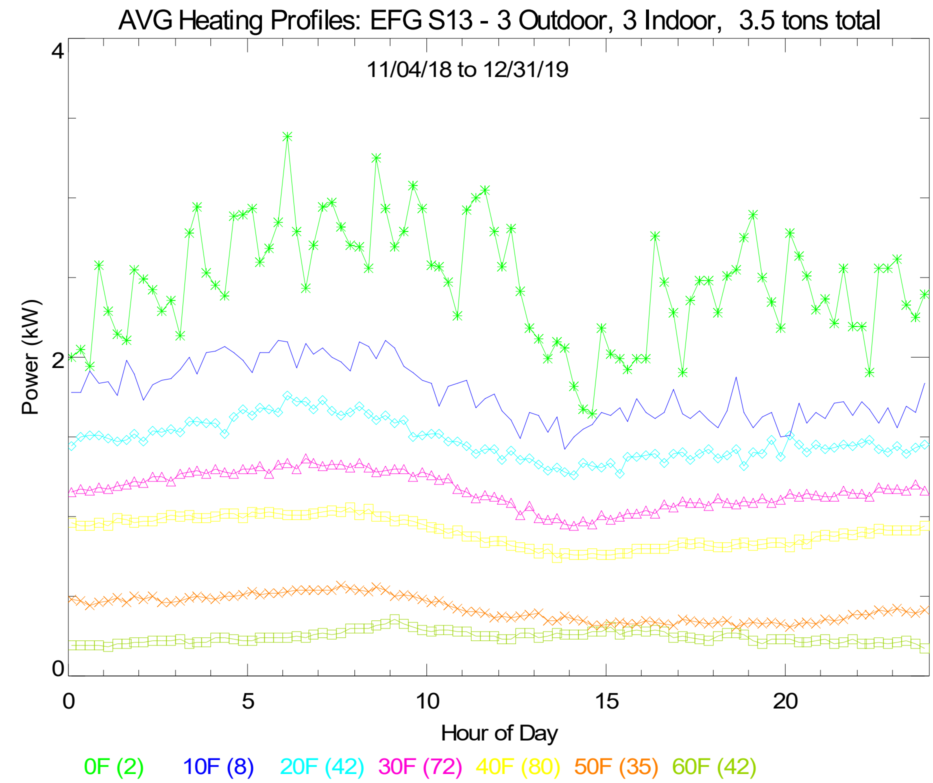


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

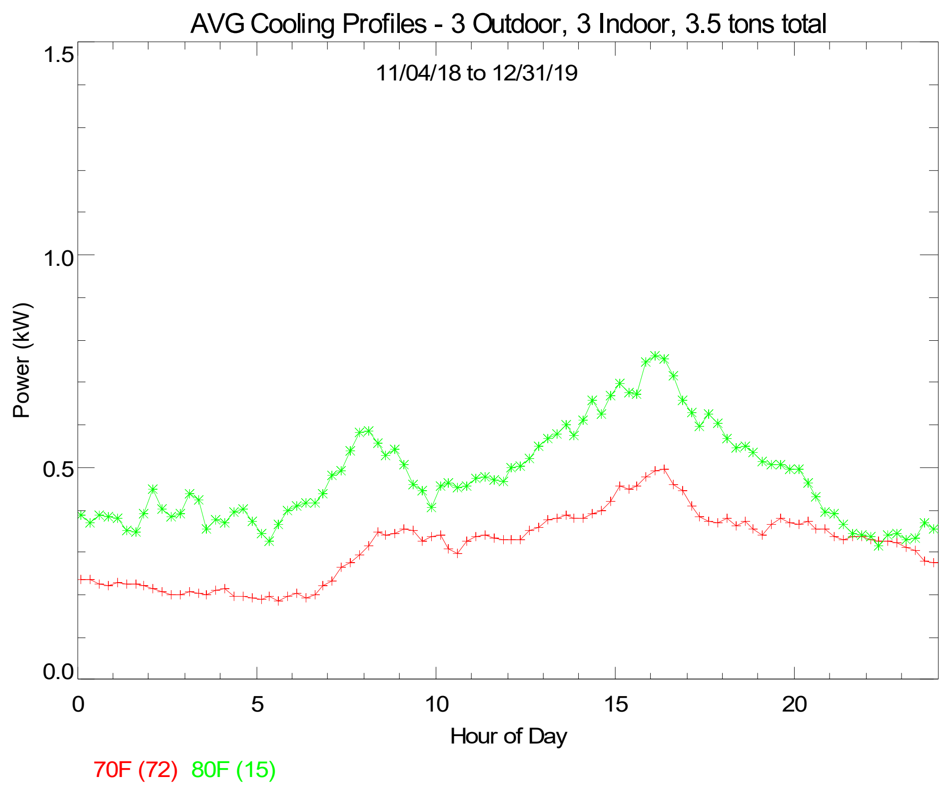


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

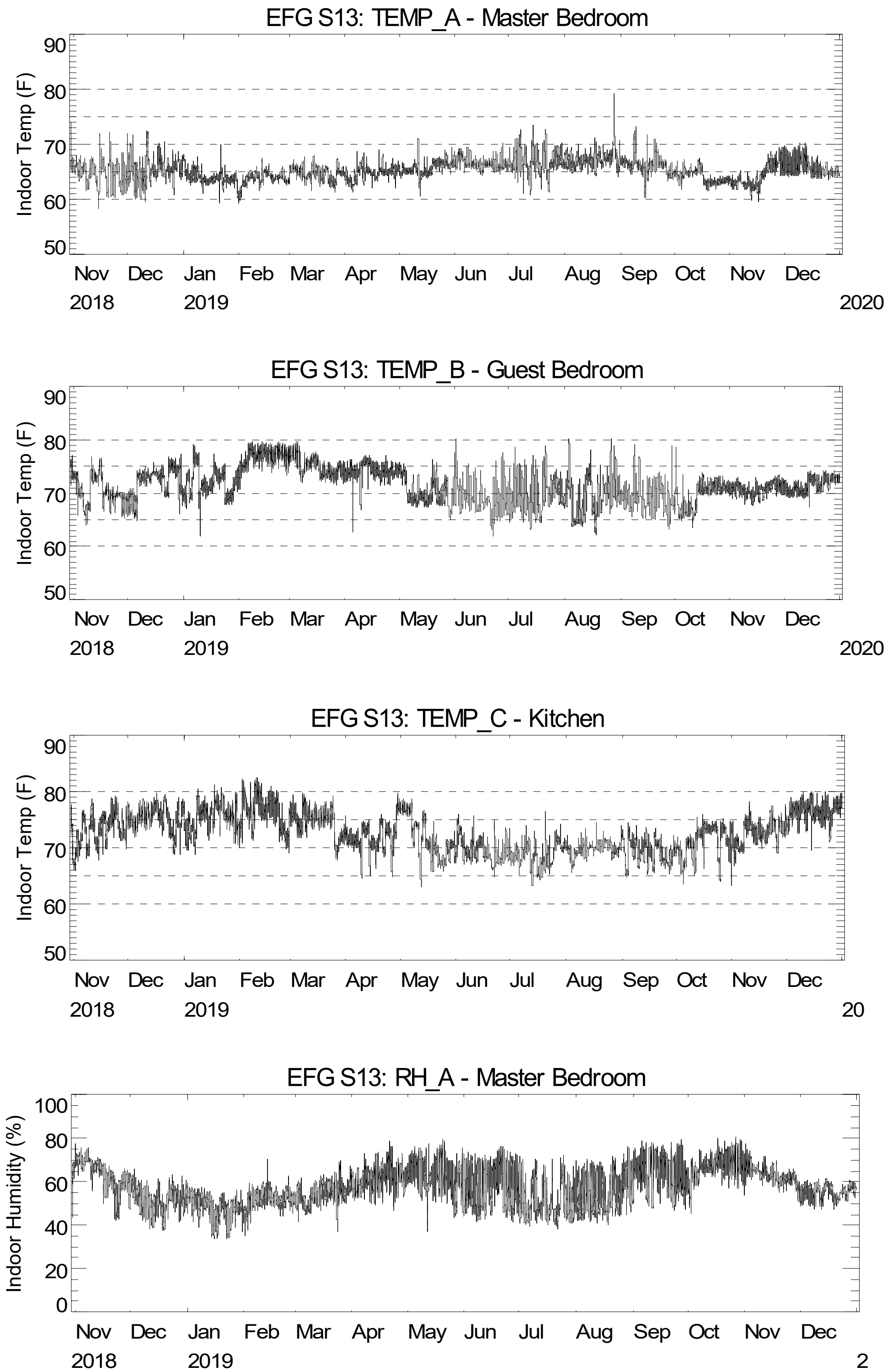


Figure 9. Space Temperatures and Humidity Levels

EFG S14 Savings Analysis

This 2,600 sq ft house is in Esopus, NY near Newburgh. The house was originally heated by a propane boiler with hydronic air handler units. The boiler also provided water heating. The boiler was left in-place for supplemental heating (though the post-retrofit propane logs indicated very little use after HP installation). A heat pump hot water heater was installed at the time of the heat pump installation. The two ducted ASHP systems were installed in September of 2018. Monitoring began in February 2019. This unit also operated in cooling. The AHUs also have electric resistance heater elements, but very little operation was observed.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. In this case the AHU power was also included in the HP power. Figure 2 shows the power use for the house and heat pumps across the monitoring period (some data was lost in July and August 2019).

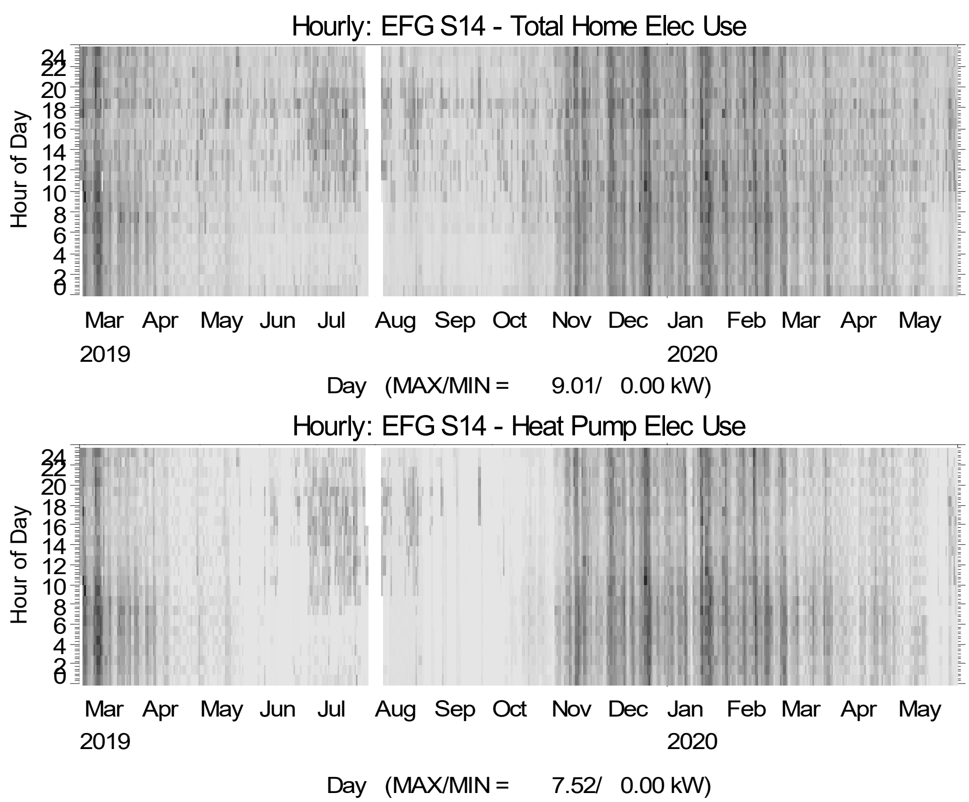


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

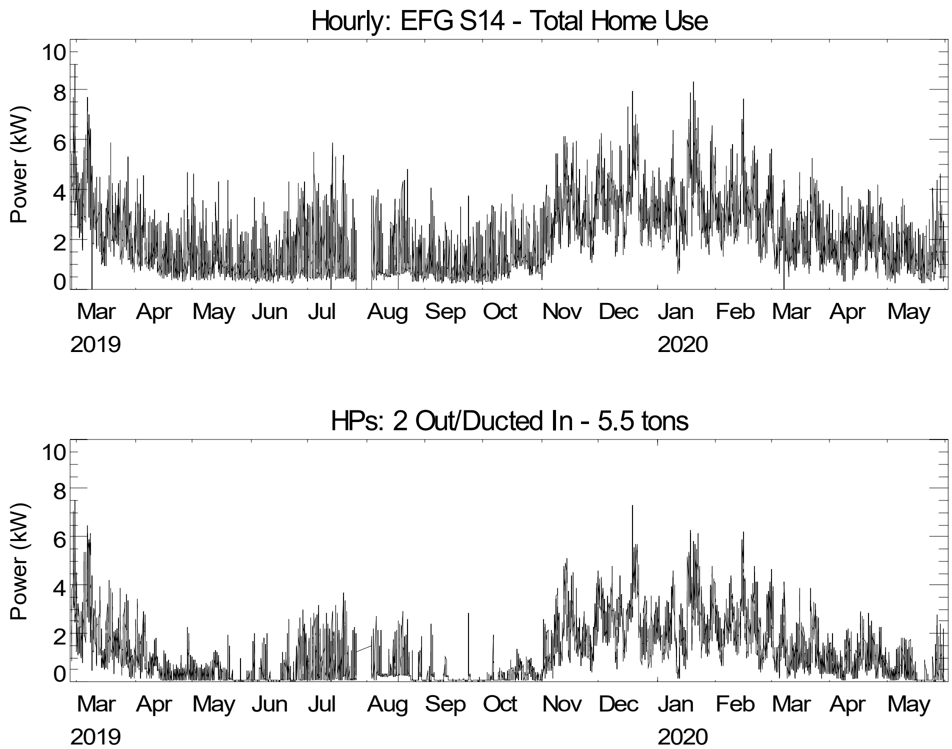


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

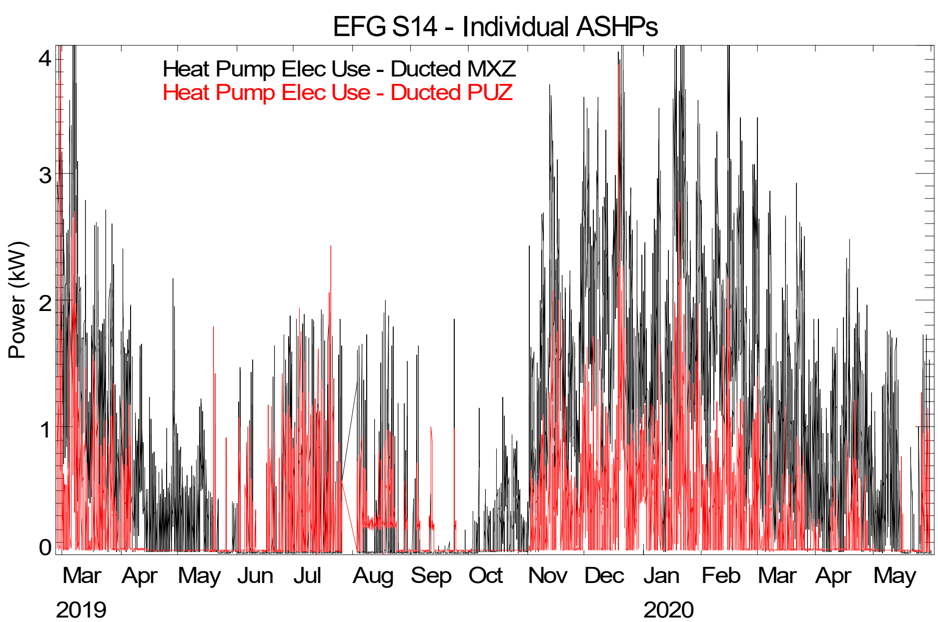


Figure 3. Powe Use of Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)
Feb-19	3	291.4	223.5
Mar-19	31	2,153.0	1,462.2
Apr-19	30	1,093.0	484.3
May-19	31	886.3	200.0
Jun-19	30	849.9	248.1
Jul-19	26	1,006.1	530.1
Aug-19	29	835.9	337.3
Sep-19	30	636.8	102.8
Oct-19	31	921.5	200.0
Nov-19	30	2,095.6	1,318.4
Dec-19	31	2,740.2	1,977.1
Jan-20	31	2,614.4	1,886.3
Feb-20	29	2,280.4	1,623.0
Mar-20	31	1,625.1	990.8
Apr-20	30	1,348.7	679.6
Annual	359	17,585.2	9,898.2
Htg Season	244	14,256.5	8,679.9
Jun-Sep	115	3,328.7	1,218.3

Note: Some data was lost in July and August 2019.

<u>Measured Trends</u>

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature (from Stewart Airport). There was moderate scatter in the daily energy use data, implying the occupants used the heat pumps in a consistent manner. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy use for cooling in the summer is also apparent at this site. The knee (or increase) in the heating trend near 25°F was due to resistance element operation in the AHUs.

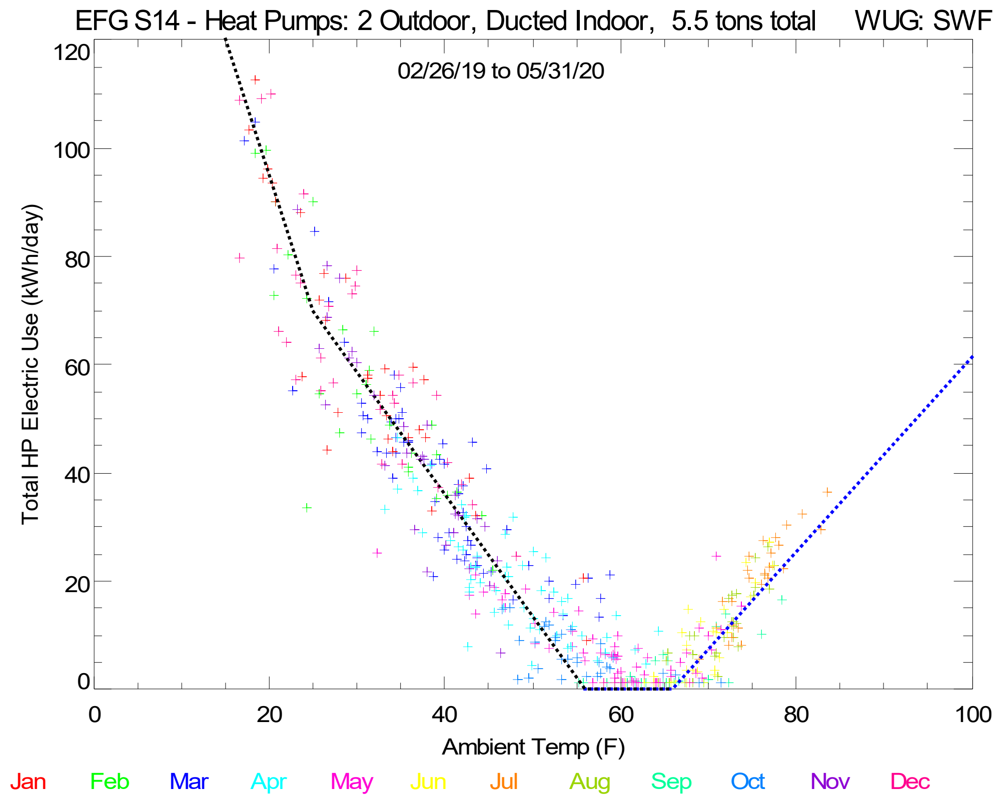


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced all of the propane use by the boiler. Figure 5 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. A limited amount of post-retrofit data was available to confirm the fuel use trend in this period.

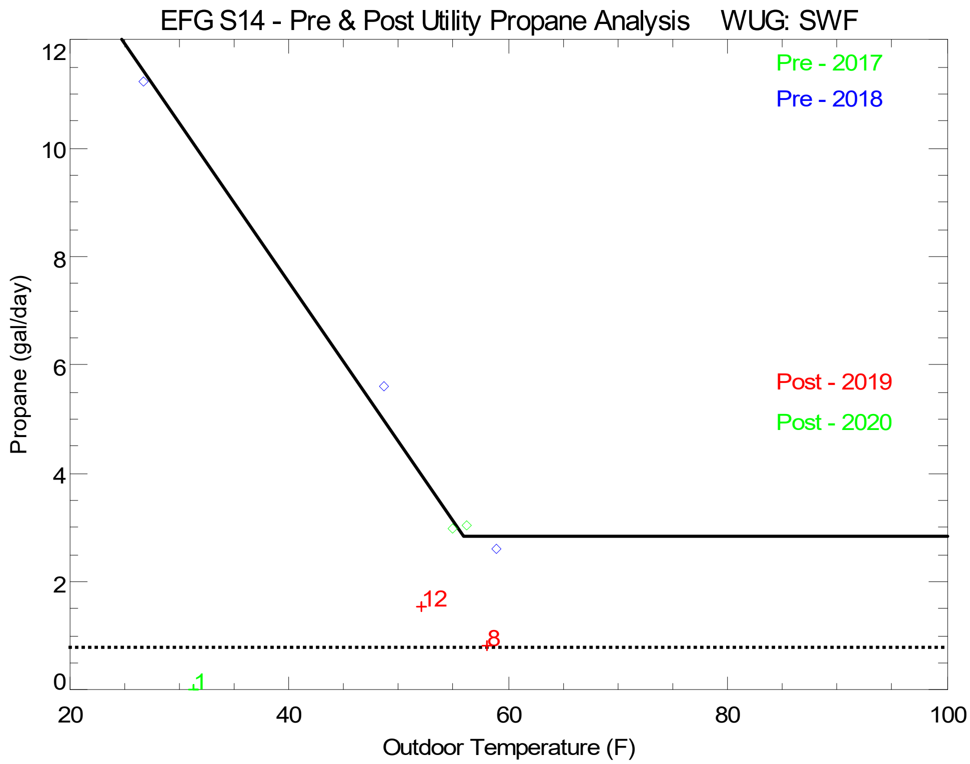


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

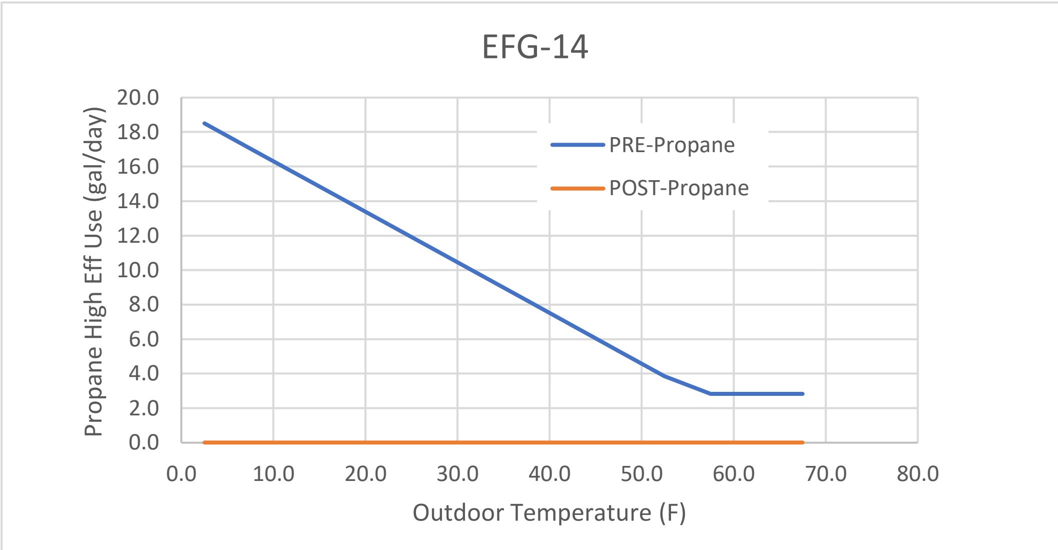
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	EFG-14	WEATHER:	Newburgh	$ 0.150 per kWh
FUEL:	Propane High Eff			$ 2.440 per gal (propane)
Floor Area	2600	LOCATION:	Esopus	

Temp Bin	Hours	FUEL PRE-Propane (gal/day)	FUEL POST-Propane (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Propane (gal/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Propane adjustment factor
-27.5	0	27.3	0.8	332.5	2.8	1.7	66.6	56.7	0.1
-22.5	0	25.8	0.8	307.5	2.8	1.8	63.0	53.0	0.1
-17.5	0	24.4	0.8	282.5	2.8	1.8	59.4	49.2	0.1
-12.5	0	22.9	0.8	257.5	2.8	1.9	55.9	45.5	0.1
-7.5	1	21.4	0.8	232.5	2.8	1.9	52.3	41.7	0.1
-2.5	13	20.0	0.8	207.5	2.8	2.0	48.7	38.0	0.1
2.5	36	18.5	0.8	182.5	2.8	2.0	45.1	34.2	0.2
7.5	45	17.0	0.8	157.5	2.8	2.1	41.6	30.5	0.2
12.5	113	15.6	0.8	132.5	2.8	2.3	38.0	26.7	0.2
17.5	222	14.1	0.8	107.5	2.8	2.5	34.4	23.0	0.2
22.5	367	12.6	0.8	82.5	2.8	2.8	30.9	19.2	0.2
27.5	373	11.2	0.8	64.4	2.8	3.1	27.3	16.5	0.3
32.5	764	9.7	0.8	53.1	2.8	3.1	23.7	14.8	0.3
37.5	814	8.2	0.8	41.8	2.8	3.1	20.1	13.1	0.3
42.5	727	6.8	0.8	30.5	2.8	3.1	16.6	11.4	0.4
47.5	668	5.3	0.8	19.2	2.8	3.1	13.0	9.7	0.5
52.5	480	3.9	0.8	7.9	2.8	3.2	9.4	8.0	0.7
57.5	748	2.8	0.8	0.0	2.8		6.9	6.8	1.0
62.5	831	2.8	0.8	0.0	2.8		6.9	6.8	1.0
67.5	902	2.8	0.8	0.0	2.8		6.9	6.8	1.0
72.5	538	2.8	0.8	0.0	2.8		6.9	6.8	1.0
77.5	603	2.8	0.8	0.0	2.8		6.9	6.8	1.0
82.5	358	2.8	0.8	0.0	2.8		6.9	6.8	1.0
87.5	134	2.8	0.8	0.0	2.8		6.9	6.8	1.0
92.5	23	2.8	0.8	0.0	2.8		6.9	6.8	1.0
97.5	1	2.8	0.8	0.0	2.8		6.9	6.8	1.0
102.5	0	2.8	0.8	0.0	2.8		6.9	6.8	1.0



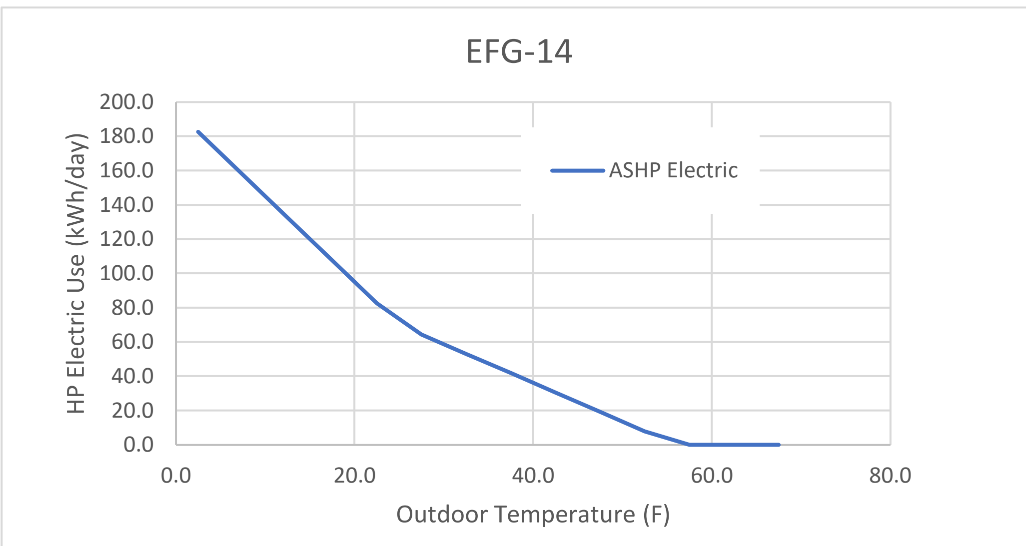


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis using typical year data for Newburgh. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 2.9 in this case. Since the unit power included some electric resistance, this number may be conservative.

In this instance the implied COP is calculated from

$$COP = (Fuel_{pre} - Fuel_{post})*eff/(3.412xkWh_{hp}) = (1117-0)*92*0.88 / (3.412*9293)$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Propane High Eff (gal/yr)	1,117	-	1,117
HP Electric (kWh/yr)		9,293	(9,293)
Total Heating Costs	$2,725	$1,394	$1,331
Implied Seasonal COP			2.9

Summary Statistics	
0.43	Fuel gal per sq ft per yr
34.8	Htg MBtu per sq ft per yr
100%	Reduction in Fuel Use
8,680	Measured HP for Htg (kWh/yr)
93%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

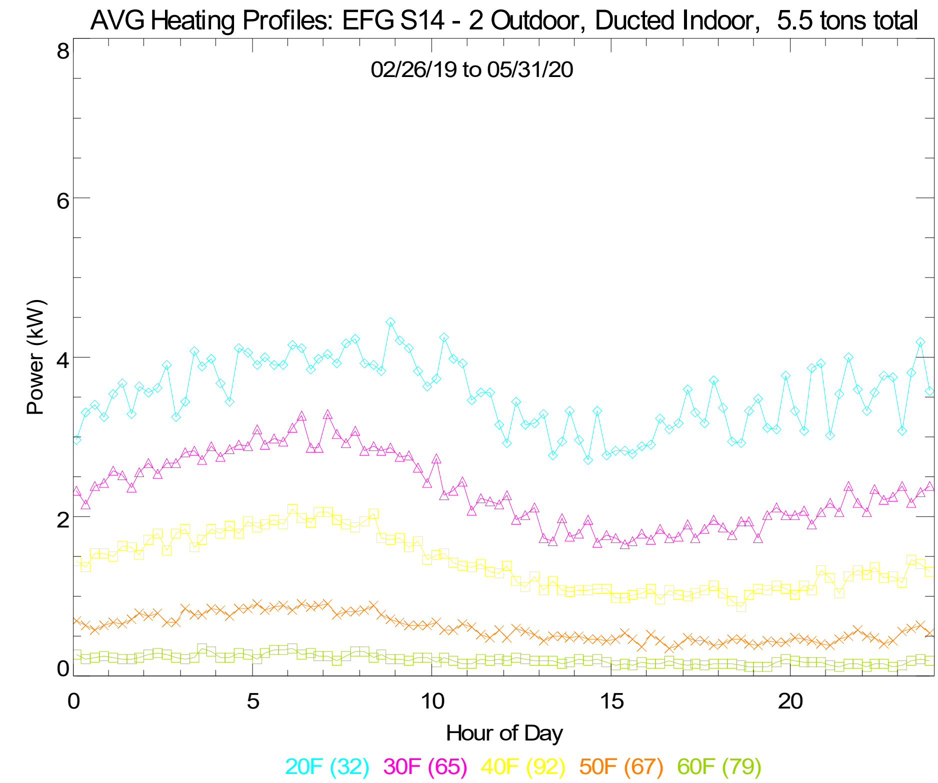


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

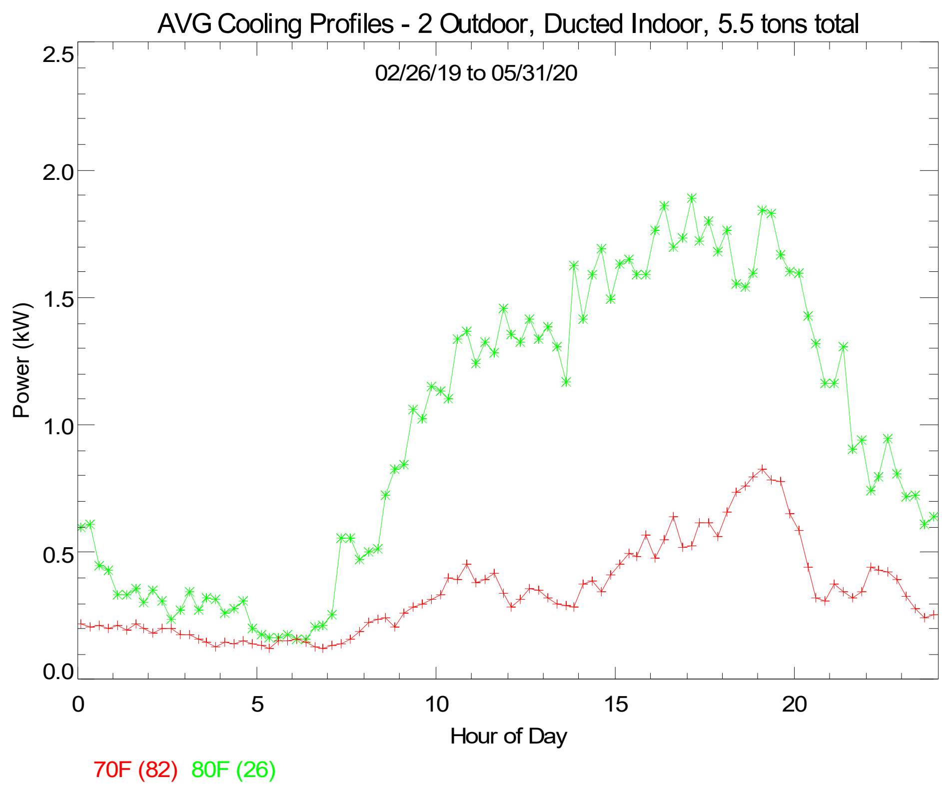


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

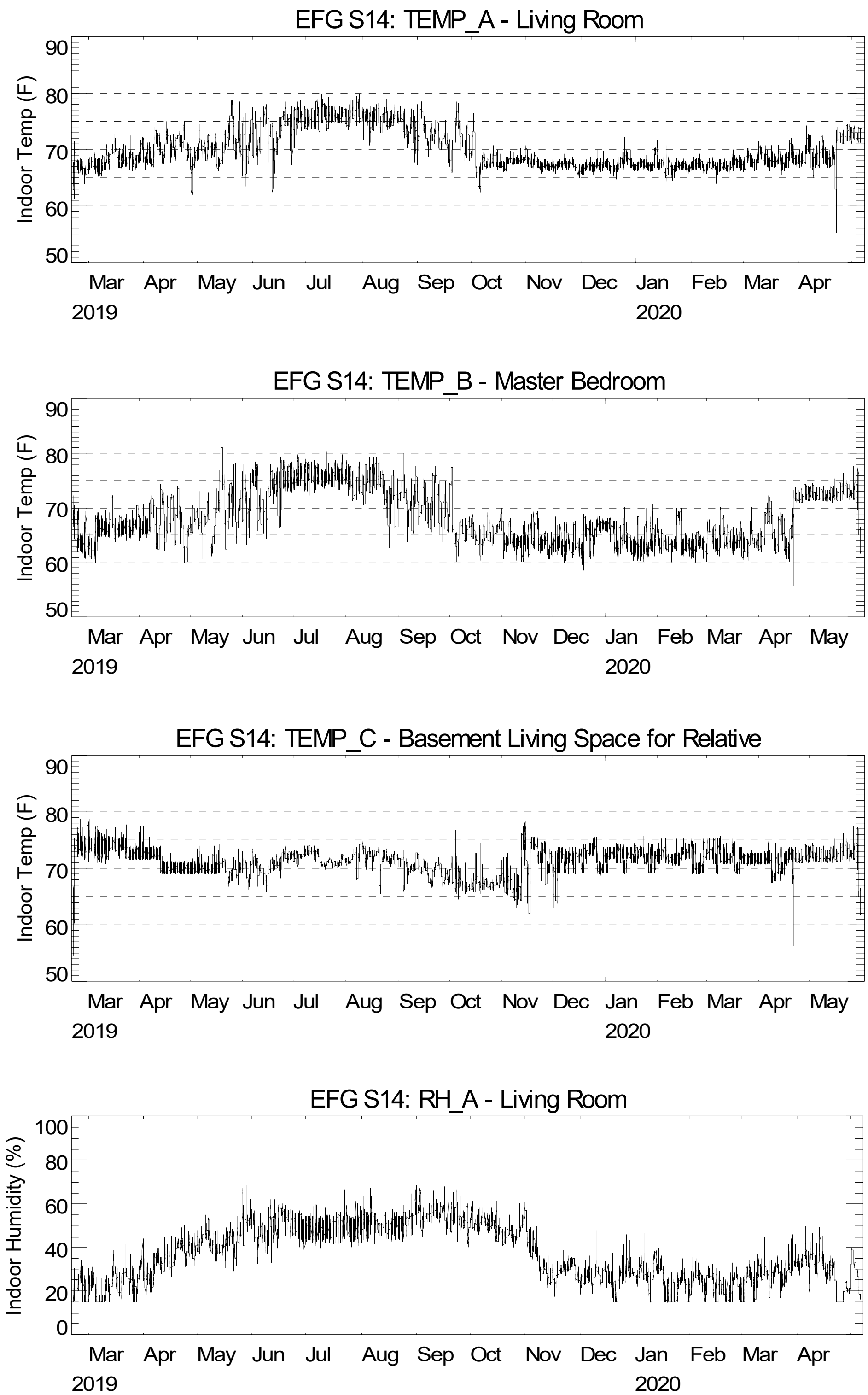


Figure 9. Space Temperatures and Humidity Levels

EFG S15 Savings Analysis

This 6,500 sq ft house is in New Paltz, NY near Newburgh. A total of eight ASHPs are installed in the house, with the first units installed in 2013 and the last units installed in 2017 as part of HVHPP. Monitoring began in March 2019. The ASHP units operated frequently to provide cooling in the summer.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use of the individual heat pumps.

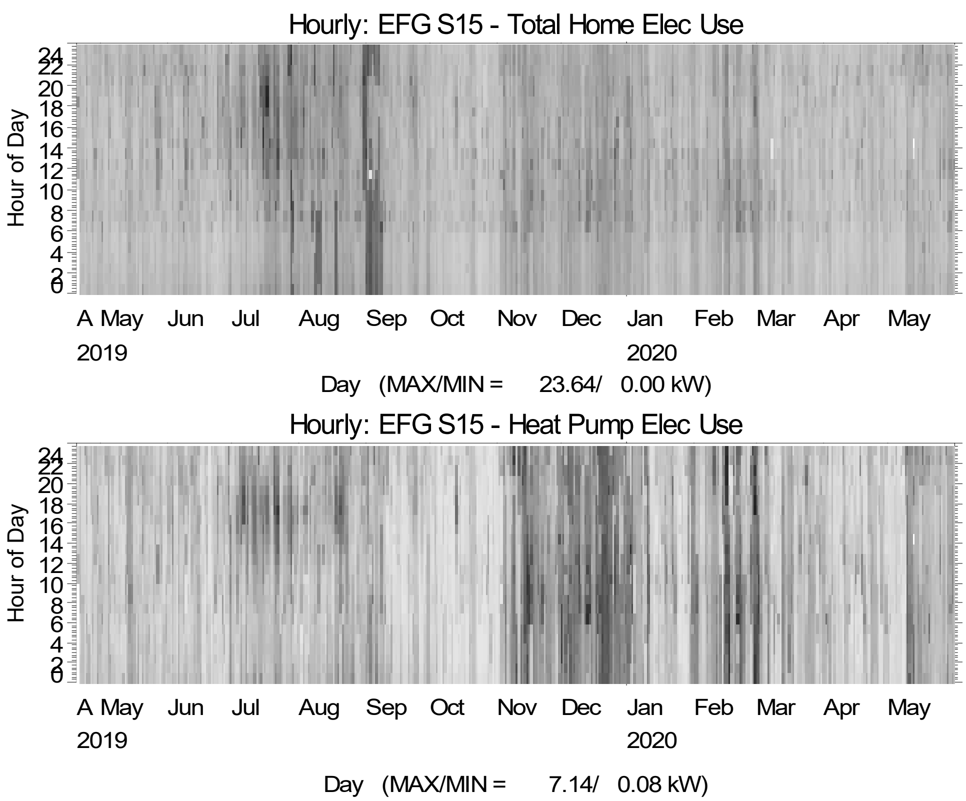


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

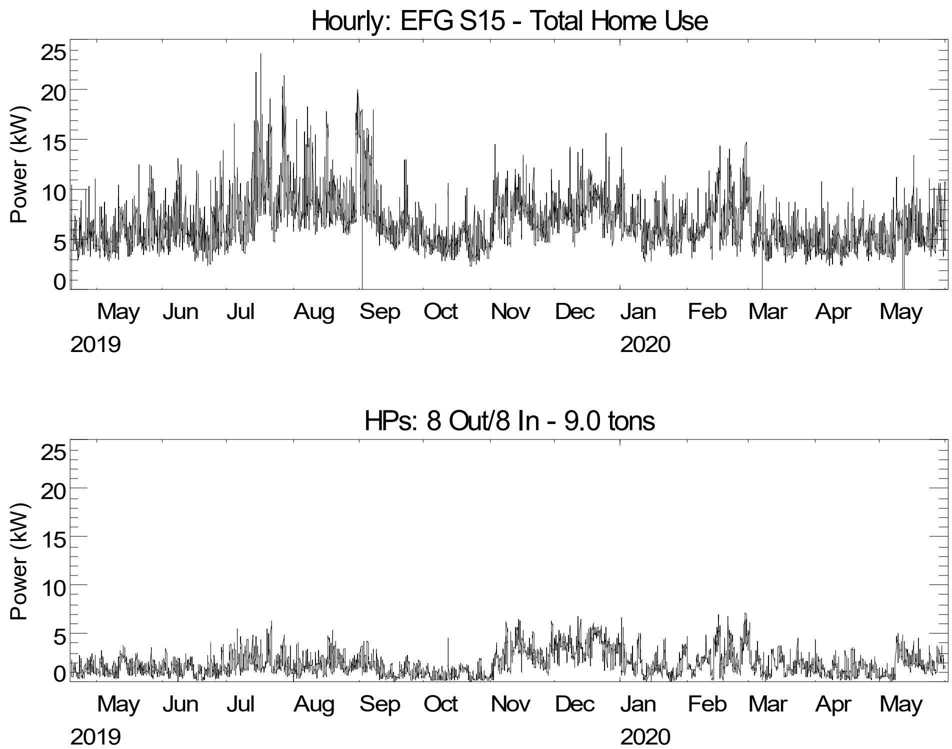


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

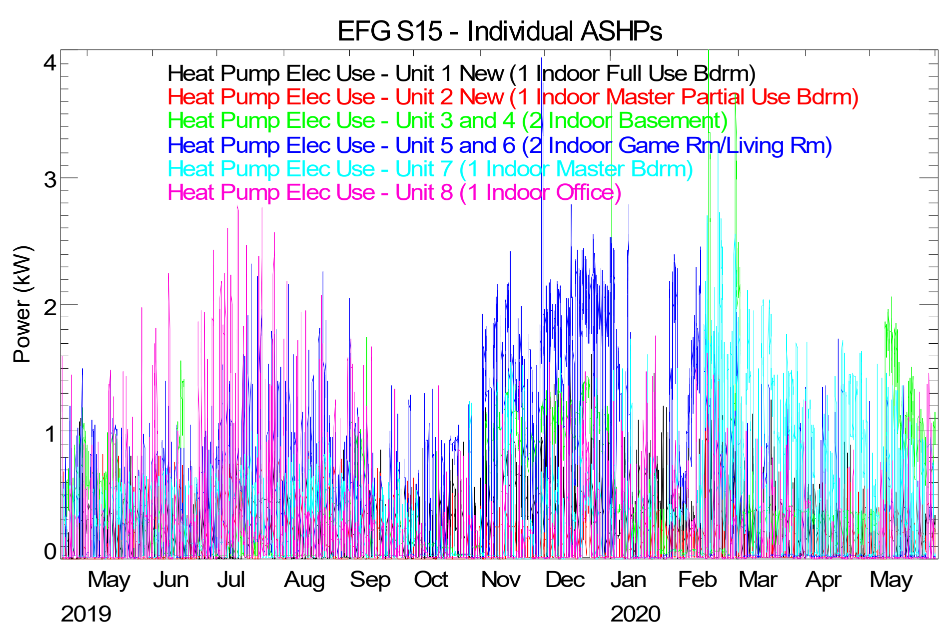


Figure 3. Power Use of Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. The usage for the house is nearly 59,000 kWh per year – so internal gains are significant. As a result, heating loads are relatively modest and energy use for cooling is more than 4,800 kWh per year.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)
Apr-19	12	1,479.4	342.9
May-19	31	4,116.8	1,033.6
Jun-19	30	4,290.2	939.1
Jul-19	31	6,763.1	1,619.0
Aug-19	31	6,789.6	1,373.0
Sep-19	30	5,400.2	912.8
Oct-19	31	3,452.9	516.6
Nov-19	30	5,283.6	1,985.5
Dec-19	31	6,040.2	2,760.7
Jan-20	31	4,584.7	1,291.8
Feb-20	29	4,938.9	1,871.0
Mar-20	31	3,790.1	1,287.8
Apr-20	30	3,419.5	834.2
May-20	31	4,260.4	1,339.5
Annual	366	58,869.8	16,425.1
Htg Season	244	35,626.7	11,581.2
Jun-Sep	122	23,243.1	4,843.9

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature (from Stewart Airport in Newburgh). There was considerable scatter in the daily energy use data, indicating significant variations in how the occupants used the ductless heat pumps. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy use for cooling in the summer is also apparent at this site.

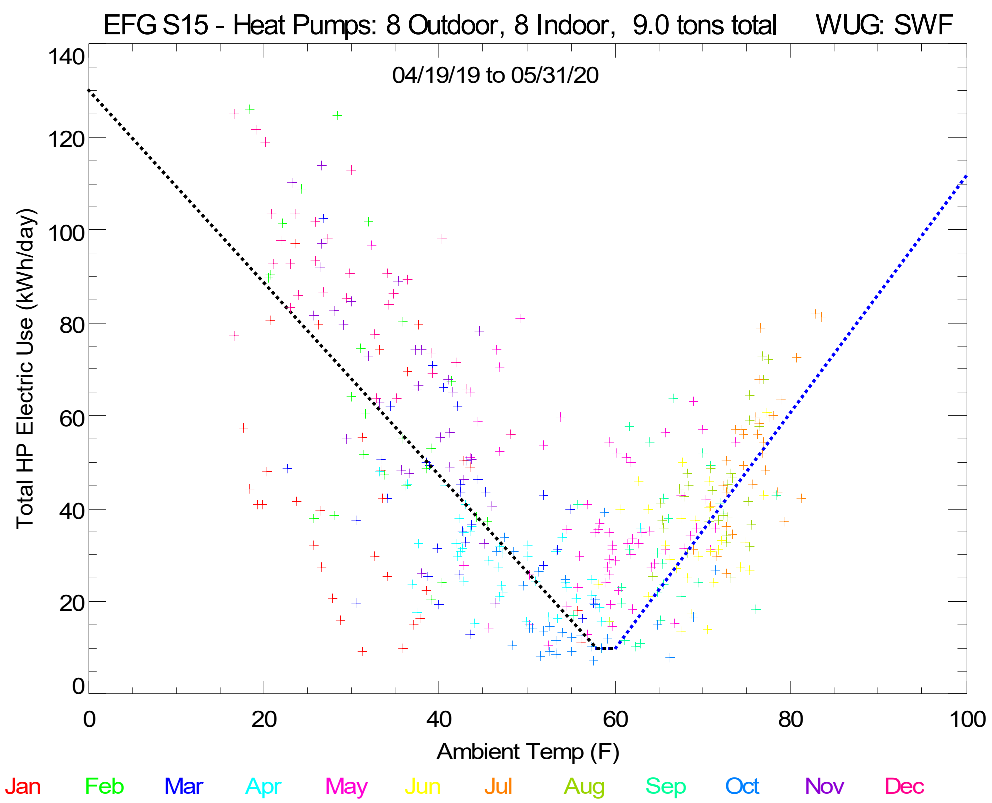


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced all propane use by the boiler. Figure 5 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The pre-retrofit data was from 2016 and 2017, after the earliest heat pumps were installed. There was no post-retrofit fuel use.

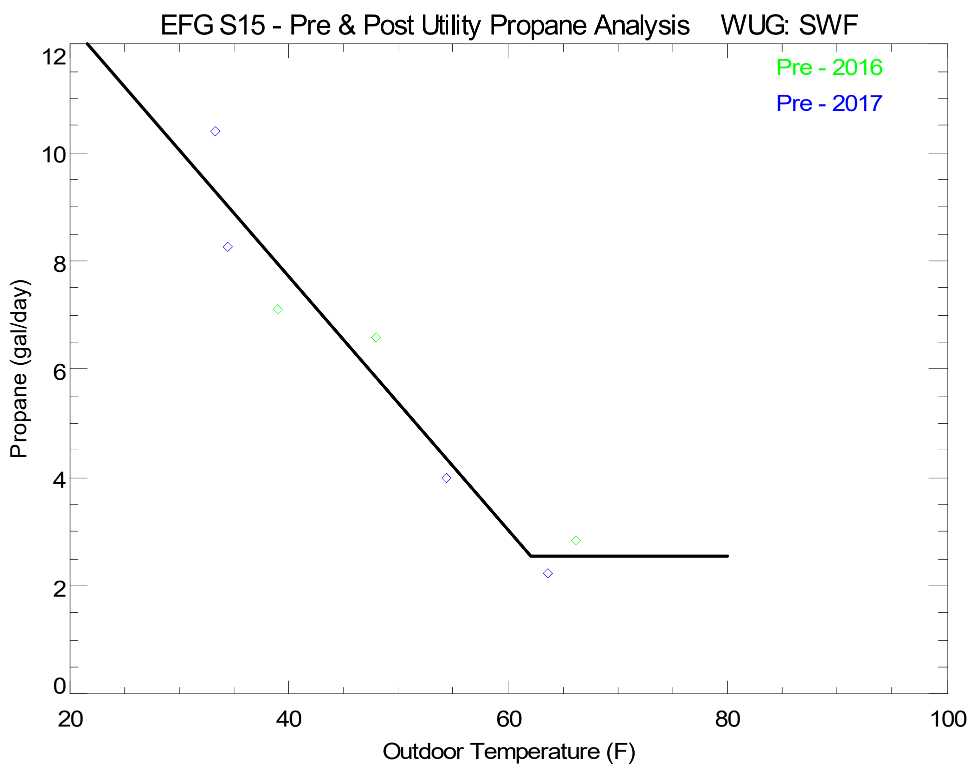


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

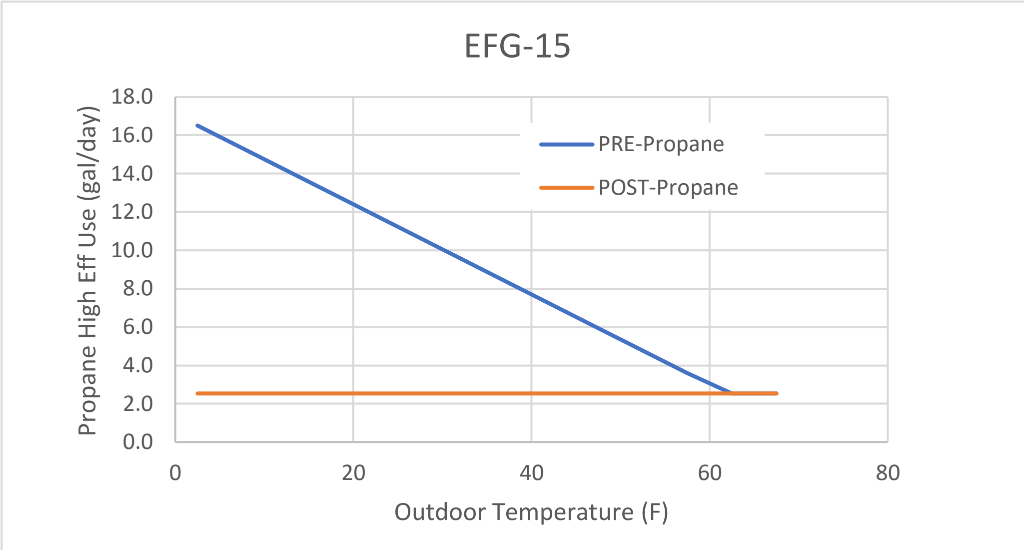
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Newburgh. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis. The actual post-retrofit propane use was zero, but the adjusted post-retrofit use was set equal to the pre-retrofit baseline.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	**EFG-15**				WEATHER:	**Newburgh**		$ 0.150	per kWh	
FUEL:	**Propane High Eff**		Propane					$ 2.440	per gal (propane)	
Floor Area	6500				LOCATION:	New Paltz				

Temp Bin	Hours	FUEL PRE-Propane (gal/day)	FUEL POST-Propane (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Propane (gal/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Propane adjustment factor
-27.5	0	23.5	0.0	186.9	2.5	2.7	$ 57.5	$ 34.2	
-22.5	0	22.4	0.0	176.6	2.5	2.7	$ 54.6	$ 32.7	
-17.5	0	21.2	0.0	166.2	2.5	2.7	$ 51.7	$ 31.1	
-12.5	0	20.0	0.0	155.9	2.5	2.7	$ 48.9	$ 29.6	
-7.5	1	18.9	0.0	145.5	2.5	2.7	$ 46.0	$ 28.0	
-2.5	13	17.7	0.0	135.2	2.5	2.7	$ 43.1	$ 26.5	
2.5	36	16.5	0.0	124.8	2.5	2.7	$ 40.3	$ 24.9	
7.5	45	15.3	0.0	114.5	2.5	2.7	$ 37.4	$ 23.4	
12.5	113	14.2	0.0	104.1	2.5	2.6	$ 34.5	$ 21.8	
17.5	222	13.0	0.0	93.8	2.5	2.6	$ 31.7	$ 20.3	
22.5	367	11.8	0.0	83.4	2.5	2.6	$ 28.8	$ 18.7	
27.5	373	10.6	0.0	73.1	2.5	2.6	$ 26.0	$ 17.2	
32.5	764	9.5	0.0	62.8	2.5	2.6	$ 23.1	$ 15.6	
37.5	814	8.3	0.0	52.4	2.5	2.6	$ 20.2	$ 14.1	
42.5	727	7.1	0.0	42.1	2.5	2.6	$ 17.4	$ 12.5	
47.5	668	5.9	0.0	31.7	2.5	2.5	$ 14.5	$ 11.0	
52.5	480	4.8	0.0	21.4	2.5	2.5	$ 11.6	$ 9.4	
57.5	748	3.6	0.0	11.0	2.5	2.3	$ 8.8	$ 7.9	
62.5	831	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	
67.5	902	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	
72.5	538	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	
77.5	603	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	
82.5	358	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	
87.5	134	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	
92.5	23	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	
97.5	1	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	
102.5	0	2.5	0.0	10.0	2.5	0.0	$ 6.2	$ 7.7	



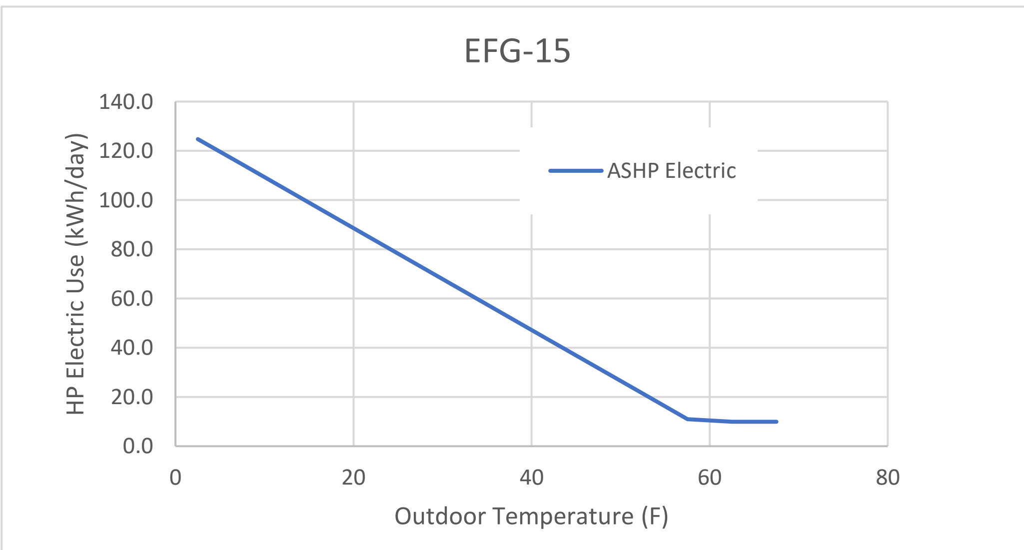


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is

2.4 in this case. However, the pre-retrofit propane bills are from 2016 and 2017. Since heat pumps were installed as far back as 2013, it is unclear how many of the original ASHP units were operating in 2016-2017. Therefore, the pre-retrofit space heating load corresponding to propane use (only 14.9 MBtu/sq ft-yr) may not account for all the space heating in the home.

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Propane High Eff (gal/yr)	1,199	-	1,199
HP Electric (kWh/yr)		11,677	(11,677)
Total Heating Costs	$2,926	$1,752	$1,174
Implied Seasonal COP			2.4

Summary Statistics	
0.18	Fuel gal per sq ft per yr
14.9	Htg MBtu per sq ft per yr
100%	Reduction in Fuel Use
11,581	Measured HP for Htg (kWh/yr)
99%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

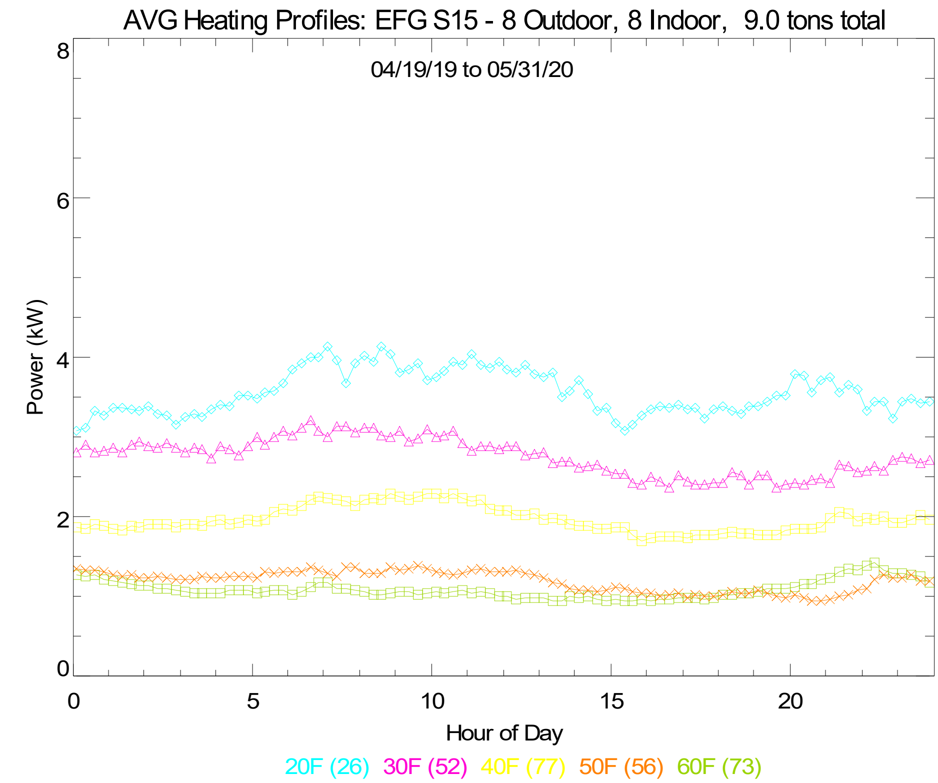


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

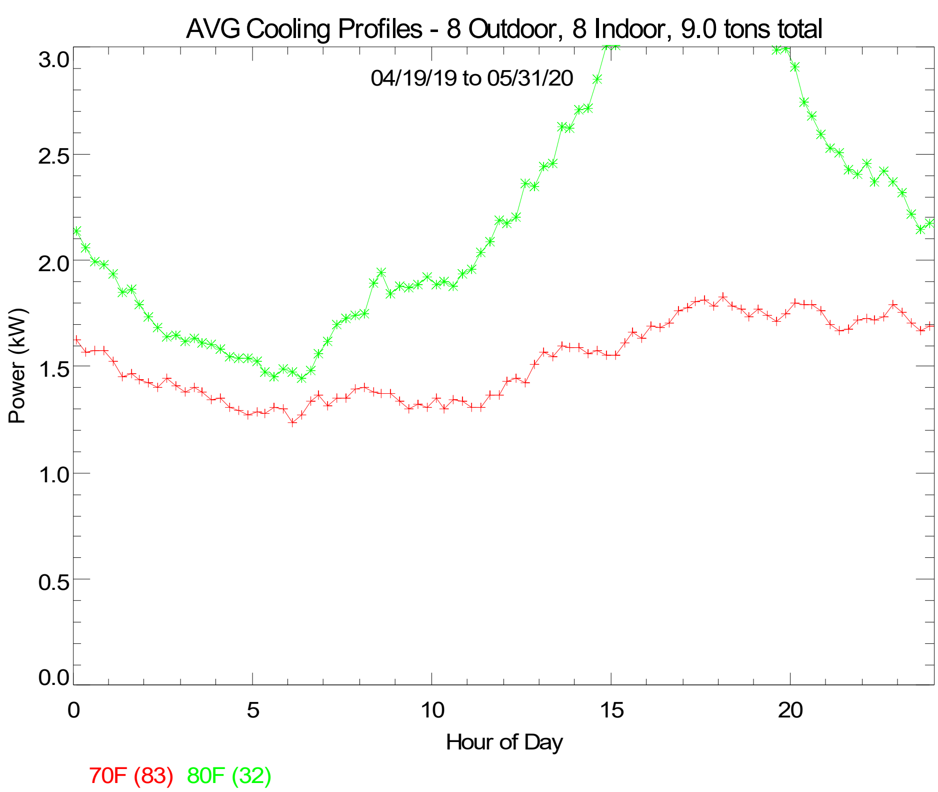


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

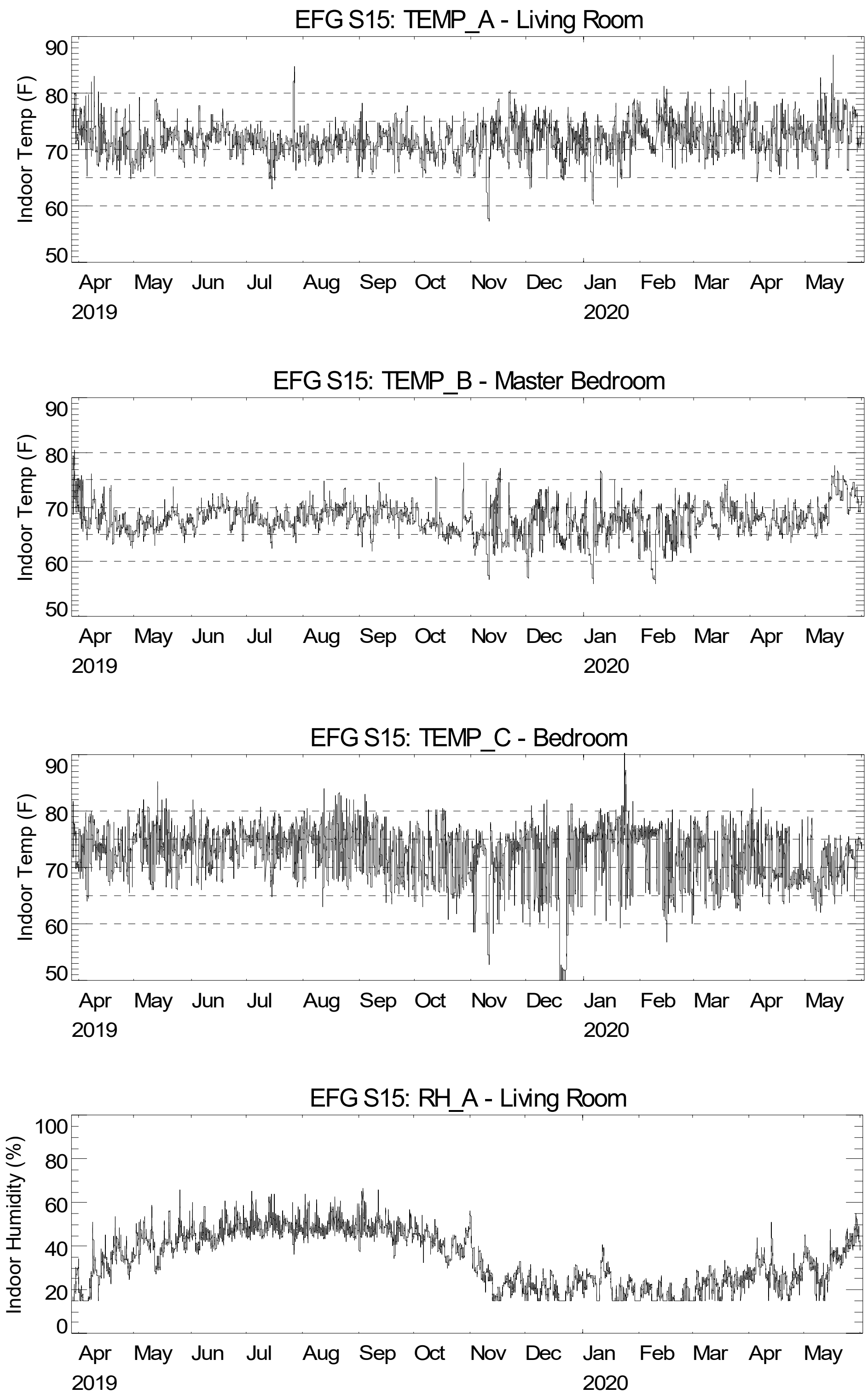


Figure 9. Space Temperatures and Humidity Levels

EFG S16 Savings Analysis

This 2600 sq ft house is in Claryville, NY near Newburgh. The house was originally heated by baseboard electric heat. The electric baseboard was monitored in the post-retrofit period. The three ASHPs were installed in October 2018. Monitoring began in March 2019.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. Data were lost for June through September. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use for the individual heat pumps.

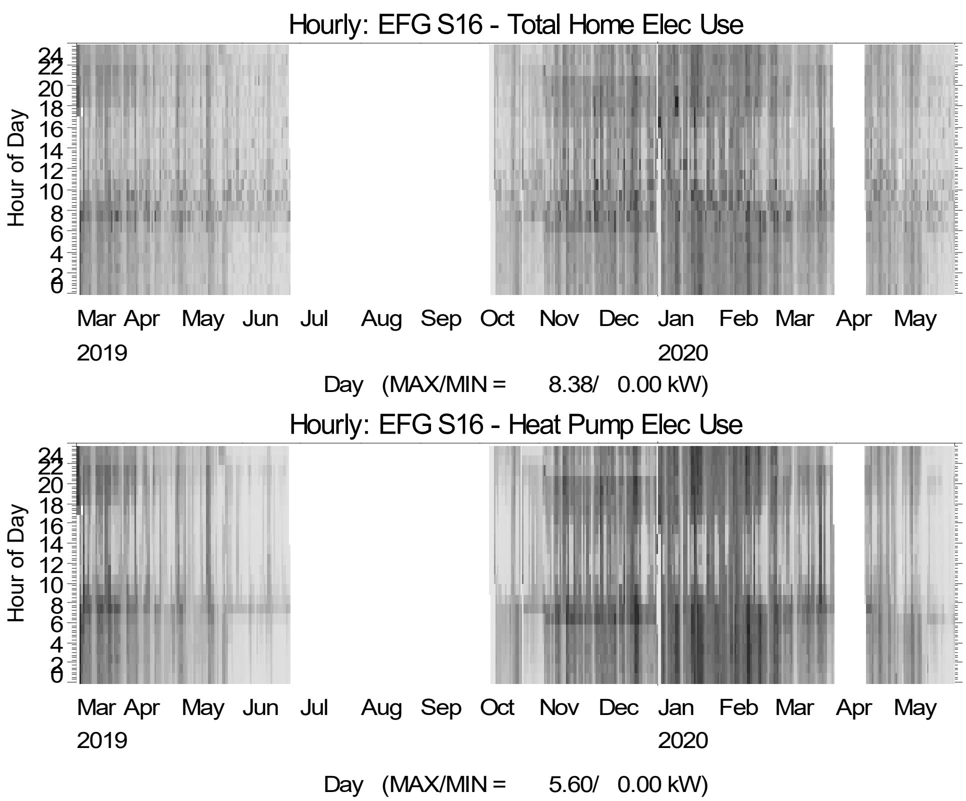


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

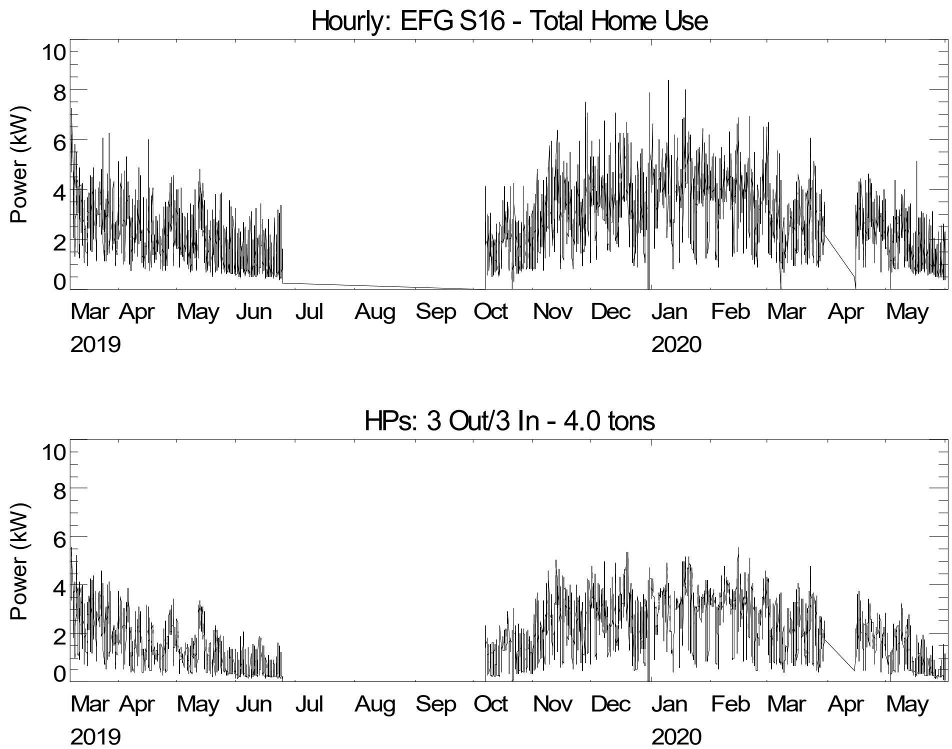


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

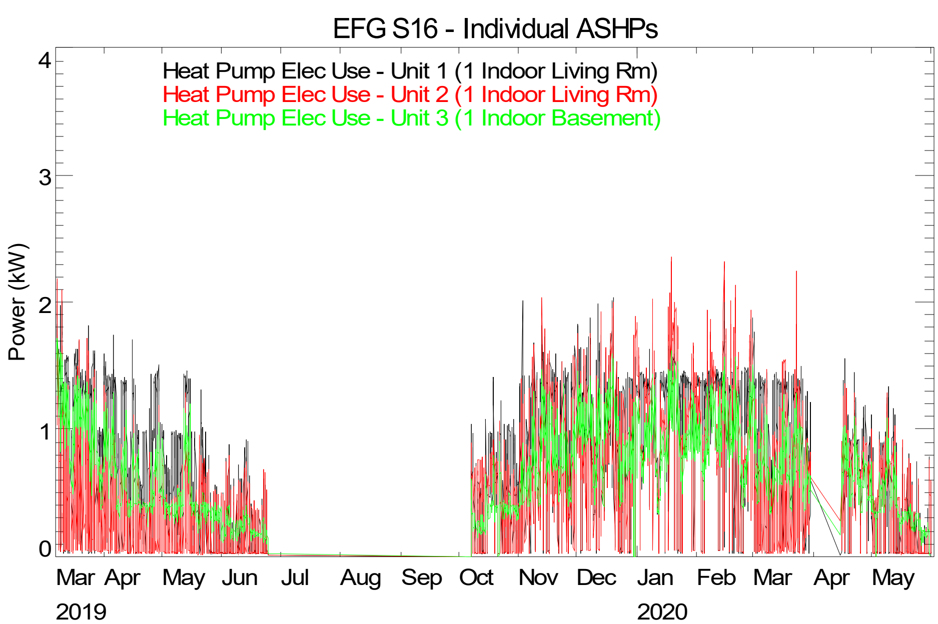


Figure 3. Power Use of Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. It also includes the resistance electric heaters that were monitored in the post-retrofit period.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)
Mar-19	25	1,761.4	1,467.2	0.1
Apr-19	30	1,640.3	1,165.2	5.6
May-19	31	1,333.4	834.4	0.1
Jun-19	24	666.1	276.8	0.1
Jul-19				
Aug-19				
Sep-19				
Oct-19	27	1,050.4	663.9	-
Nov-19	30	2,206.3	1,700.3	39.3
Dec-19	31	2,587.2	1,967.1	154.2
Jan-20	31	2,961.4	2,322.1	125.7
Feb-20	29	2,641.5	2,157.2	28.2
Mar-20	30	1,858.2	1,453.3	0.1
Apr-20	16	1,006.1	729.5	-
May-20	31	1,211.9	680.8	0.1
Annual	263	16,944.8	12,540.3	353.3
Htg Season	239	16,278.7	12,263.5	353.2
Jun-Sep	24	666.1	276.8	0.1

Note: data was lost in the summer of 2019

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature. There is moderate scatter in the data, indicating that the occupants used the ductless heat pump in a fairly consistent manner. The dotted line on the plot represents to a best fit of the trend with temperature. No data were available for the cooling season.

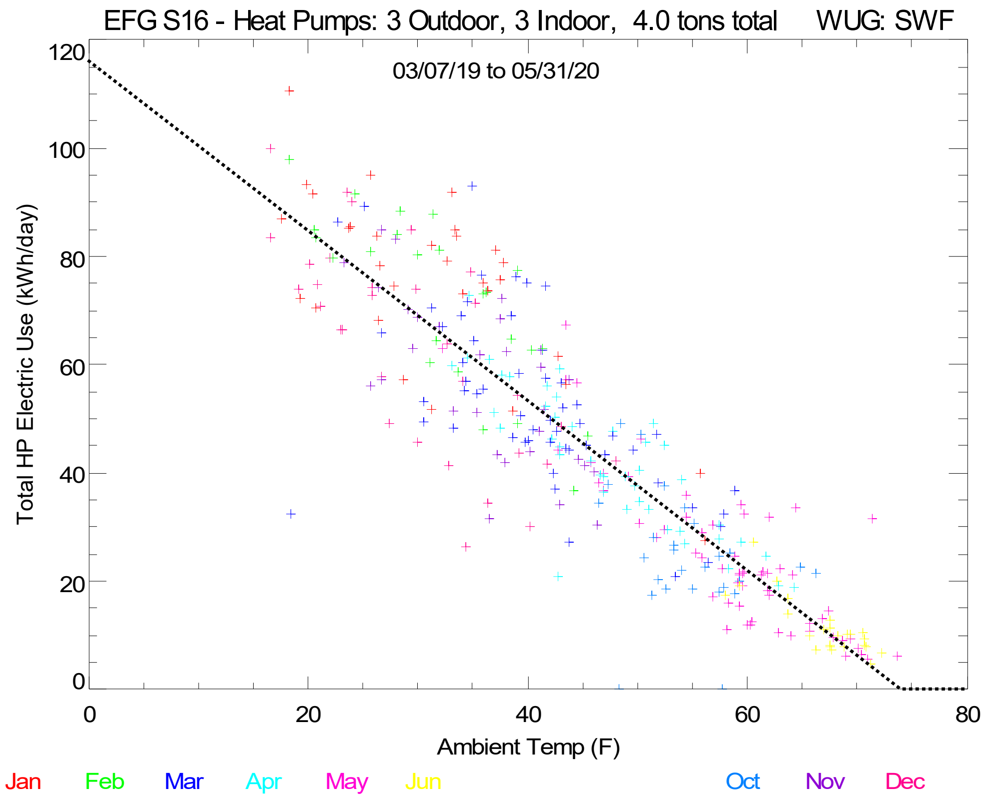


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced baseboard electric heat use. Figure 5 compares the trend of monthly electric use for the house with temperature for both the pre- and post-retrofit periods. The solid line represents the overall electric use trend in the pre-retrofit period. The dotted line represents the electric use trend in the post-retrofit period.

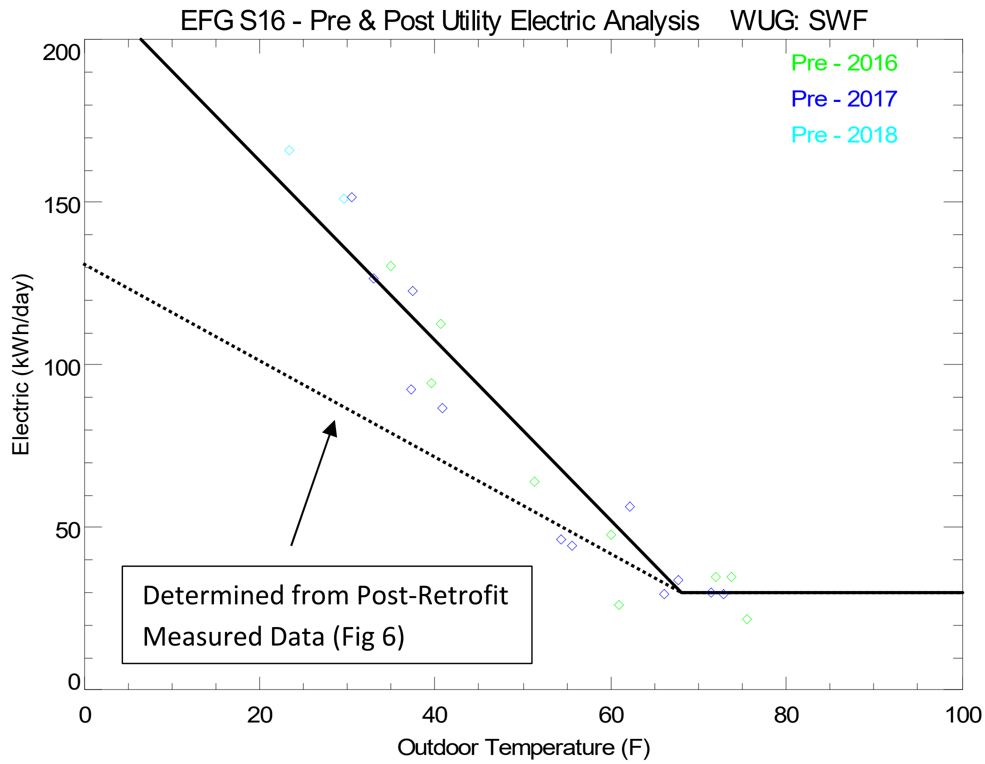


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

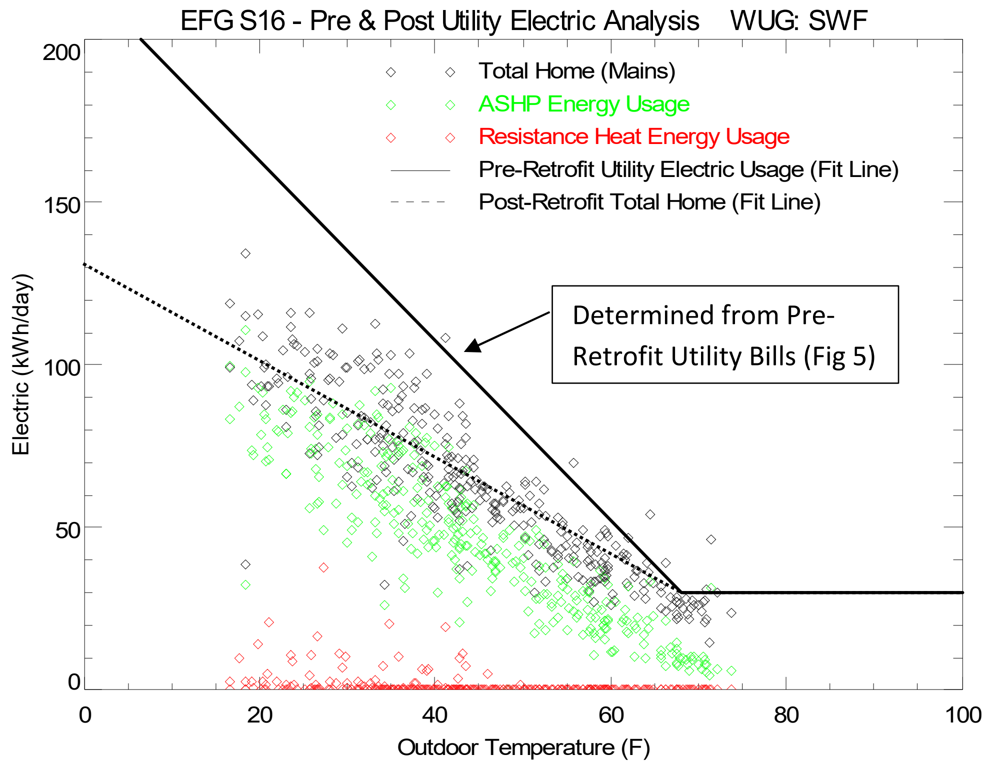


Figure 6. Analysis of Total House Energy Use versus Outdoor Temperature in the Post-Retrofit Period (ASHP and Resistance Heat also shown)

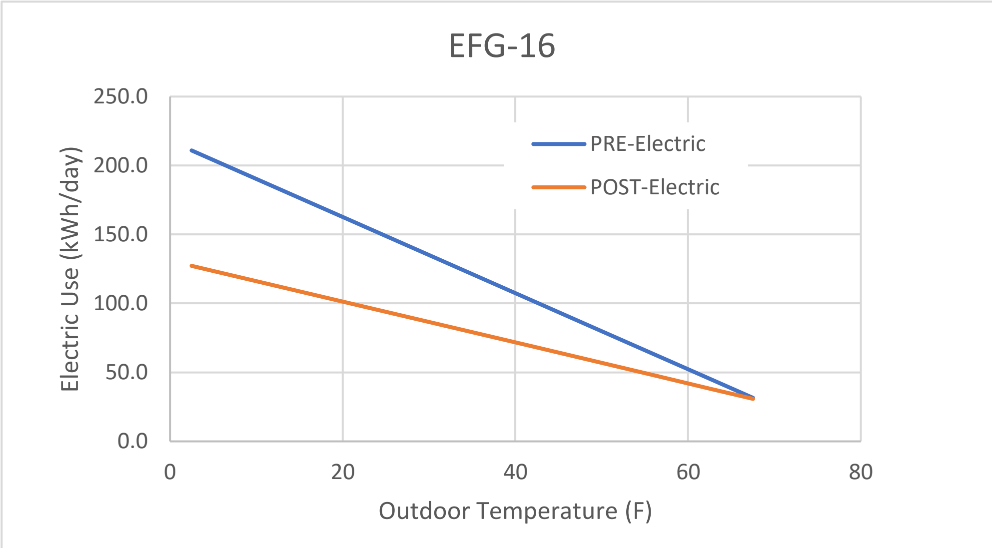
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Albany. Table 2 shows the details of bin analysis and Figure 7 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	EFG-16			WEATHER:		Newburgh		$ 0.150 per kWh	
FUEL:	Electric							$ 0.150 per kWh	
Floor Area	2600			LOCATION:		Claryville			
Temp Bin	**Hours**	**FUEL PRE-Electric (kWh/day)**	**FUEL POST-Electric (kWh/day)**	**ASHP Electric (kWh/day)**	**Adjusted POST-Electric (kWh/day)**	**Implied COP (-)**	**PRE-Costs**	**POST-Costs**	**POST-Electric adjustment factor**
-27.5	0	293.9	171.8	159.1	171.8	1.8	44.1	49.6	
-22.5	0	280.1	164.4	151.3	164.4	1.8	42.0	47.3	
-17.5	0	266.3	157.0	143.4	157.0	1.8	39.9	45.1	
-12.5	0	252.5	149.5	135.6	149.5	1.8	37.9	42.8	
-7.5	1	238.7	142.1	127.8	142.1	1.8	35.8	40.5	
-2.5	13	224.9	134.7	119.9	134.7	1.8	33.7	38.2	
2.5	36	211.0	127.3	112.1	127.3	1.7	31.7	35.9	
7.5	45	197.2	119.9	104.2	119.9	1.7	29.6	33.6	
12.5	113	183.4	112.5	96.4	112.5	1.7	27.5	31.3	
17.5	222	169.6	105.0	88.6	105.0	1.7	25.4	29.0	
22.5	367	155.8	97.6	80.7	97.6	1.7	23.4	26.8	
27.5	373	142.0	90.2	72.9	90.2	1.7	21.3	24.5	
32.5	764	128.2	82.8	65.1	82.8	1.7	19.2	22.2	
37.5	814	114.4	75.4	57.2	75.4	1.7	17.2	19.9	
42.5	727	100.6	68.0	49.4	68.0	1.7	15.1	17.6	
47.5	668	86.8	60.6	41.5	60.6	1.6	13.0	15.3	
52.5	480	73.0	53.1	33.7	53.1	1.6	10.9	13.0	
57.5	748	59.2	45.7	25.9	45.7	1.5	8.9	10.7	
62.5	831	45.3	38.3	18.0	38.3	1.4	6.8	8.5	
67.5	902	31.5	30.9	10.2	30.9	1.1	4.7	6.2	
72.5	538	30.2	30.2	2.4	30.2	1.0	4.5	4.9	
77.5	603	30.2	30.2	0.0	30.2	0.0	4.5	4.5	
82.5	358	30.2	30.2	0.0	30.2	0.0	4.5	4.5	
87.5	134	30.2	30.2	0.0	30.2	0.0	4.5	4.5	
92.5	23	30.2	30.2	0.0	30.2	0.0	4.5	4.5	
97.5	1	30.2	30.2	0.0	30.2	0.0	4.5	4.5	
102.5	0	30.2	30.2	0.0	30.2	0.0	4.5	4.5	

Note: The COP associated with each temperature bin shows the unexpected trend of decreasing at warmer temperatures.



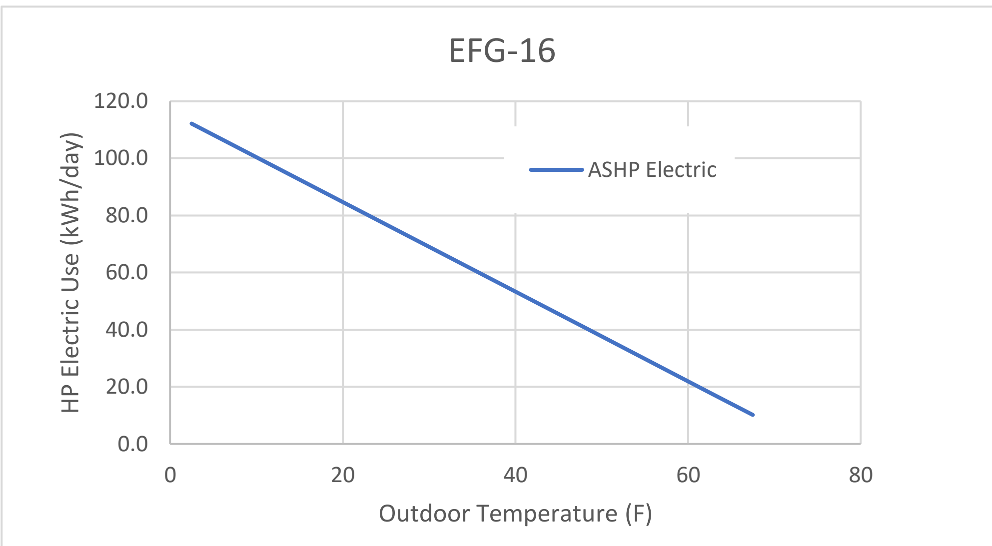


Figure 7. Trends of (Pre and Post Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis using typical year data for Newburgh. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. Since the base fuel is electric, the savings calculation only considers the pre- and post-retrofit electric use. The implied seasonal heating COP is 1.6, using both electric savings and heat pump energy use which is shown on the bottom of the table.

In this instance the implied COP is calculated from

$$COP = (kWh_{pre} - kWh_{post} + kWh_{hp})/kW_{hp} = (18394 - 9877 + 13224) / 13224$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	**PRE-Retrofit**	**POST-Retrofit**	**Savings**
Electric (kWh/yr)	18,394	9,877	8,517
		-	-
Total Heating Costs	$2,759	$1,482	$1,277
Implied Seasonal COP			1.6
HP Electric (kWh/yr)			13,224

Summary Statistics	
7.07	Fuel kWh per sq ft per yr
24.1	Htg MBtu per sq ft per yr
46%	Reduction in Fuel Use
12,264	Measured HP for Htg (kWh/yr)
93%	Measured as % of Typical yr

Table 4 uses the measured resistance heating electricity in the post-retrofit period to determine the savings from installing the heat pump. An implied COP with and without resistance heating is given. The implied COP was lower with this approach using the measured resistance heating power.

Table 4. Results of Bin Analysis Showing Seasonal Impact to Resistant Heating Use

Heating Only	**PRE-Retrofit**	**POST-Retrofit**	**Savings**
Resistance (kWh/yr)	18,394	353	18,041
ASHP (kWh/yr)		13,224	(13,224)
Total Heat (kWh/yr)	18,394	13,577	4,816
Total Heating Costs	$2,759	$2,037	$722
Implied ASHP COP			1.36
Overall COP Including Resistance			1.35

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 9 shows the temperature bins associated with cooling operation.

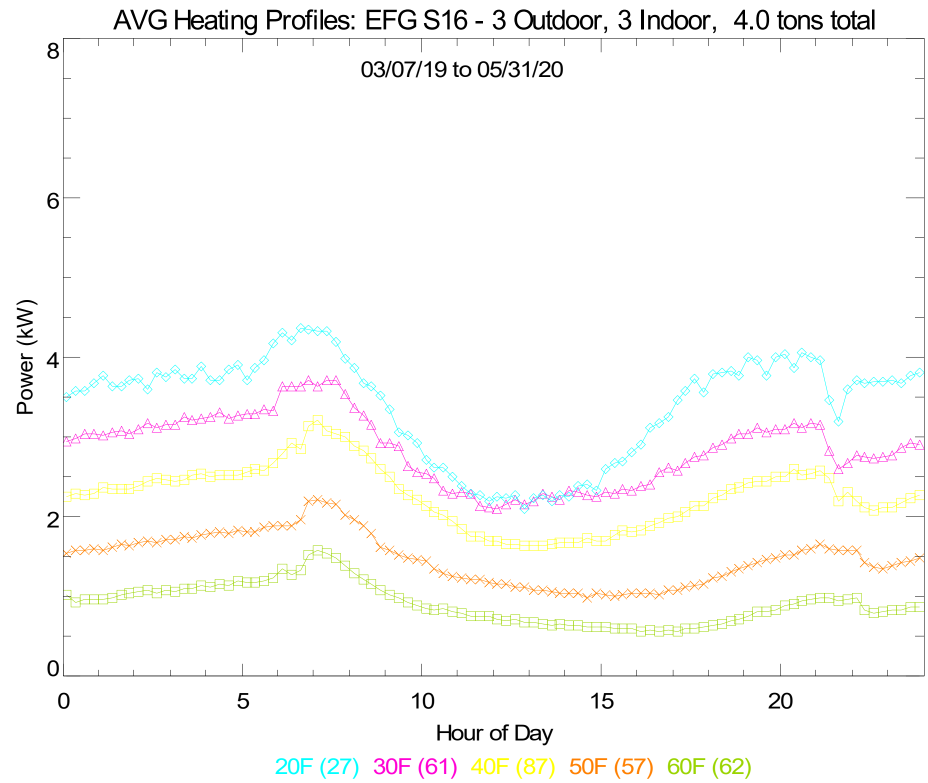


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

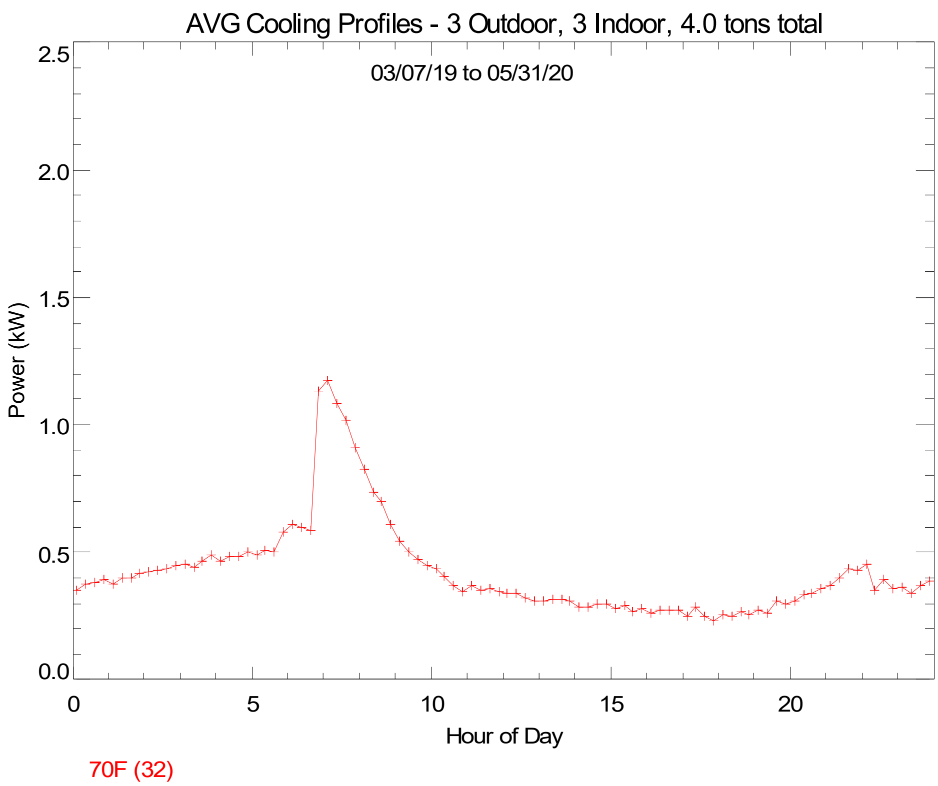


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10. The HOBO installed in the living roo may have periodically failed starting in the fall of 2019.

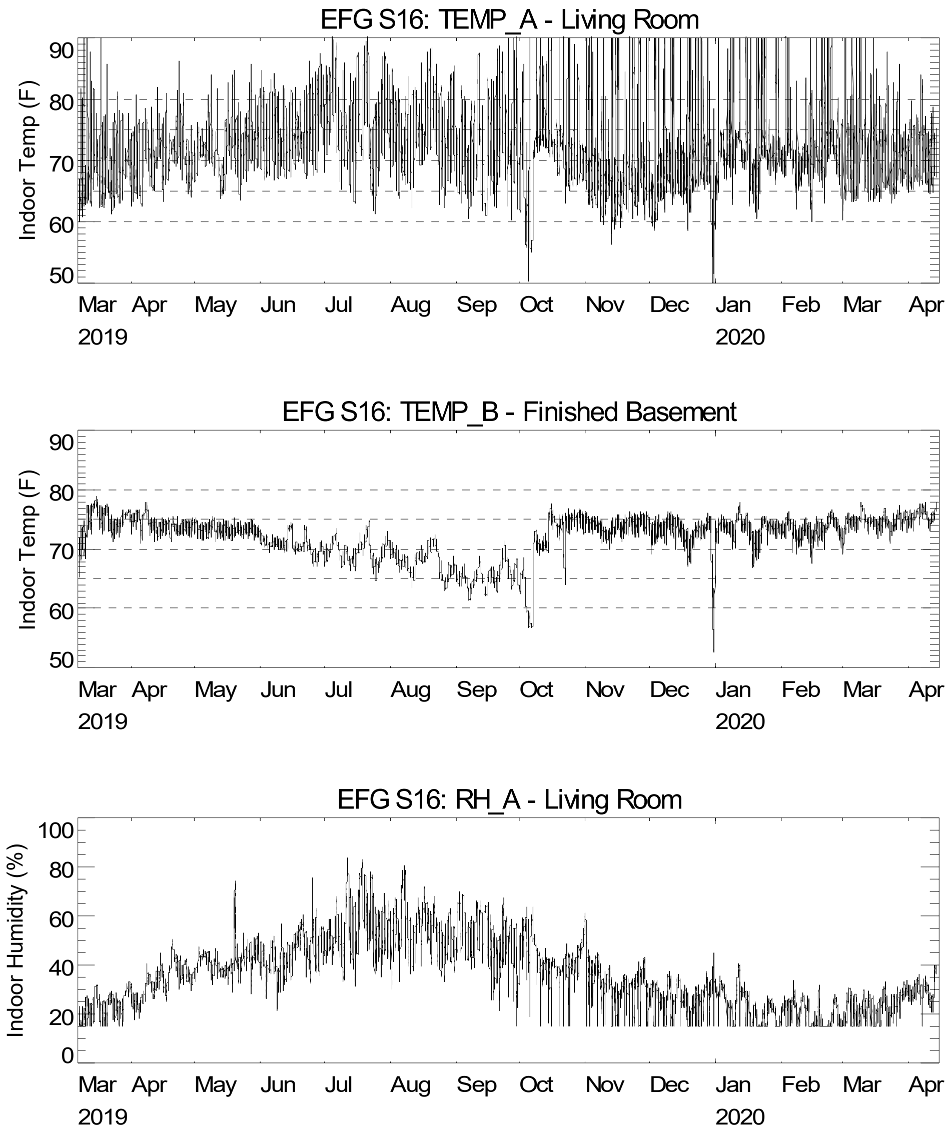


Figure 10. Space Temperatures and Humidity Levels

EFG S17 Savings Analysis

This 1,950 sq ft house is New Paltz near Newburgh. The house was originally heated by an oil boiler with hydronic baseboard. The boiler was also used for supplemental heating and some hot water heating after the 3.5-ton ducted ASHP system was installed in October2018. Monitoring began in February 2019. The house reportedly used wood pellets for heating in the pre-retrofit period (about 80 40-lb bags per season).

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pump. Figure 2 shows the power use for the house and heat pumps across the monitoring period. They use the heat pump much less during the second winter. Figure 3 shows the power use for the individual heat pumps.

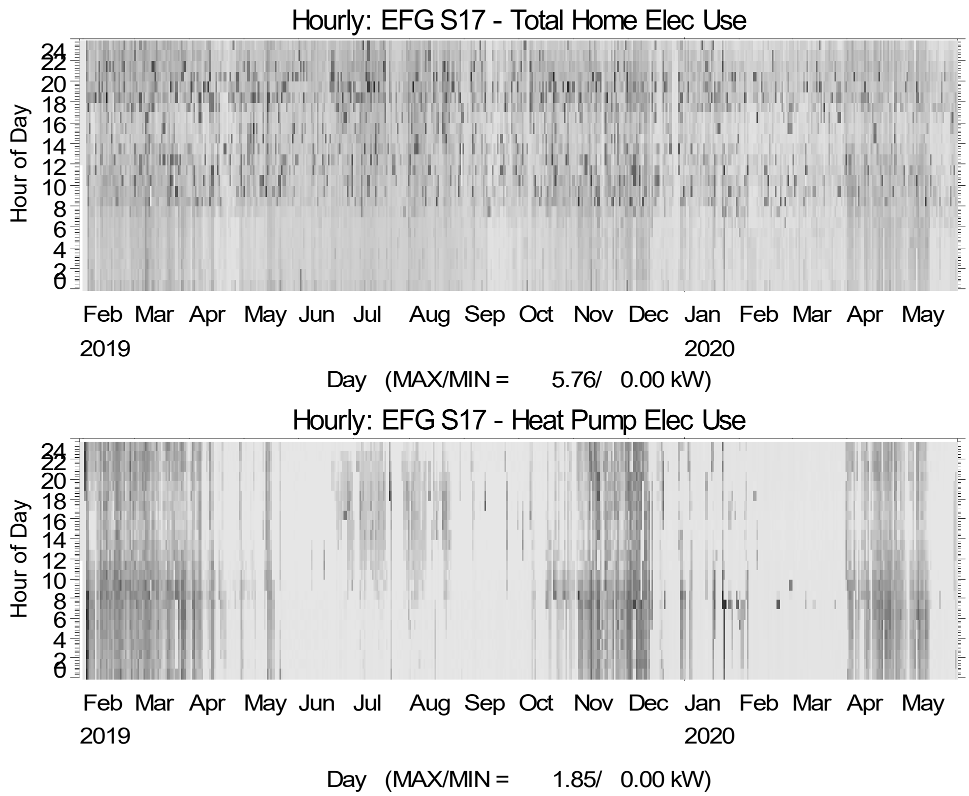


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

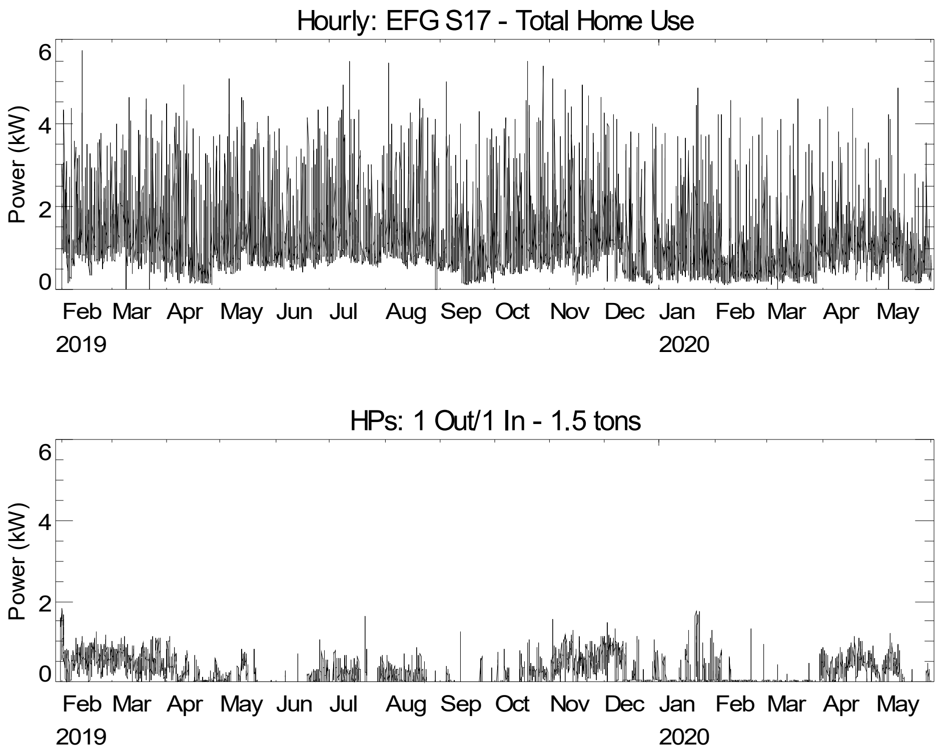


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

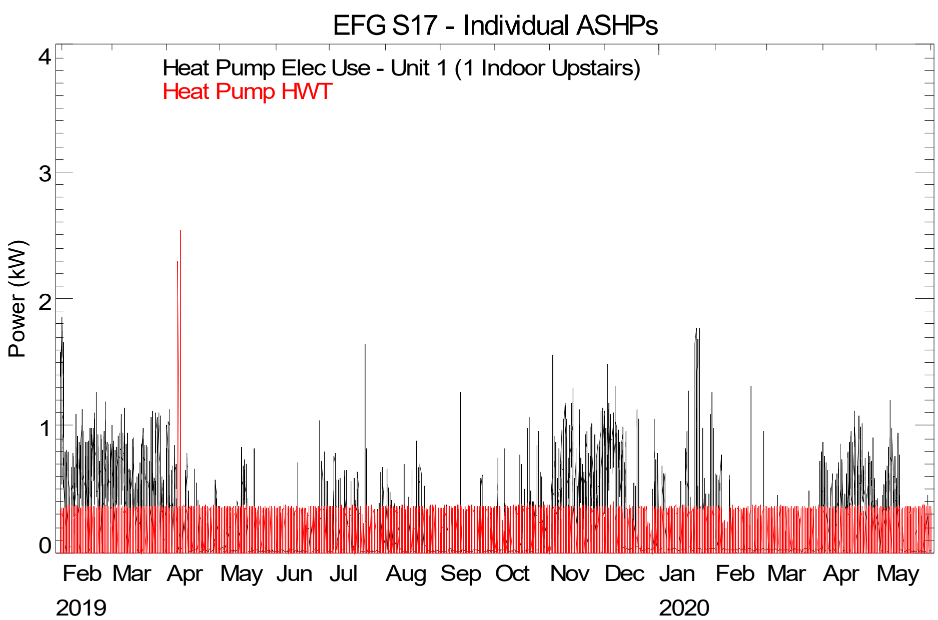


Figure 3. Power Use for Individual Heat Pumps Across the Monitoring Period (HPWH shown but not included in total heat pump power above)

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. HPWH use is also shown.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Solar (kWh)	DHW (kWh)
Feb-19	28	897.3	395.4	-	66.8
Mar-19	31	1,036.4	372.7	-	73.9
Apr-19	30	707.8	135.4	-	85.2
May-19	31	880.2	69.3	-	77.7
Jun-19	30	802.0	40.5	-	70.1
Jul-19	31	943.1	104.9	-	57.3
Aug-19	31	937.9	84.1	-	66.1
Sep-19	30	624.9	21.8	-	73.7
Oct-19	31	837.3	88.6	-	81.0
Nov-19	30	933.9	368.7	-	62.0
Dec-19	31	748.6	250.0	-	58.3
Jan-20	31	675.2	96.5	-	68.8
Feb-20	29	489.2	37.3	-	53.1
Mar-20	31	568.2	31.4	-	71.8
Apr-20	30	809.9	296.0	-	59.8
May-20	31	635.2	127.4	-	62.9
Annual	366	9,616.5	1,669.8	-	827.2
Htg Season	244	6,308.6	1,418.5	-	560.0
Jun-Sep	122	3,307.9	251.3	-	267.2

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature (from Stewart Airport). There was considerable scatter in the daily energy use data, implying the occupants used the ducted heat pump in an inconsistent manner. The dotted line on the plot represents to a best fit of the trend with temperature. A trend of energy use for cooling in the summer is also apparent at this site.

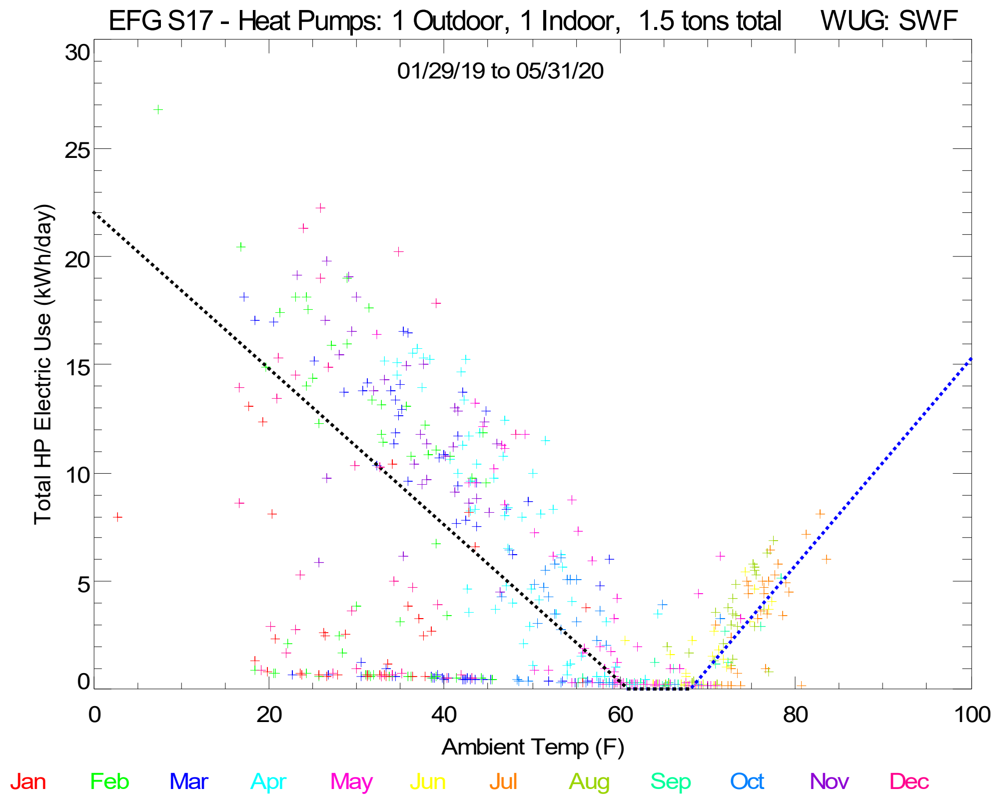


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced some of the fuel oil use by the boiler. Figure 5 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. A fair amount of post-retrofit data was available to confirm the fuel use trend in this period.

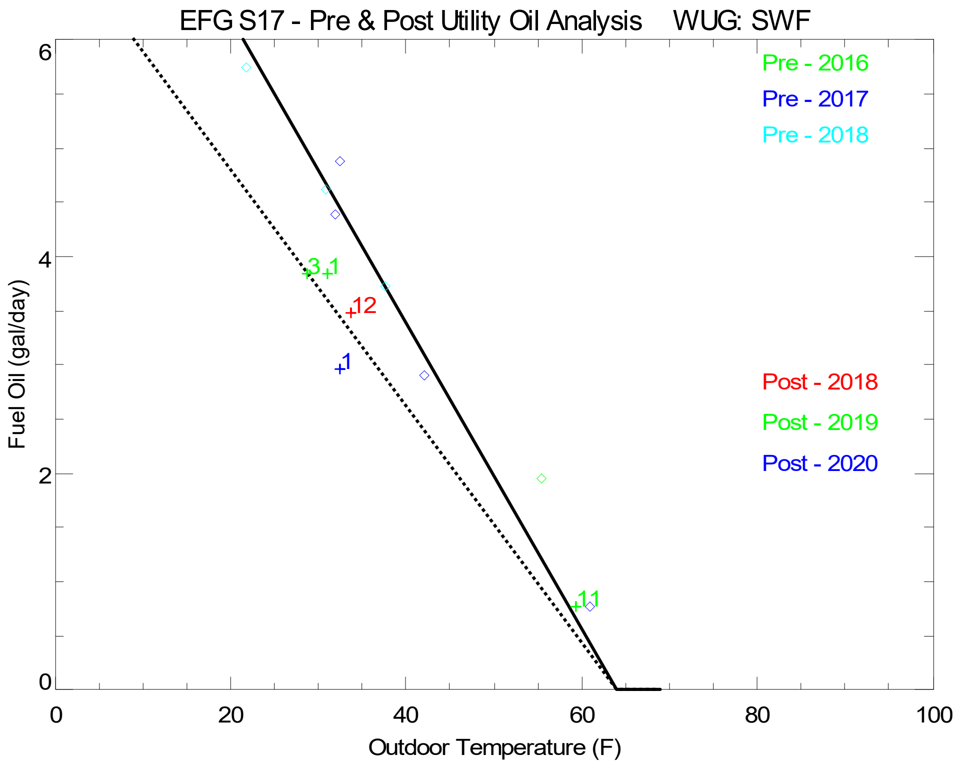


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

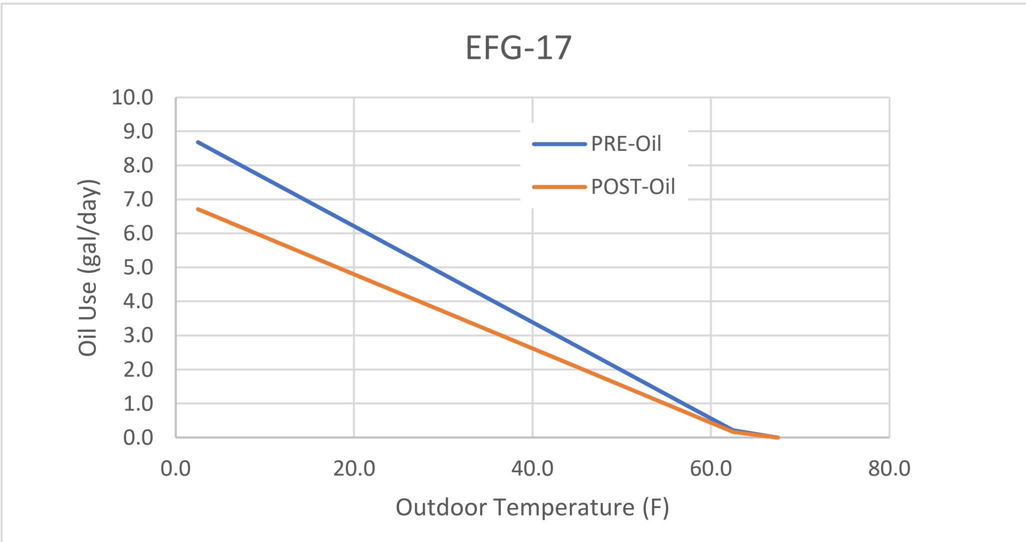
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE: **EFG-17** WEATHER: **Newburgh** $ 0.150 per kWh
FUEL: **Oil** $ 2.686 per gal (oil)
Floor Area 1950 LOCATION: New Paltz

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	12.9	10.0	31.9	10.0	3.1	34.7	31.6	0.0
-22.5	0	12.2	9.4	30.1	9.4	3.2	32.8	29.9	0.0
-17.5	0	11.5	8.9	28.3	8.9	3.2	30.9	28.1	0.0
-12.5	0	10.8	8.3	26.5	8.3	3.2	29.0	26.4	0.0
-7.5	1	10.1	7.8	24.7	7.8	3.2	27.1	24.7	0.0
-2.5	13	9.4	7.3	22.9	7.3	3.2	25.2	22.9	0.0
2.5	36	8.7	6.7	21.1	6.7	3.2	23.3	21.2	0.0
7.5	45	8.0	6.2	19.3	6.2	3.2	21.4	19.5	0.0
12.5	113	7.3	5.6	17.5	5.6	3.2	19.5	17.7	0.0
17.5	222	6.6	5.1	15.7	5.1	3.3	17.6	16.0	0.0
22.5	367	5.9	4.5	13.9	4.5	3.3	15.7	14.2	0.0
27.5	373	5.2	4.0	12.1	4.0	3.3	13.8	12.5	0.0
32.5	764	4.4	3.4	10.3	3.4	3.4	11.9	10.8	0.0
37.5	814	3.7	2.9	8.5	2.9	3.4	10.0	9.0	0.0
42.5	727	3.0	2.3	6.7	2.3	3.5	8.2	7.3	0.0
47.5	668	2.3	1.8	4.9	1.8	3.7	6.3	5.6	0.0
52.5	480	1.6	1.3	3.1	1.3	4.1	4.4	3.8	0.0
57.5	748	0.9	0.7	1.3	0.7	5.7	2.5	2.1	0.0
62.5	831	0.2	0.2	0.0	0.2	#######	0.6	0.4	0.0
67.5	902	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
72.5	538	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
77.5	603	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
82.5	358	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
87.5	134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
92.5	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
97.5	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
102.5	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0



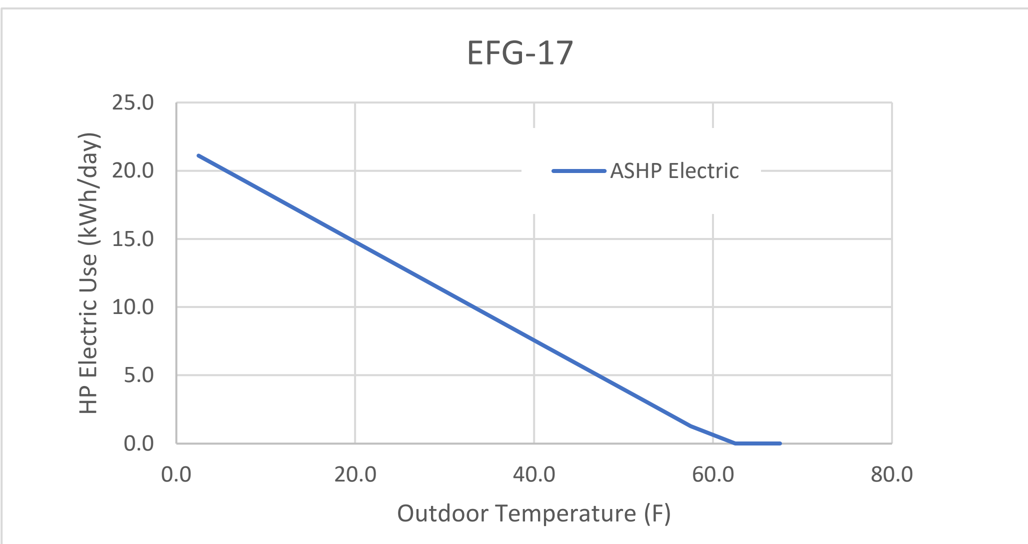


Figure 6. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 3.5 in this case.

The wide variation in heat pump operation and the use of a pellet stove at this site may have confounded the pre-post analysis. The site reportedly used 80 bags of wood pellets (40 lbs each) per season in the pre-retrofit period. They used the heat pump in the first winter season but used it very little in the coldest part of the second winter.

.

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Oil (gal/yr)	792	612	180
HP Electric (kWh/yr)		1,762	(1,762)
Total Heating Costs	$2,127	$1,908	$219
Implied Seasonal COP			3.5

Summary Statistics	
0.41	Fuel gal per sq ft per yr
47.4	Htg MBtu per sq ft per yr
23%	Reduction in Fuel Use
1,419	Measured HP for Htg (kWh/yr)
81%	Measured as % of Typical yr

Average Heat Pump Demand Profiles

Figure 7 and Figure 8 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

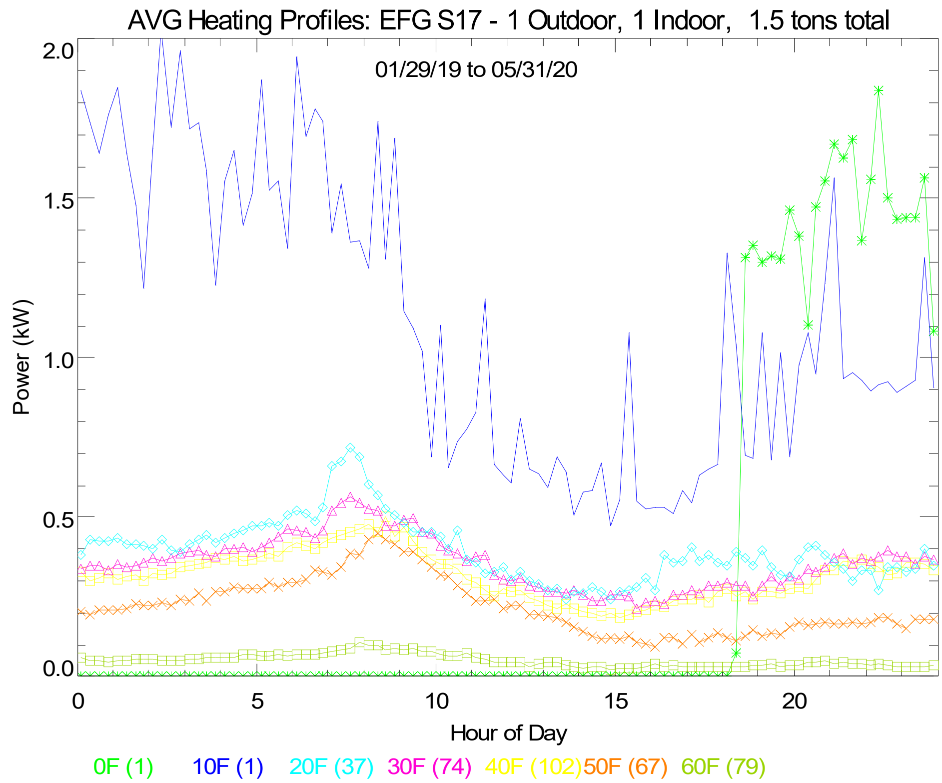


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

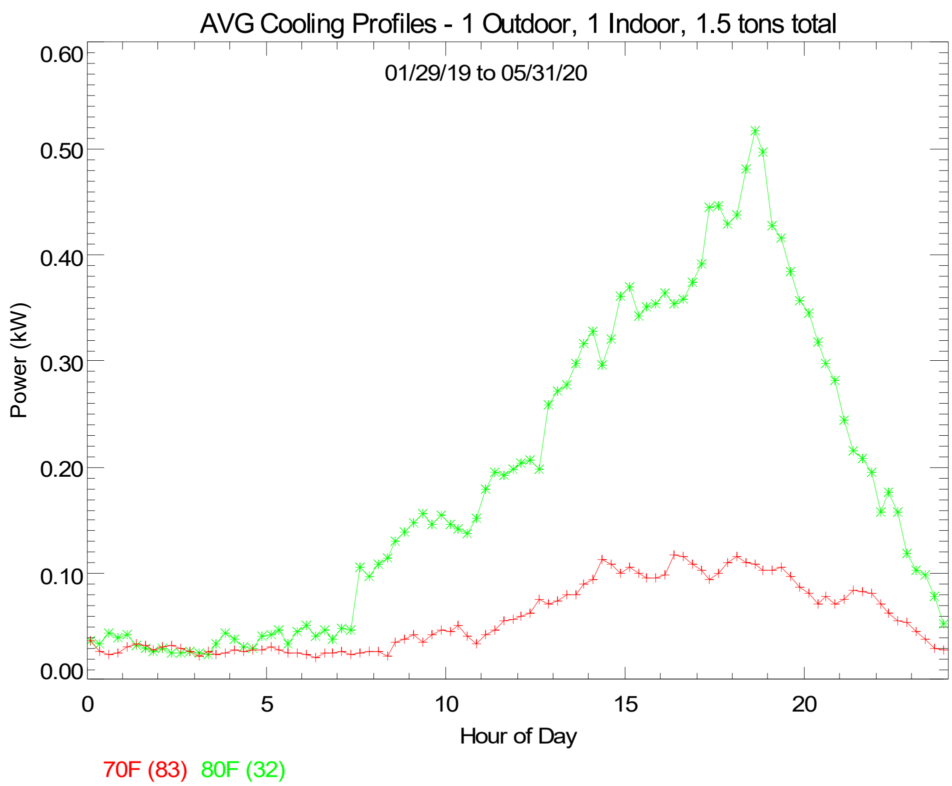


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

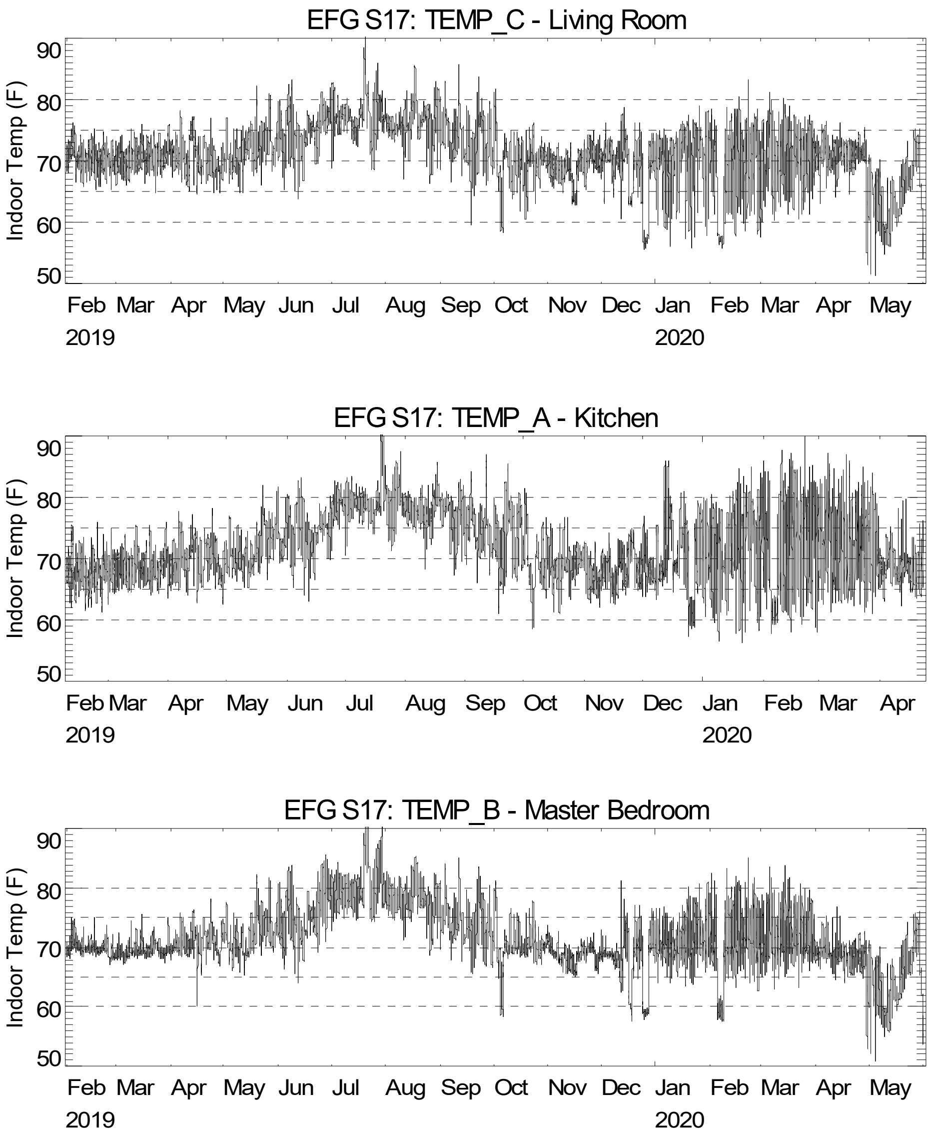
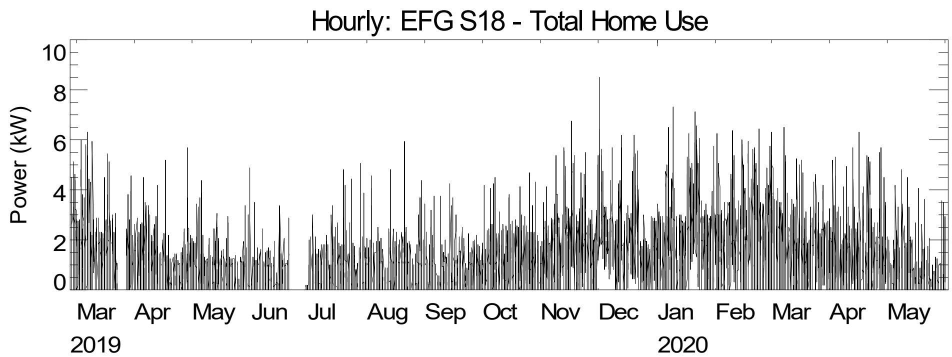


Figure 9. Space Temperatures and Humidity Levels

EFG S18 Savings Analysis

This 1,388 sq ft house is located in Gardiner, NY near Newburgh. The house was originally heated by an oil boiler with hydronic baseboard. The boiler was also used for supplemental heating and some hot water heating after the 3-ton ducted ASHP system was installed on Jan 11, 2019. The ducted AHU included fan power and electric resistance heating which was included in the heat pump power. Monitoring began in February 2019. This house also had an electric vehicle charging station.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps.



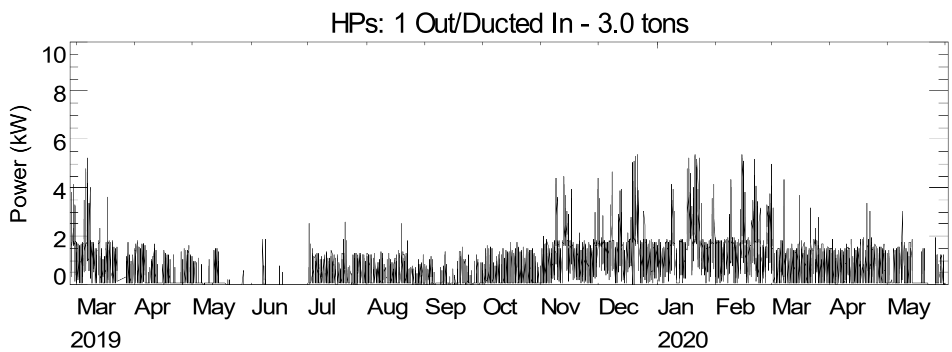


Figure 2 shows the power use for the house and heat pumps across the monitoring period.

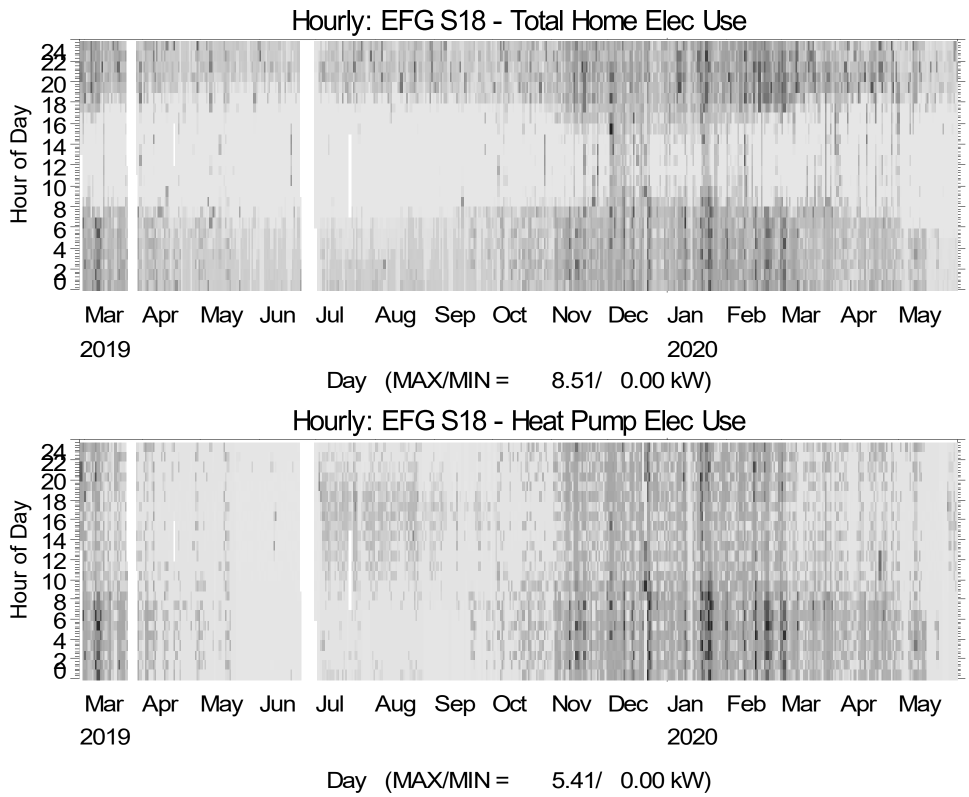
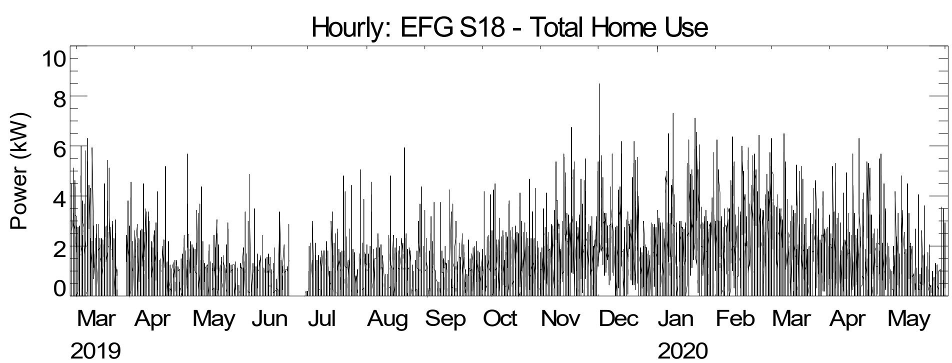


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.



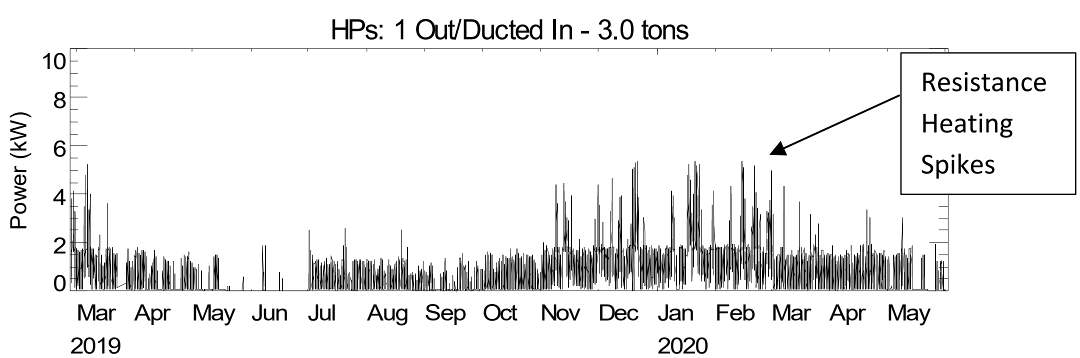


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. Solar energy production is also given.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Solar (kWh)
Feb-19	3	113.3	103.3	75.8
Mar-19	27	857.7	610.5	917.4
Apr-19	30	563.8	252.4	1,205.9
May-19	31	447.1	97.7	1,287.3
Jun-19	23	251.0	24.2	1,099.8
Jul-19	31	436.7	328.1	1,699.1
Aug-19	31	467.8	265.0	1,563.4
Sep-19	30	425.2	126.8	1,215.1
Oct-19	31	678.1	298.0	732.9
Nov-19	30	1,157.7	850.9	557.8
Dec-19	31	1,439.5	1,103.2	191.9
Jan-20	31	1,545.4	1,172.4	391.2
Feb-20	29	1,440.9	1,059.1	654.4
Mar-20	31	1,147.5	673.3	1,051.5
Apr-20	30	863.1	531.3	1,173.6
May-20	31	395.4	225.0	1,759.8
Annual	359	10,000.7	6,251.1	11,650.3
Htg Season	244	8,420.0	5,507.0	6,072.9
Jun-Sep	115	1,580.7	744.1	5,577.4

Measured Trends

Daily heat pump power use is shown in Figure 3 as function of daily average outdoor temperature (from Stewart Airport). The dotted line on the plot represents to a best fit of the trend with temperature. The increase in power use below about 25°F is due to resistance heat operation. A trend of energy use for cooling in the summer is also apparent at this site.

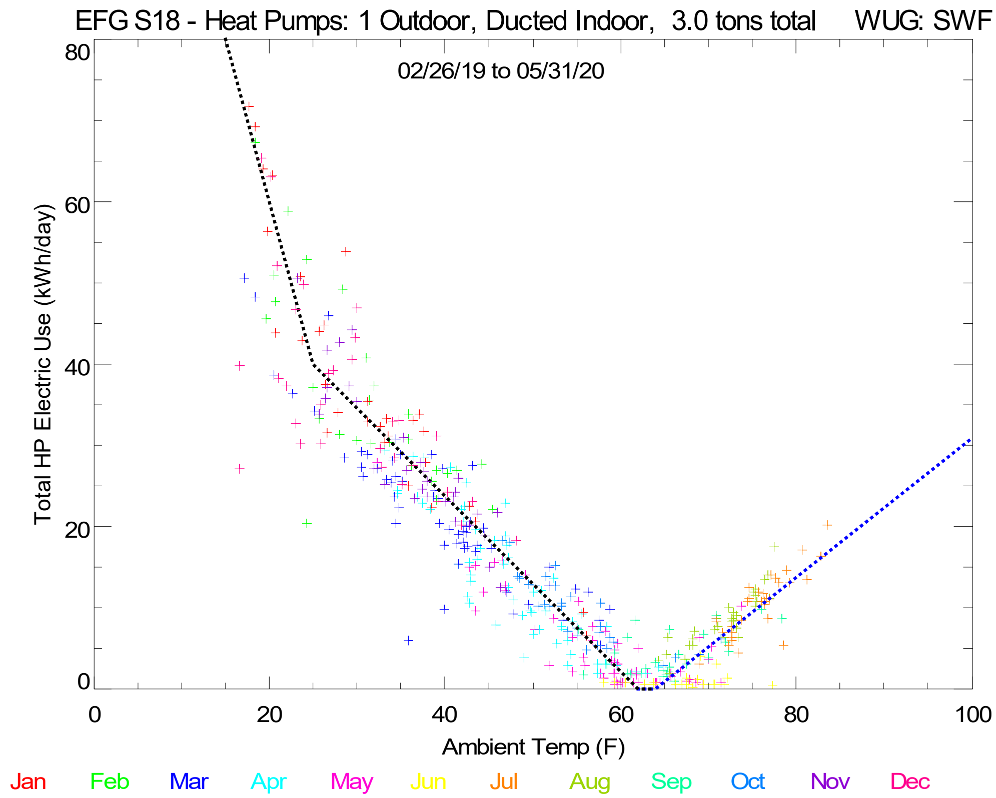


Figure 3. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced some of the fuel oil use by the boiler. Figure 4 compares the trend of monthly fuel use with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period. Limited post-retrofit data were available to confirm the fuel use trend in this period.

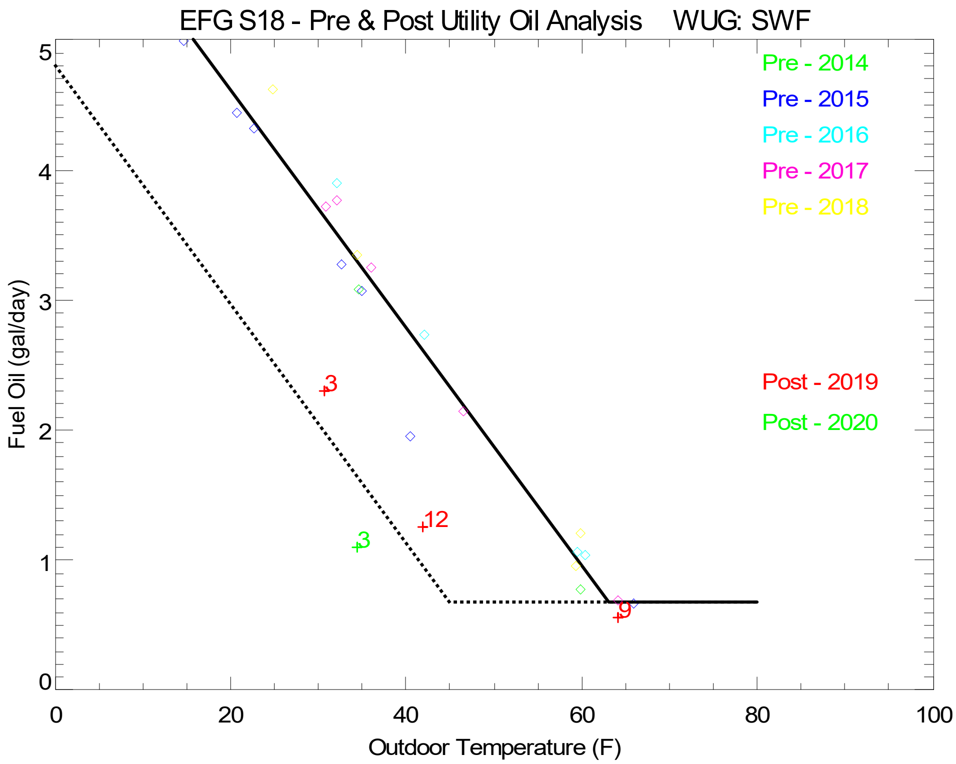


Figure 4. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

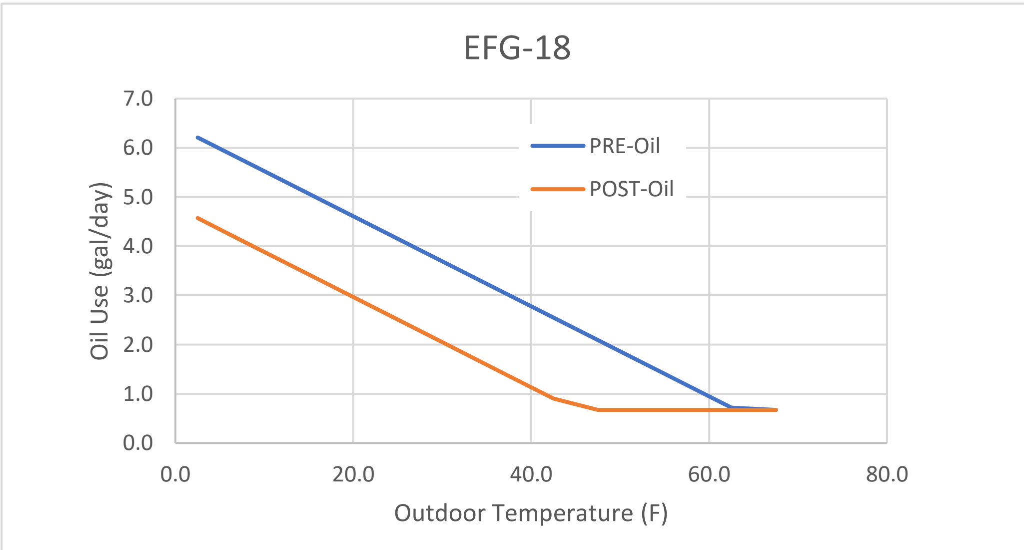
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Newburgh. Table 2 shows the details of bin analysis and Figure 5 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	**EFG-18**	WEATHER:	**Newburgh**	$ 0.150	per kWh
FUEL:	**Oil**			$ 2.686	per gal (oil)
Floor Area	1388	LOCATION:	Gardiner		

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	9.0	7.3	250.0	7.3	0.2	24.0	57.2	
-22.5	0	8.5	6.9	230.0	6.9	0.2	22.8	52.9	
-17.5	0	8.0	6.4	210.0	6.4	0.3	21.6	48.7	
-12.5	0	7.6	5.9	190.0	5.9	0.3	20.4	44.5	
-7.5	1	7.1	5.5	170.0	5.5	0.3	19.1	40.2	
-2.5	13	6.7	5.0	150.0	5.0	0.4	17.9	36.0	
2.5	36	6.2	4.6	130.0	4.6	0.4	16.7	31.8	
7.5	45	5.7	4.1	110.0	4.1	0.5	15.4	27.5	
12.5	113	5.3	3.7	90.0	3.7	0.6	14.2	23.3	
17.5	222	4.8	3.2	70.0	3.2	0.8	13.0	19.1	
22.5	367	4.4	2.7	50.0	2.7	1.1	11.8	14.9	
27.5	373	3.9	2.3	37.3	2.3	1.5	10.5	11.7	
32.5	764	3.5	1.8	31.9	1.8	1.8	9.3	9.7	
37.5	814	3.0	1.4	26.5	1.4	2.1	8.1	7.6	
42.5	727	2.5	0.9	21.1	0.9	2.7	6.8	5.6	
47.5	668	2.1	0.7	15.7	0.7	3.1	5.6	4.2	
52.5	480	1.6	0.7	10.3	0.7	3.2	4.4	3.4	
57.5	748	1.2	0.7	4.9	0.7	3.5	3.2	2.5	
62.5	831	0.7	0.7	0.0	0.7		1.9	1.8	
67.5	902	0.7	0.7	0.0	0.7	0.0	1.8	1.8	
72.5	538	0.7	0.7	0.0	0.7	0.0	1.8	1.8	



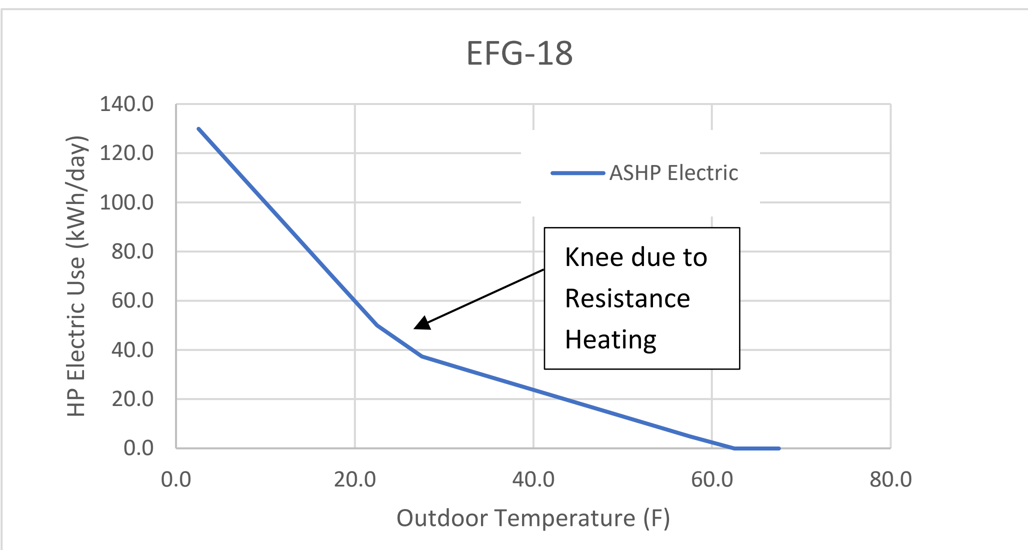


Figure 5. Trends of Pre- and Post-Retrofit Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. The implied seasonal heating COP for the ASHP is 1.7 in this case.

In this instance the implied COP is calculated from

$$COP = (Fuel_{pre} – Fuel_{post})*eff/(3.412xkWh_{hp}) = (489 - 175)*139*0.84 / (3.412*6250)$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Oil (gal/yr)	489	175	314
HP Electric (kWh/yr)		6,250	(6,250)
Total Heating Costs	$1,314	$1,409	-$95
Implied Seasonal COP			1.7

Summary Statistics	
0.35	Fuel gal per sq ft per yr
41.2	Htg MBtu per sq ft per yr
64%	Reduction in Fuel Use
5,507	Measured HP for Htg (kWh/yr)
88%	Measured as % of Typical yr

The ducted ASHP included AHU fan power and resistance element power, so the COP is lower in this case than it is for the ductless heat pumps at other sites. We inferred that the spikes in electric heat power shown in Figure 2 equated to 435 kWh over the monitoring period (or about 310 kWh annually). If we deduct this resistance heat use, **the heating COP for heat pump becomes 1.8 without resistance**. This corrected COP is used in the main report.

Cooling Energy Savings

This site showed one of the best pre-retrofit trends in summertime electric use and it allowed us to make a pre-retrofit to post-retrofit comparison. Figure 6 shows the pre-retrofit trend for electric use (before the HPs were installed). Cooling was provided in the pre-retrofit summer by a central air conditioner.

The cooling trend for the ASHP in the post retrofit period are by the line on Figure 3. The bin analysis shown in Table 4 uses these trend lines with typical year weather data for Newburgh. The pre- and post-retrofit trend lines are compared in Figure 7. Table 5 shows that the trendlines were so close that there was no detectible energy savings when comparing the two cooling systems. The lack of savings may be due to uncertainty of the pre-retrofit trend in Figure 6.

The monthly summertime utility bill readings do not provide enough detail to discern a precise enough pre-retrofit trend. It also may be that the relatively small load did not allow the cooling efficiency difference between the central system and the new ASHP to translate into noticeable change in cooling energy use. The predicted energy use of approximately 950 kWh was reasonably close to the summertime power allocation to cooling in Table 1.

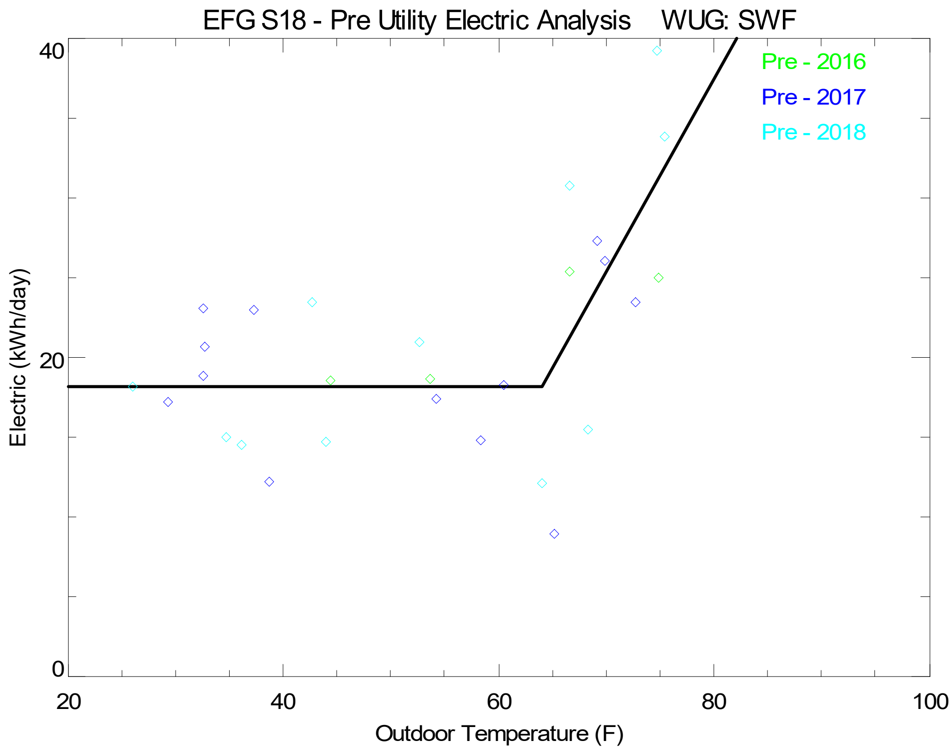


Figure 6. Analysis of Monthly Utility Bills with Temperature, Showing the Pre-retrofit Trend of Summertime Electric Use

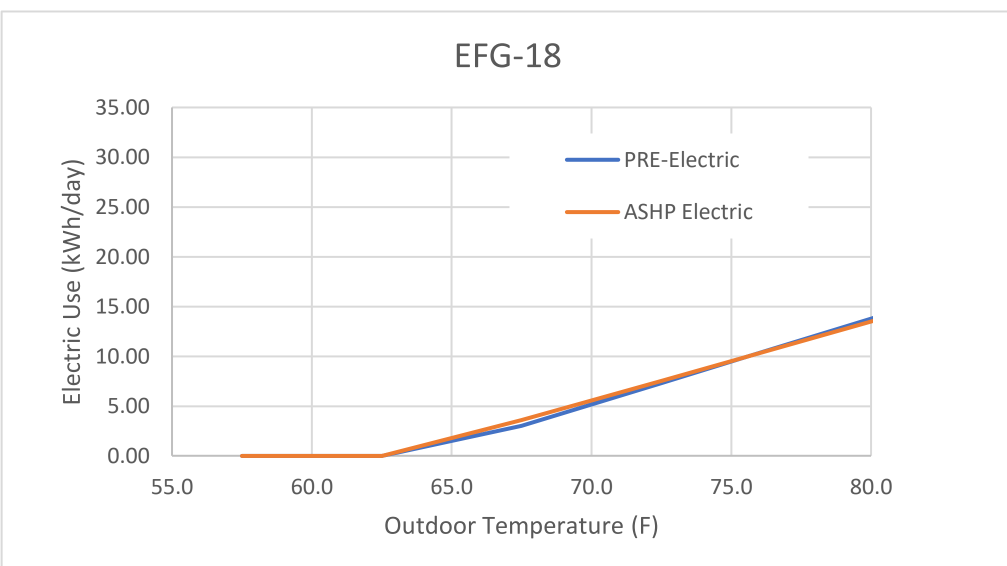


Figure 7. Trends of Pre- and Post-Retrofit Cooling Electric Use in Bin Analysis

Table 4. Bin Analysis Used to Predict Cooling Seasonal Impacts from Trendlines

SITE:	EFG-18	WEATHER:	Newburgh	$ 0.15 per kWh
FUEL:	Electric			$ 0.15 per kWh
Floor Area	1388			

Temp Bin	Hours	FUEL PRE-Electric (kWh/day)	ASHP Electric (kWh/day)	Adjusted PRE-Electric (kWh/day)	Implied EER (-)	PRE-Costs	POST-Costs	PRE-Electric adjustment factor
-27.5	0.0	18.3	0.0	0.00	0.0	0.0	0.0	
-22.5	0.0	18.3	0.0	0.00	0.0	0.0	0.0	
-17.5	0.0	18.3	0.0	0.00	0.0	0.0	0.0	
-12.5	0.0	18.3	0.0	0.00	0.0	0.0	0.0	
-7.5	1.0	18.3	0.0	0.00	0.0	0.0	0.0	
-2.5	12.7	18.3	0.0	0.00	0.0	0.0	0.0	
2.5	36.3	18.3	0.0	0.00	0.0	0.0	0.0	
7.5	45.0	18.3	0.0	0.00	0.0	0.0	0.0	
12.5	113.3	18.3	0.0	0.00	0.0	0.0	0.0	
17.5	222.0	18.3	0.0	0.00	0.0	0.0	0.0	
22.5	366.8	18.3	0.0	0.00	0.0	0.0	0.0	
27.5	373.3	18.3	0.0	0.00	0.0	0.0	0.0	
32.5	763.5	18.3	0.0	0.00	0.0	0.0	0.0	
37.5	813.9	18.3	0.0	0.00	0.0	0.0	0.0	
42.5	727.1	18.3	0.0	0.00	0.0	0.0	0.0	
47.5	667.7	18.3	0.0	0.00	0.0	0.0	0.0	
52.5	480.3	18.3	0.0	0.00	0.0	0.0	0.0	
57.5	747.6	18.3	0.0	0.00	0.0	0.0	0.0	
62.5	830.9	18.3	0.0	0.00	0.0	0.0	0.0	
67.5	901.5	22.5	3.6	3.01	10.1	0.5	0.5	
72.5	538.4	28.5	7.5	7.32	11.6	1.1	1.1	
77.5	603.0	34.5	11.5	11.63	12.1	1.7	1.7	
82.5	357.9	40.5	15.5	15.93	12.3	2.4	2.3	
87.5	134.4	46.5	19.5	20.24	12.5	3.0	2.9	
92.5	22.7	52.5	23.4	24.54	12.6	3.7	3.5	
97.5	0.7	58.5	27.4	28.85	12.6	4.3	4.1	
102.5	0.0	64.5	31.4	33.15	12.7	5.0	4.7	

Table 5. Results of Bin Analysis Showing Cooling Seasonal Results

Cooling Only	PRE-Retrofit	ASHP Cooling	Savings
Electric (kWh/yr)	944	956	(12)
		-	-
Total Cooling Costs	$142	$143	-$2

Average Heat Pump Demand Profiles

Figure 8 and Figure 9 show the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 9 shows the temperature bins associated with cooling operation.

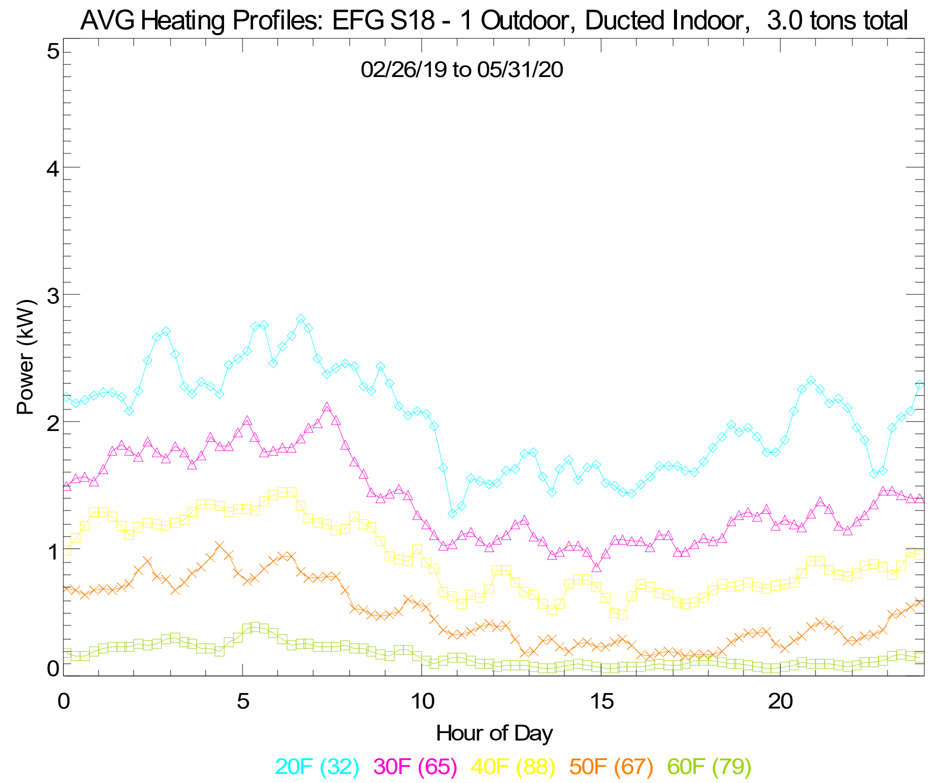


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

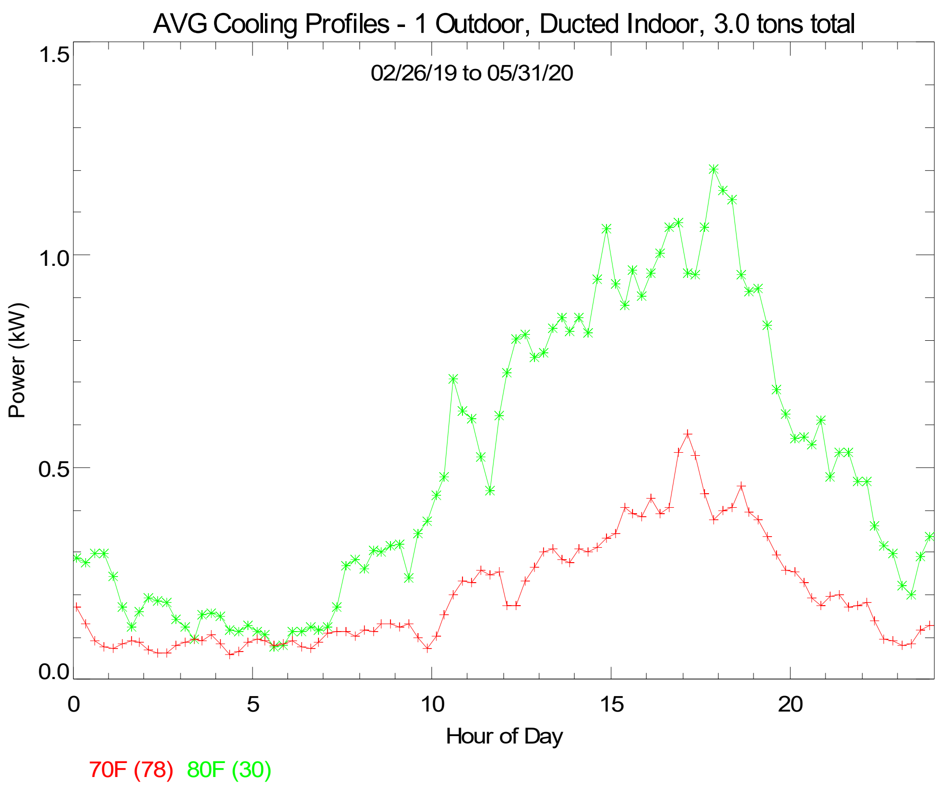


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

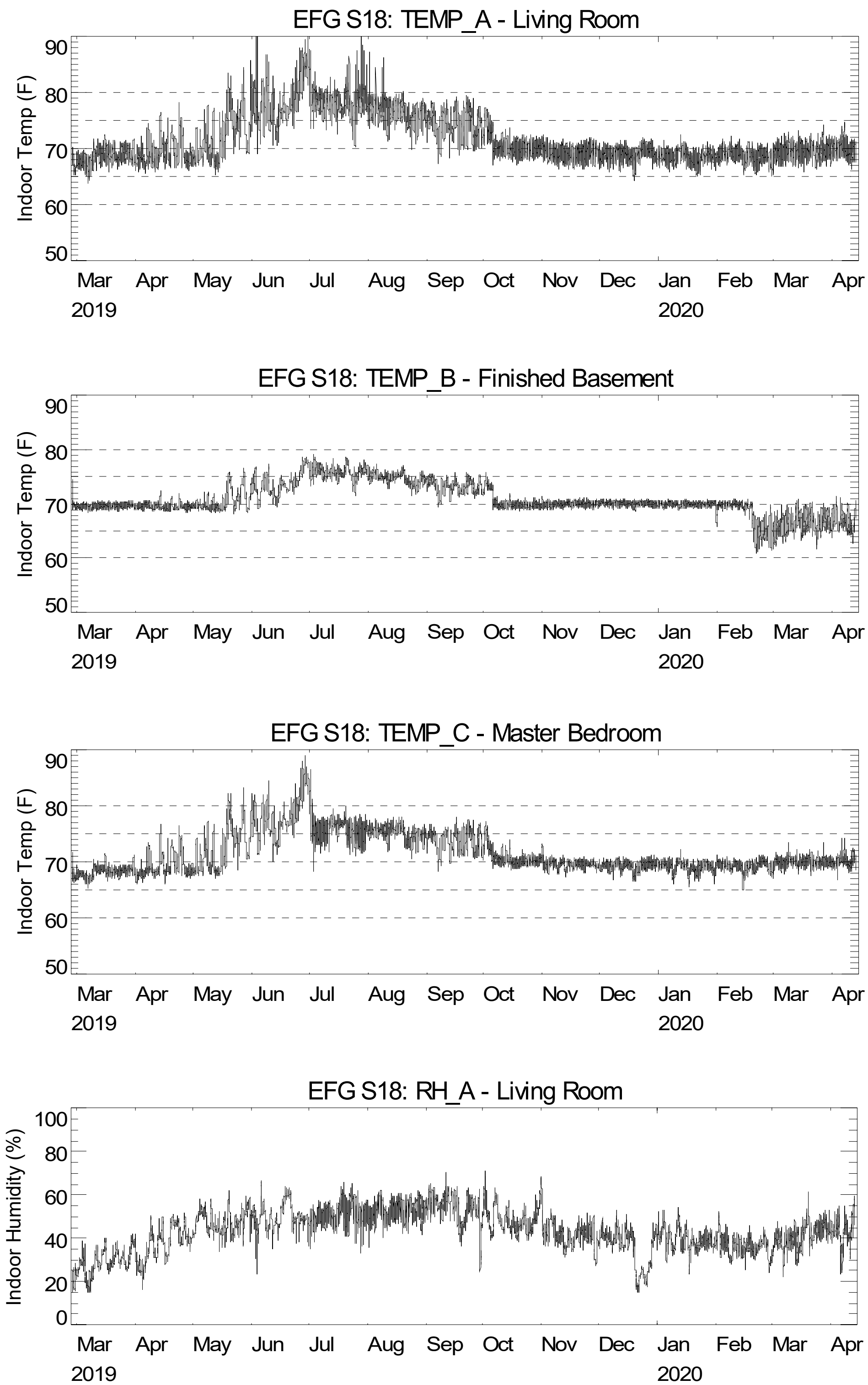


Figure 10. Space Temperatures and Humidity Levels

EFG S19 Savings Analysis

This 1500 sq ft house is in Marlboro, NY near Newburgh. The house was originally heated by baseboard electric heat. The electric baseboard was monitored in the post retrofit period. The three ASHPs were installed on January 10, 2019. Monitoring began in March 2019.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use for the individual heat pumps.

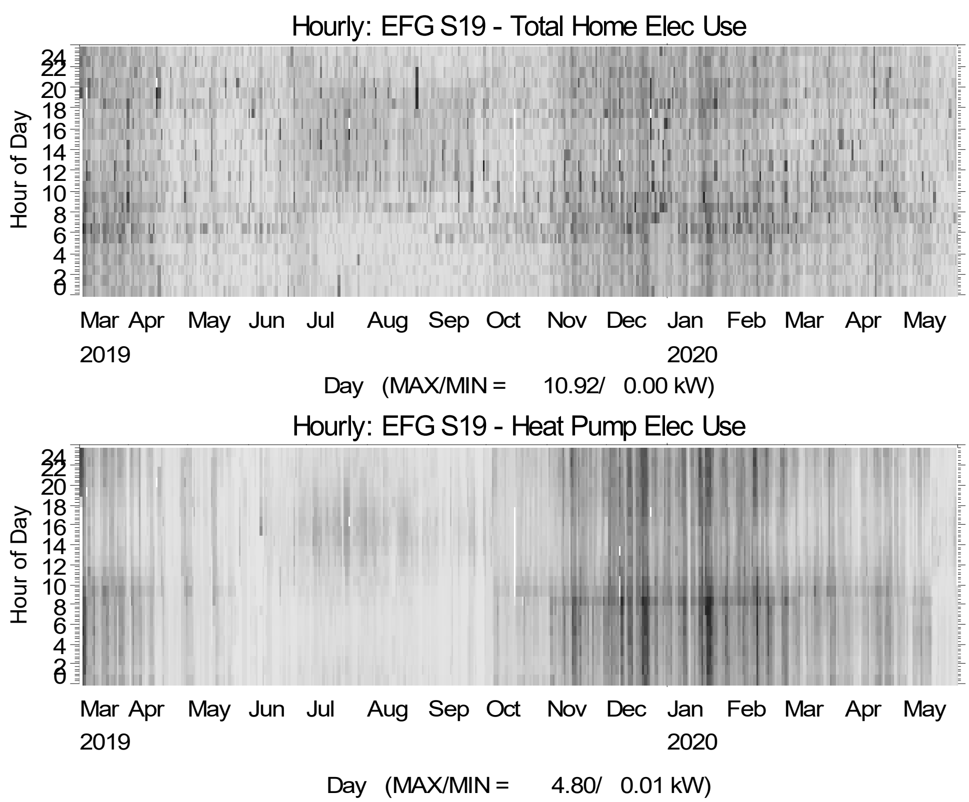


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

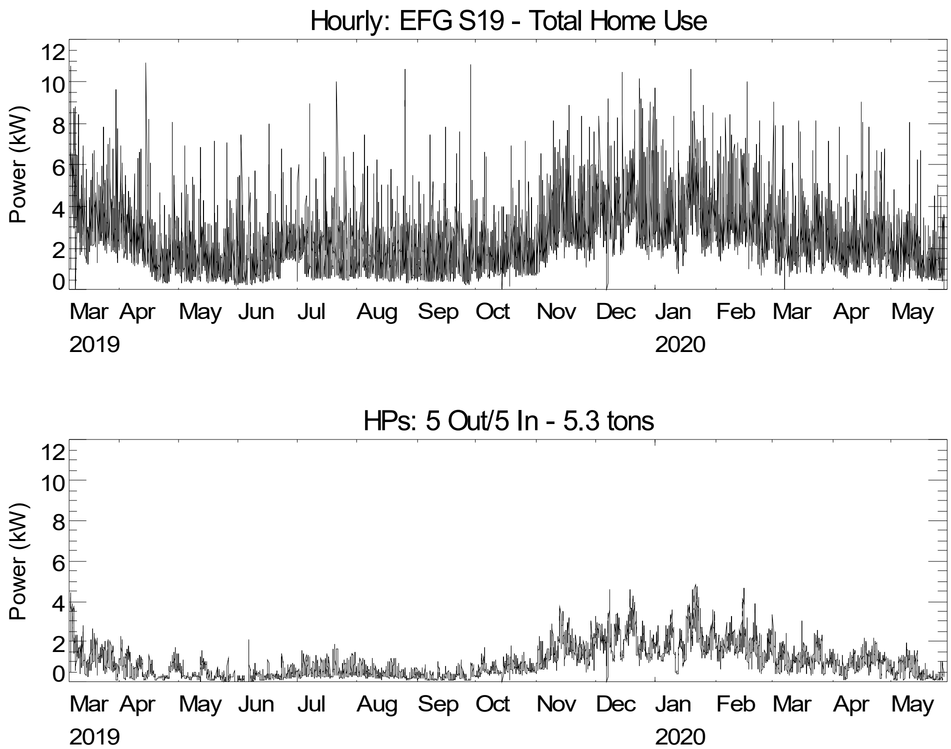


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

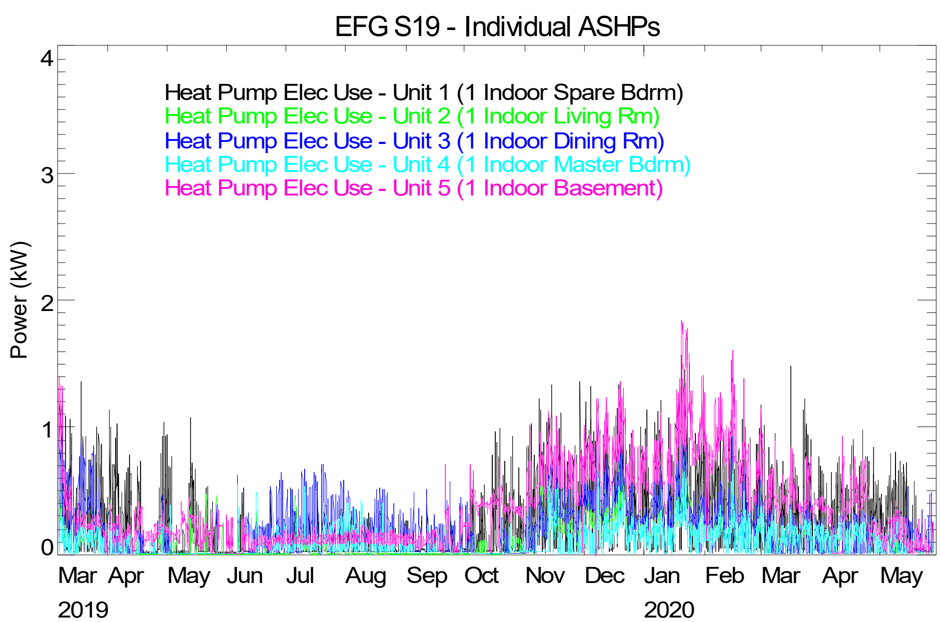


Figure 3. Power Use for the Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. It also includes the energy use for resistance electric heaters that were monitored.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Electric Resist HT (kWh)
Mar-19	27	2,197.3	783.8	644.1
Apr-19	30	1,594.5	422.6	372.4
May-19	31	1,025.5	235.7	34.6
Jun-19	30	1,218.8	202.3	1.4
Jul-19	31	1,524.8	419.2	1.5
Aug-19	31	1,297.7	309.8	1.6
Sep-19	30	1,239.0	198.3	1.5
Oct-19	31	1,246.3	487.1	1.3
Nov-19	30	2,261.3	1,089.4	247.3
Dec-19	31	2,907.2	1,571.4	293.6
Jan-20	31	2,736.1	1,522.6	261.2
Feb-20	29	2,344.8	1,252.8	235.9
Mar-20	31	1,872.2	839.7	77.4
Apr-20	30	1,651.1	677.2	47.0
May-20	28	1,049.2	323.5	5.6
Annual	366	21,324.8	8,805.5	1,204.3
Htg Season	244	16,044.5	7,675.9	1,198.3
Jun-Sep	122	5,280.3	1,129.6	6.0

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature. There is moderate scatter in the data, indicating that the occupants used the ductless heat pump in a fairly consistent manner. The dotted line on the plot represents to a best fit of the trend with temperature.

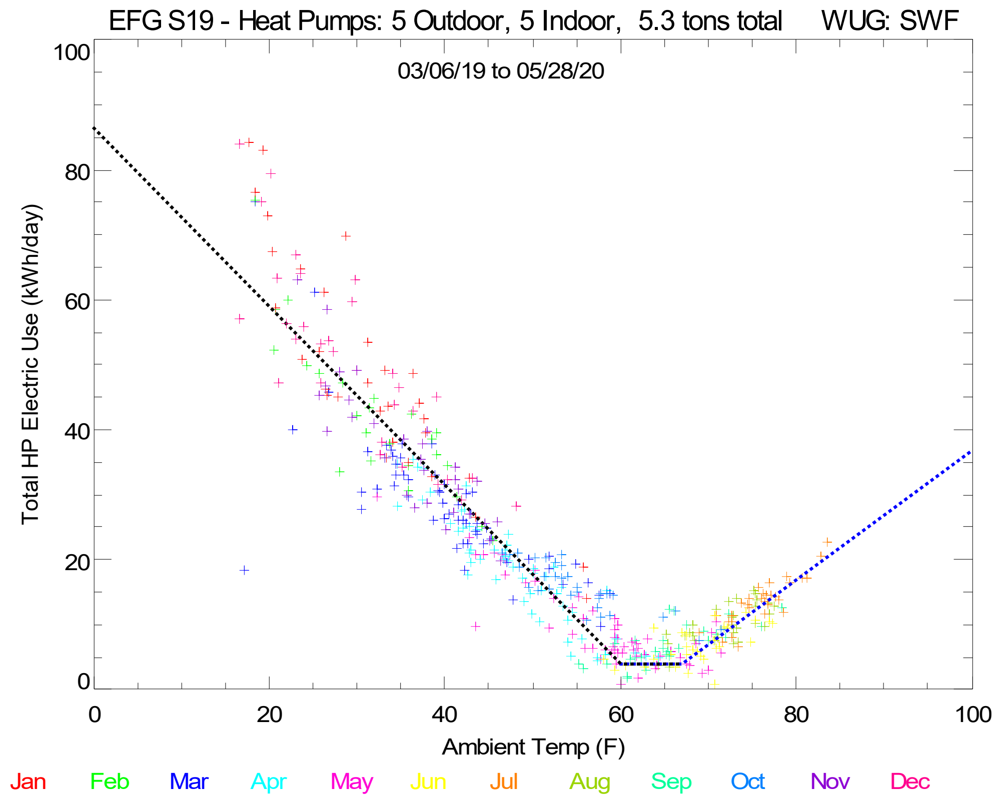


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced baseboard electric heat use. Figure 5 compares the trend of monthly electric with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. The dotted line represents the fuel use trend in the post-retrofit period.

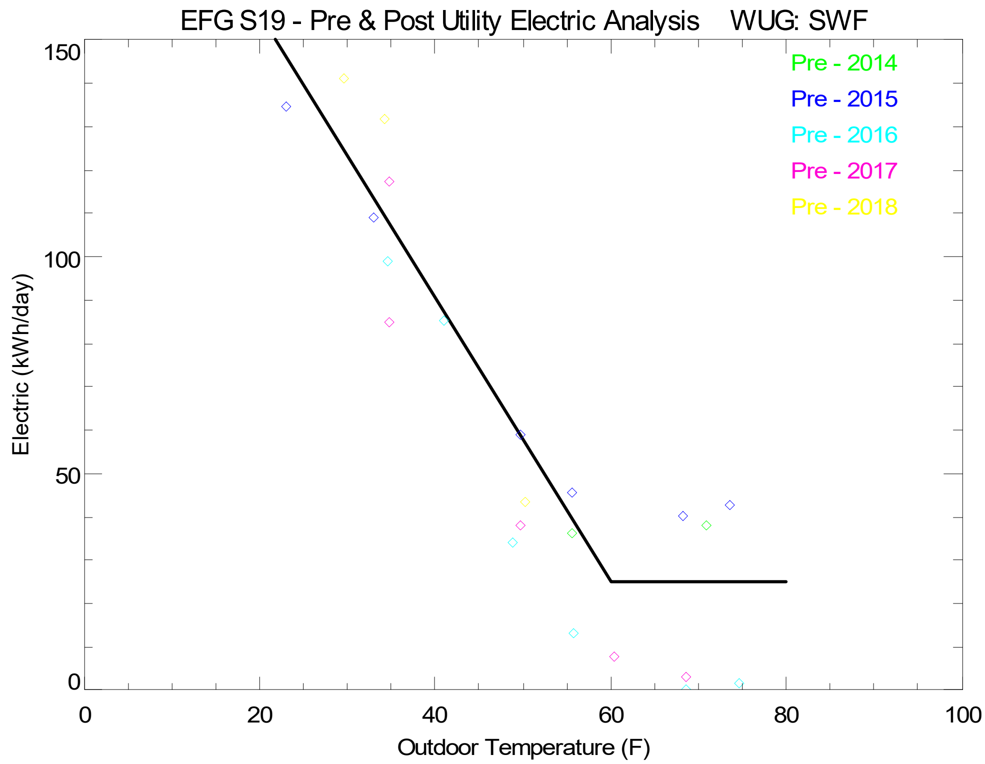


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

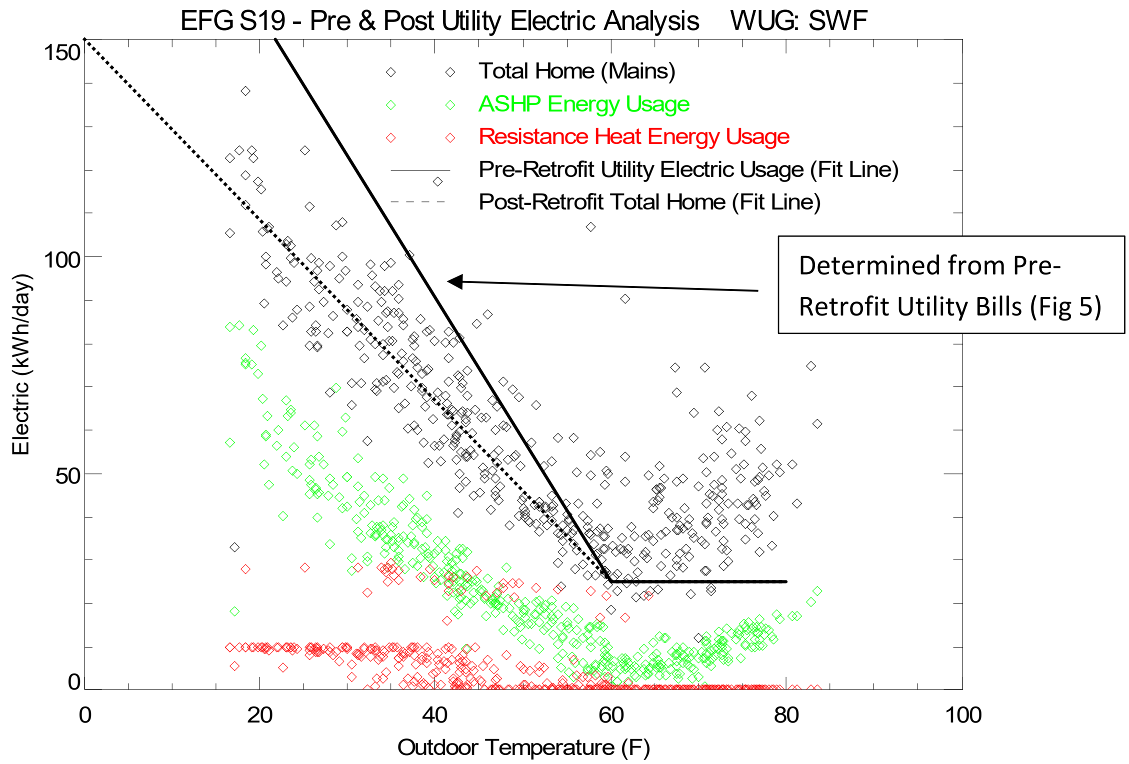


Figure 6. Analysis of Total House Energy Use versus Outdoor Temperature in the Post-Retrofit Period (ASHP and Resistance Heat also shown)

<u>Bin Analysis to Predict Seasonal Impacts</u>

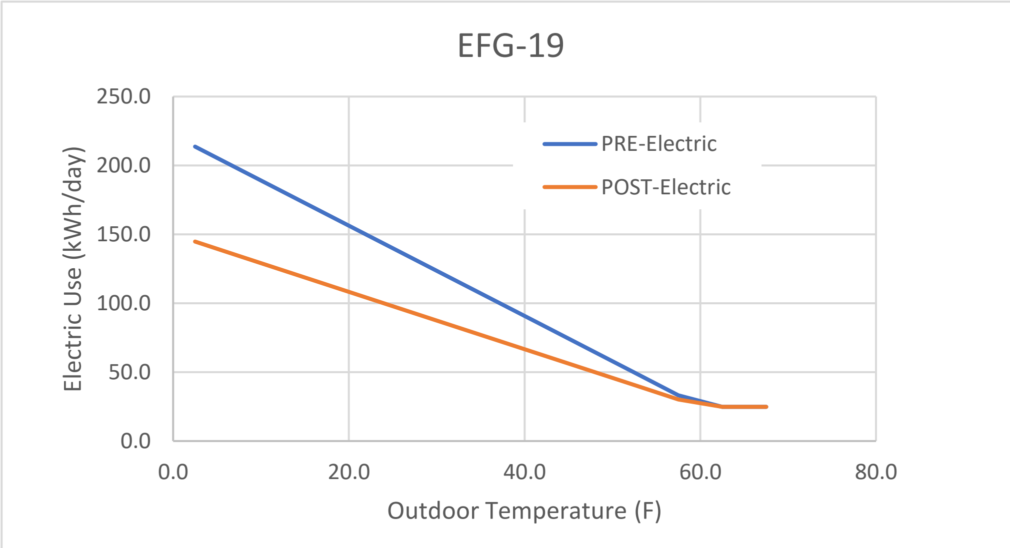
The trend lines above were used in a bin analysis using typical year weather data for Albany. Table 2 shows the details of bin analysis and Figure 7 plots the trend lines used for the analysis.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	**EFG-19**	WEATHER:	**Newburgh**
FUEL:	**Electric**		
Floor Area	1500	LOCATION:	Marlboro

$ 0.150 per kWh
$ 0.150 per kWh

Temp Bin	Hours	FUEL PRE-Electric (kWh/day)	FUEL POST-Electric (kWh/day)	ASHP Electric (kWh/day)	Adjusted POST-Electric (kWh/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Electric adjustment factor
-27.5	0	312.3	207.3	124.3	207.3	1.8	46.8	49.7	
-22.5	0	295.9	196.9	117.4	196.9	1.8	44.4	47.1	
-17.5	0	279.5	186.5	110.6	186.5	1.8	41.9	44.6	
-12.5	0	263.0	176.0	103.7	176.0	1.8	39.5	42.0	
-7.5	1	246.6	165.6	96.8	165.6	1.8	37.0	39.4	
-2.5	13	230.2	155.2	89.9	155.2	1.8	34.5	36.8	
2.5	36	213.8	144.8	83.1	144.8	1.8	32.1	34.2	
7.5	45	197.4	134.4	76.2	134.4	1.8	29.6	31.6	
12.5	113	181.0	124.0	69.3	124.0	1.8	27.1	29.0	
17.5	222	164.5	113.5	62.4	113.5	1.8	24.7	26.4	
22.5	367	148.1	103.1	55.6	103.1	1.8	22.2	23.8	
27.5	373	131.7	92.7	48.7	92.7	1.8	19.8	21.2	
32.5	764	115.3	82.3	41.8	82.3	1.8	17.3	18.6	
37.5	814	98.9	71.9	34.9	71.9	1.8	14.8	16.0	
42.5	727	82.5	61.5	28.1	61.5	1.7	12.4	13.4	
47.5	668	66.0	51.0	21.2	51.0	1.7	9.9	10.8	
52.5	480	49.6	40.6	14.3	40.6	1.6	7.4	8.2	
57.5	748	33.2	30.2	7.4	30.2	1.4	5.0	5.6	
62.5	831	25.0	25.0	4.0	25.0	1.0	3.8	4.4	
67.5	902	25.0	25.0	4.0	25.0	1.0	3.8	4.4	
72.5	538	25.0	25.0	4.0	25.0	1.0	3.8	4.4	
77.5	603	25.0	25.0	4.0	25.0	1.0	3.8	4.4	
82.5	358	25.0	25.0	4.0	25.0	1.0	3.8	4.4	
87.5	134	25.0	25.0	4.0	25.0	1.0	3.8	4.4	
92.5	23	25.0	25.0	4.0	25.0	1.0	3.8	4.4	
97.5	1	25.0	25.0	4.0	25.0	1.0	3.8	4.4	
102.5	0	25.0	25.0	4.0	25.0	1.0	3.8	4.4	



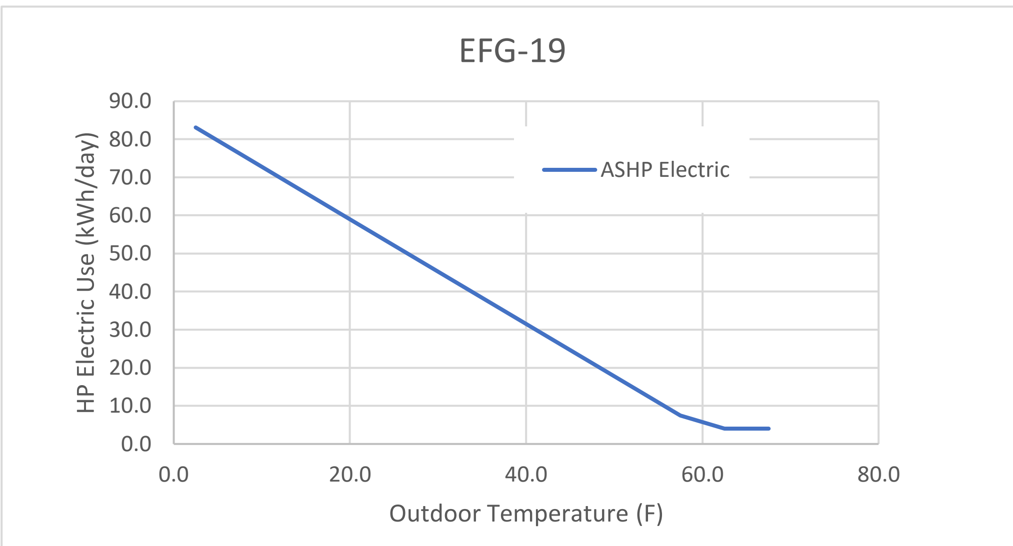


Figure 7. Trends of (Pre and Post Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. Since the base fuel is electric, the savings calculation only considers the pre- and post-retrofit electric use. The implied seasonal heating COP is 1.9, using both electric savings and heat pump energy use which is shown on the bottom of the table.

In this instance the implied COP is calculated from

$$COP = (kWh_{pre} - kWh_{post} + kWh_{hp})/kW_{hp} = (15304 - 9710 + 6409) / 8409$$

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Electric (kWh/yr)	15,304	9,710	5,593
		-	-
Total Heating Costs	$2,296	$1,457	$839
Implied Seasonal COP			1.87
HP Electric (kWh/yr)			6,409

Summary Statistics	
10.20	Fuel kWh per sq ft per yr
34.8	Htg MBtu per sq ft per yr
37%	Reduction in Fuel Use
7,676	Measured HP for Htg (kWh/yr)
120%	Measured as % of Typical yr

Table 4 uses the measured resistance heating use in the post-retrofit period to find the savings from installing the heat pumps. An implied COP with and without resistance heating is given. The implied COP with resistance was just lower with this approach using the measured resistance heating power.

Table 4. Results of Bin Analysis Showing Seasonal Impact to Resistant Heating Use

Heating Only	PRE-Retrofit	POST-Retrofit	Savings
Resistance (kWh/yr)	15,304	1,204	14,100
ASHP (kWh/yr)		6,409	(6,409)
Total Heat (kWh/yr)	15,304	7,613	7,691
Total Heating Costs	$2,296	$1,142	$1,154
Implied ASHP COP			2.2
Overall COP Including Resistance			2.0

The ASHP COP of 2.2 is used in the main report.

Average Heat Pump Demand Profiles

Figure 8 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 9 shows the temperature bins associated with cooling operation.

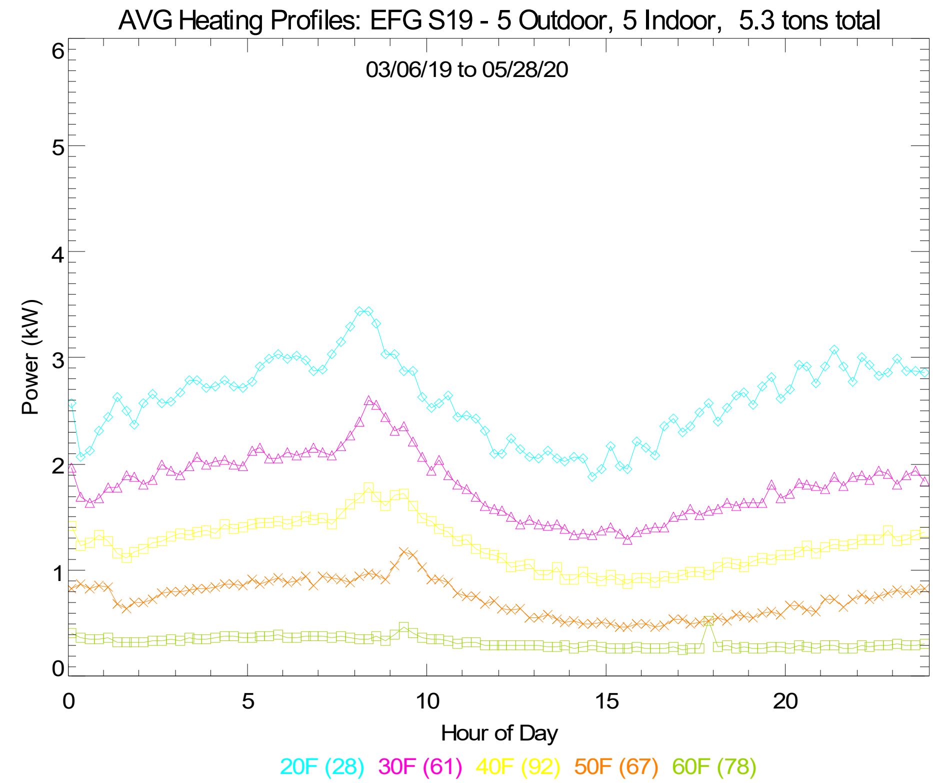


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

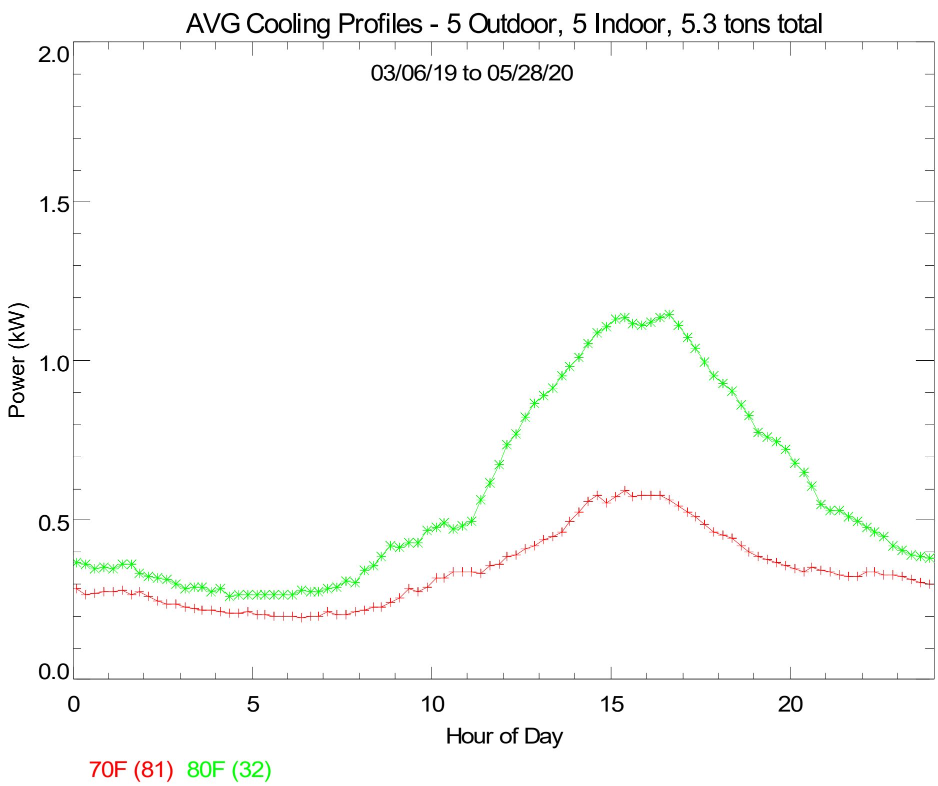


Figure 9. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 10.

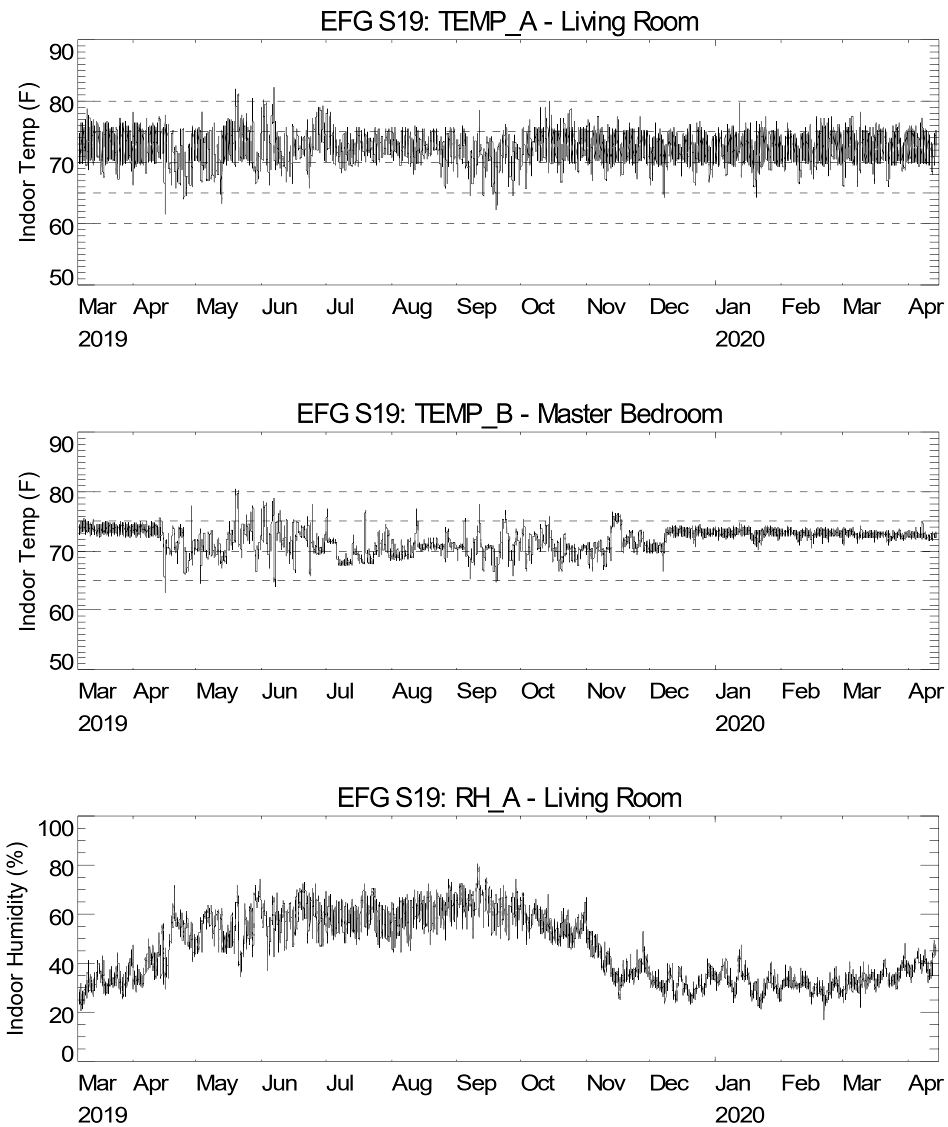


Figure 10. Space Temperatures and Humidity Levels

EFG S20 Savings Analysis

This 1320 sq ft house is in New Paltz, NY near Newburgh. The house was originally heated by a propane furnace. The furnace was removed when five ASHPs were installed in January 2019. Monitoring began in March 2019. There was baseboard electric heat in the basement area that was monitored in the post-retrofit period.

The shade plot in Figure 1 shows the annual pattern of electric use for the total home and the installed heat pumps. Figure 2 shows the power use for the house and heat pumps across the monitoring period. Figure 3 shows the power use of the individual heat pumps.

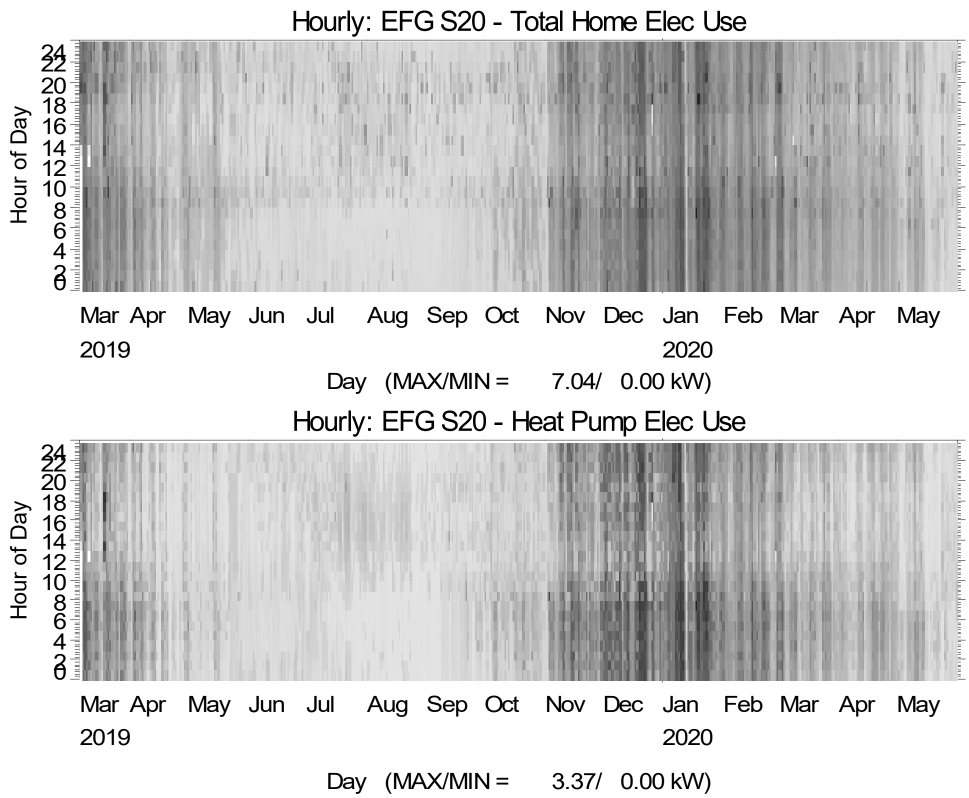


Figure 1. Shade Plots Showing Total Home and Total Heat Pump Energy Use with Shades of Gray. Darker shades indicate more power use. Light gray indicates zero use.

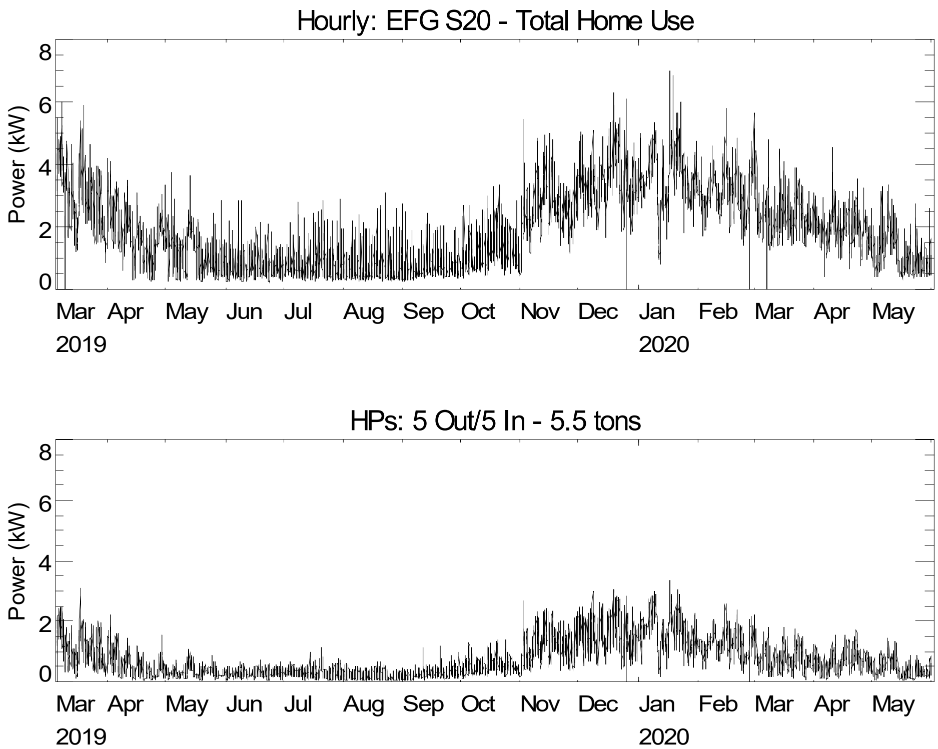


Figure 2. Total House and Heat Pump (HP) Power Across the Monitoring Period

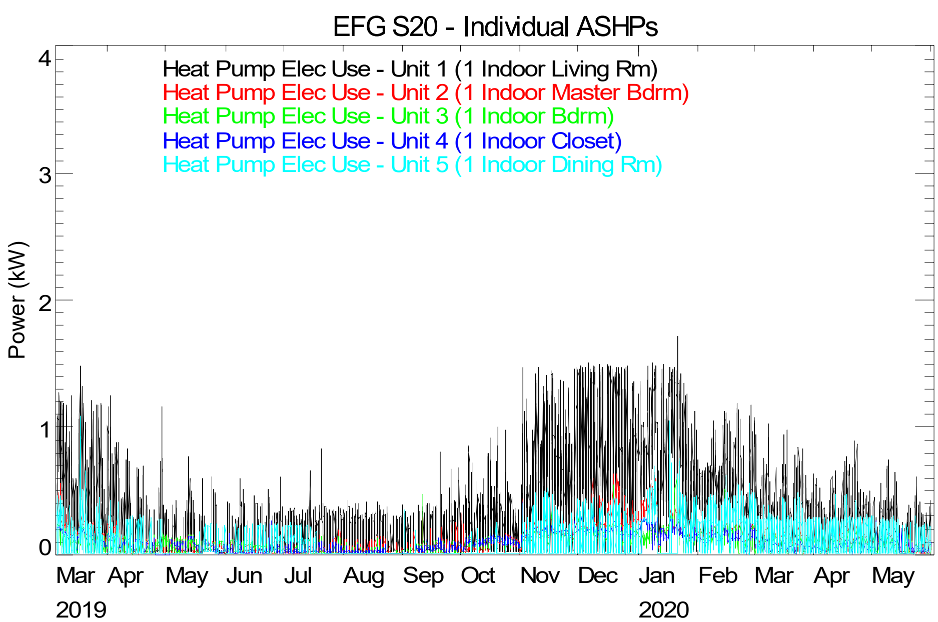


Figure 3. Power Use of Individual Heat Pumps Across the Monitoring Period

Table 1 summarizes the measured energy use for the total house and the heat pump over the monitoring period. It also includes the resistance electric heaters that were monitored.

Table 1. Measured Electric Use for the Total House and Heat Pumps

	No of Days	Total House (kWh)	All HPs (kWh)	Solar (kWh)	DHW (kWh)	Electric Resist HT (kWh)
Mar-19	27	1,890.4	693.0	-	4.4	1,255.3
Apr-19	30	1,257.1	374.3	-	4.8	665.8
May-19	31	887.1	230.3	-	4.9	387.0
Jun-19	30	517.1	187.7	-	4.6	42.0
Jul-19	31	589.0	231.7	-	5.7	2.6
Aug-19	31	526.6	153.9	-	5.4	2.5
Sep-19	30	507.3	184.9	-	4.8	4.4
Oct-19	31	924.1	374.2	-	4.9	194.2
Nov-19	30	1,950.9	890.8	-	4.7	1,128.2
Dec-19	31	2,629.5	1,268.6	-	5.2	1,667.2
Jan-20	31	2,697.5	1,277.6	-	5.0	1,564.0
Feb-20	29	2,165.3	866.1	-	4.6	1,332.3
Mar-20	31	1,761.4	595.8	-	5.4	927.3
Apr-20	30	1,420.1	496.3	-	5.0	809.2
May-20	31	837.9	308.2	-	5.1	324.4
Annual	366	16,575.9	6,757.9	-	60.2	8,060.9
Htg Season	244	14,435.9	5,999.7	-	39.7	8,009.4
Jun-Sep	122	2,140.0	758.2	-	20.5	51.5

Measured Trends

Daily heat pump power use is shown in Figure 4 as function of daily average outdoor temperature. There is moderate scatter in the data, indicating that the occupants used the ductless heat pump in a fairly consistent manner. The dotted line on the plot represents to a best fit of the trend with temperature.

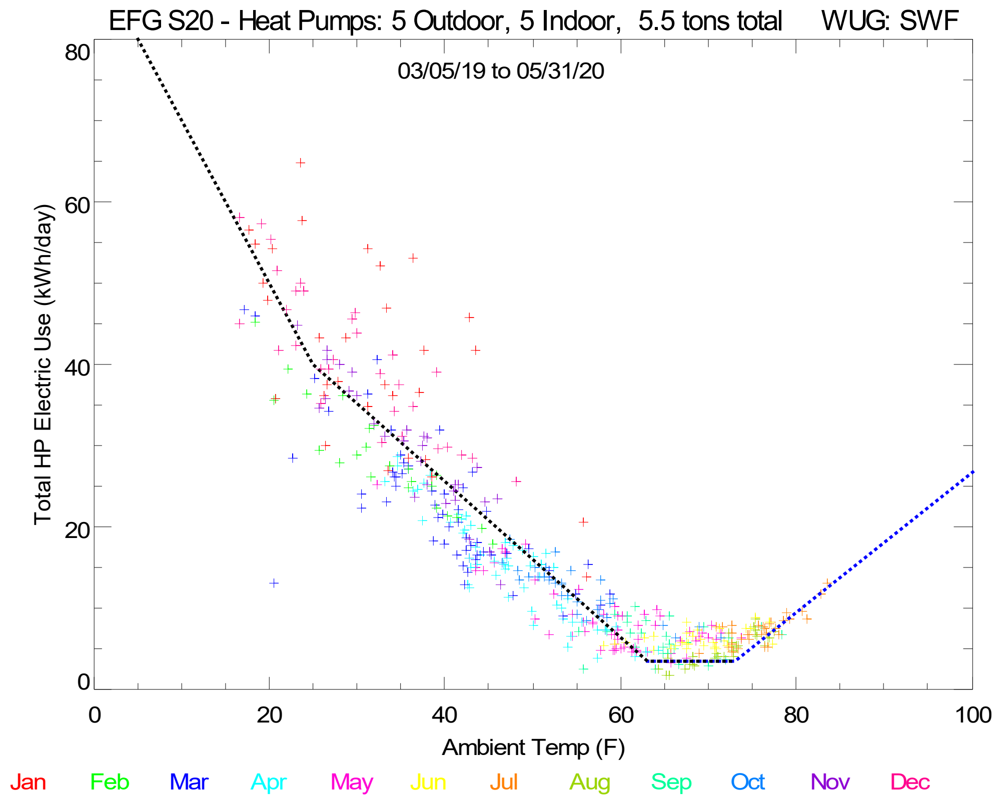


Figure 4. Daily Heat Pump Energy Use vs. Daily Average Temperature (Days in each month shown with a different color)

At this site heat pump operation displaced mostly propane use. Figure 5 compares the trend of monthly electric with temperature for both the pre- and post-retrofit periods. The solid line represents the overall fuel use trend in the pre-retrofit period. There was no post-retrofit propane use since hot water was provided by a heat pump water heater.

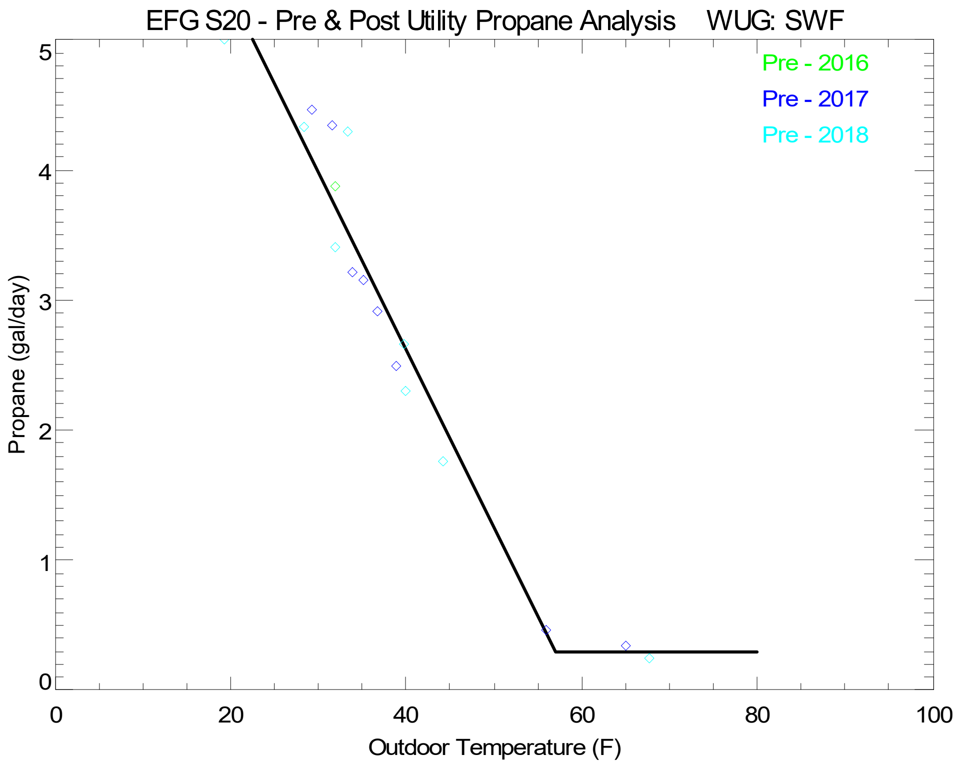


Figure 5. Analysis of Monthly Utility Bills with Temperature, Comparing Pre-Retrofit and Post-Retrofit Trends of Fuel Use (the number shown by each post-retrofit data point indicates the month)

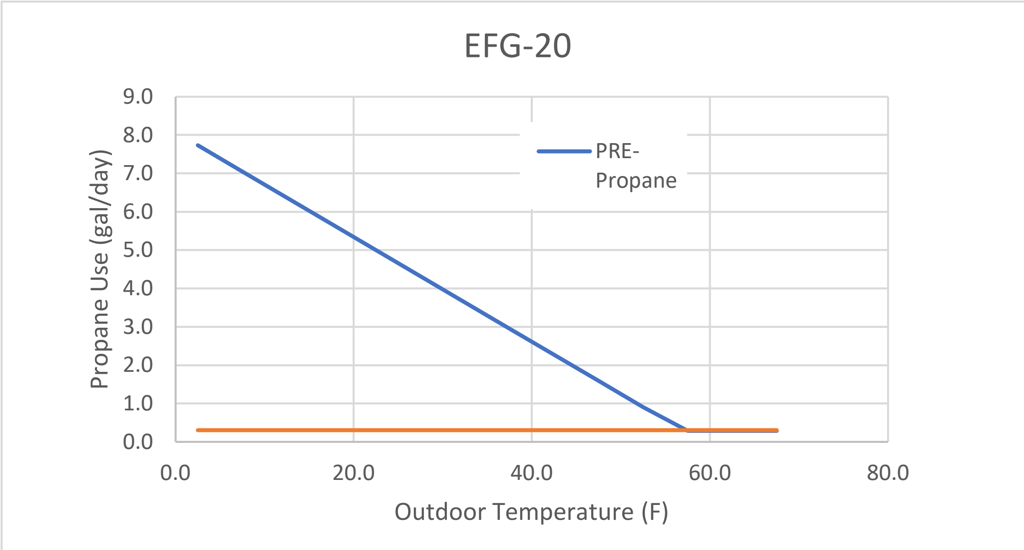
Bin Analysis to Predict Seasonal Impacts

The trend lines above were used in a bin analysis using typical year weather data for Albany. Table 2 shows the details of bin analysis and Figure 6 plots the trend lines used for the analysis. While no fuel was used in the post-retrofit periods, the adjusted post-retrofit fuel use was set to equal the pre-retrofit baseline to discern the impact of the heat pump.

Table 2. Bin Analysis Used to Predict Seasonal Impacts from Trendlines

SITE:	**EFG-20**				WEATHER:	**Newburgh**	$	0.150	per kWh
FUEL:	**Propane**						$	2.440	per gal (propane)
Floor Area	1320				LOCATION:	New Paltz			

Temp Bin	Hours	FUEL PRE-Propane (gal/day)	FUEL POST-Propane (gal/day)	ASHP Electric (kWh/day)	Adjusted POST-Propane (gal/day)	Implied COP (-)	PRE-Costs	POST-Costs	POST-Propane adjustment factor
-27.5	0	11.8	0.0	145.0	0.3	1.7	28.9	22.5	
-22.5	0	11.1	0.0	135.0	0.3	1.7	27.2	21.0	
-17.5	0	10.5	0.0	125.0	0.3	1.7	25.5	19.5	
-12.5	0	9.8	0.0	115.0	0.3	1.7	23.9	18.0	
-7.5	1	9.1	0.0	105.0	0.3	1.7	22.2	16.5	
-2.5	13	8.4	0.0	95.0	0.3	1.8	20.5	15.0	
2.5	36	7.7	0.0	85.0	0.3	1.8	18.9	13.5	
7.5	45	7.0	0.0	75.0	0.3	1.9	17.2	12.0	
12.5	113	6.4	0.0	65.0	0.3	1.9	15.5	10.5	
17.5	222	5.7	0.0	55.0	0.3	2.0	13.9	9.0	
22.5	367	5.0	0.0	45.0	0.3	2.2	12.2	7.5	
27.5	373	4.3	0.0	37.6	0.3	2.2	10.5	6.3	
32.5	764	3.6	0.0	32.8	0.3	2.1	8.9	5.6	
37.5	814	3.0	0.0	28.0	0.3	2.0	7.2	4.9	
42.5	727	2.3	0.0	23.2	0.3	1.8	5.5	4.2	
47.5	668	1.6	0.0	18.4	0.3	1.5	3.9	3.5	
52.5	480	0.9	0.0	13.6	0.3	0.9	2.2	2.7	
57.5	748	0.3	0.0	8.8	0.3	0.0	0.7	2.0	
62.5	831	0.3	0.0	4.0	0.3	0.0	0.7	1.3	
67.5	902	0.3	0.0	3.5	0.3	0.0	0.7	1.2	
72.5	538	0.3	0.0	3.5	0.3	0.0	0.7	1.2	
77.5	603	0.3	0.0	3.5	0.3	0.0	0.7	1.2	
82.5	358	0.3	0.0	3.5	0.3	0.0	0.7	1.2	
87.5	134	0.3	0.0	3.5	0.3	0.0	0.7	1.2	
92.5	23	0.3	0.0	3.5	0.3	0.0	0.7	1.2	
97.5	1	0.3	0.0	3.5	0.3	0.0	0.7	1.2	
102.5	0	0.3	0.0	3.5	0.3	0.0	0.7	1.2	



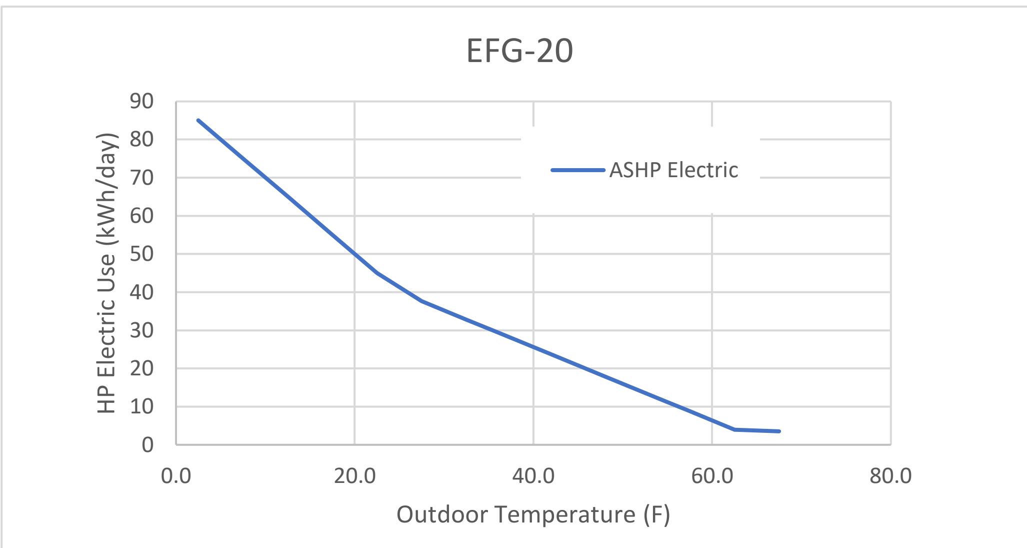


Figure 6. Trends of (Pre and Post Fuel Use (top) and Heat Pump Electric Use (bottom) Used in Bin Analysis

Table 3 shows the seasonal results from the bin analysis. The assumed fuel costs (shown on Table 2) are from the ASHP Proforma Tool developed by NYSERDA. Since the base fuel is most mostly, the savings calculation only considers the pre- and post-retrofit fuel use. The implied seasonal heating COP is 1.8

In this instance the implied COP is calculated from

$$COP = (Fuel_{pre} - Fuel_{post})*eff/(3.412 x kWh_{hp}) = (547 - 0)*92*0.77 / (3.412*6433)$$

This calculation does not consider the energy use of the resistance heaters in the basement. We assumed that the electric use for basement heating was the same in the pre and post retrofit periods. Adding in the basement electric use increases the space heating load from 29.3 MBtu/sq ft-yr to 50.2 MBtu/sq ft-yr.

Table 3. Results of Bin Analysis Showing Seasonal Results

Heating Only	**PRE-Retrofit**	**POST-Retrofit**	**Savings**
Propane (gal/yr)	547	-	547
HP Electric (kWh/yr)		6,433	(6,433)
Total Heating Costs	$1,334	$965	$369
Implied Seasonal COP			1.8

Summary Statistics	
0.41	Fuel gal per sq ft per yr
29.3	Htg MBtu per sq ft per yr
100%	Reduction in Fuel Use
6,000	Measured HP for Htg (kWh/yr)
93%	Measured as % of Typical yr

This calculation does not consider the energy use of the resistance heaters in the basement. We assumed that the electric use for basement heating was the same in the pre and post retrofit periods. Adding in the basement electric use increases the space heating load from 29.3 MBtu/sq ft-yr to 50.2 MBtu/sq ft-yr.

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

Figure 7 shows the average daily demand profile for the heat pump, grouped by different temperature conditions. Each line takes the average 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 profile. Figure 8 shows the temperature bins associated with cooling operation.

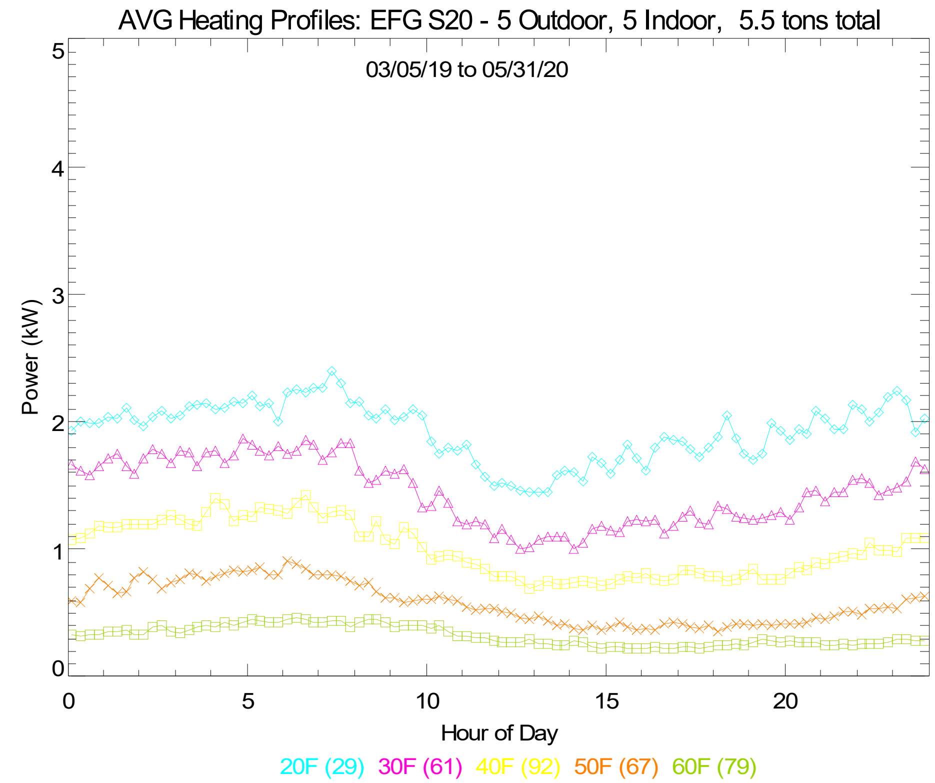


Figure 7. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Heating)

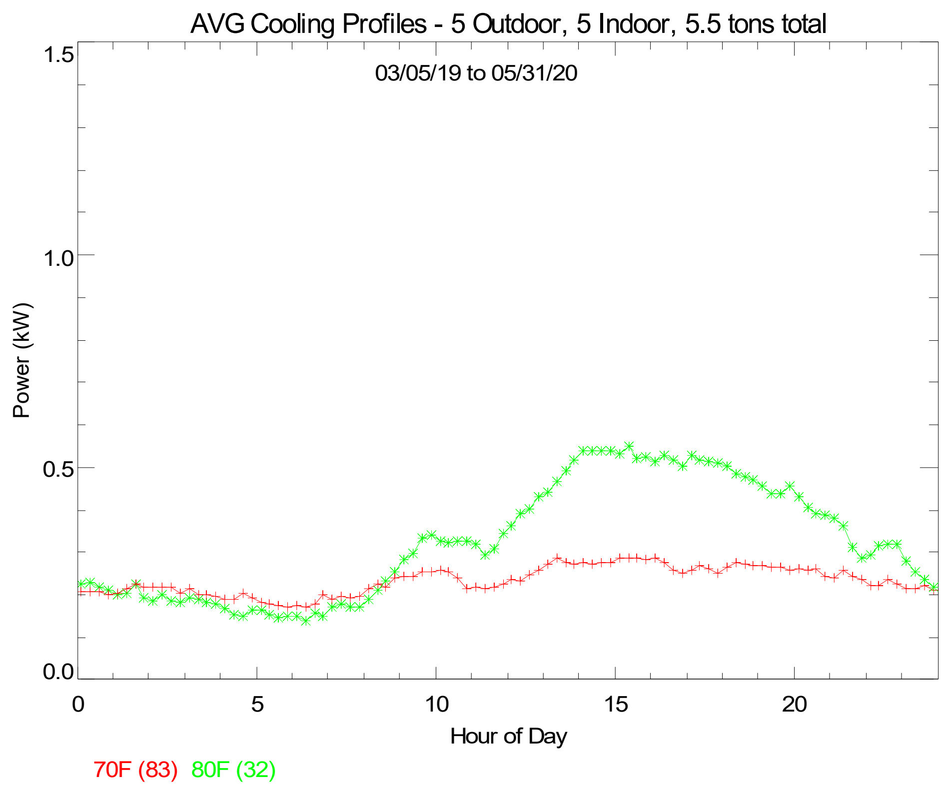


Figure 8. Heat Pump Demand Profile Across the Day – Averaged for Various Outdoor Temperature Bins (Cooling)

Space Temperatures

Space temperatures and humidity levels are shown in Figure 9.

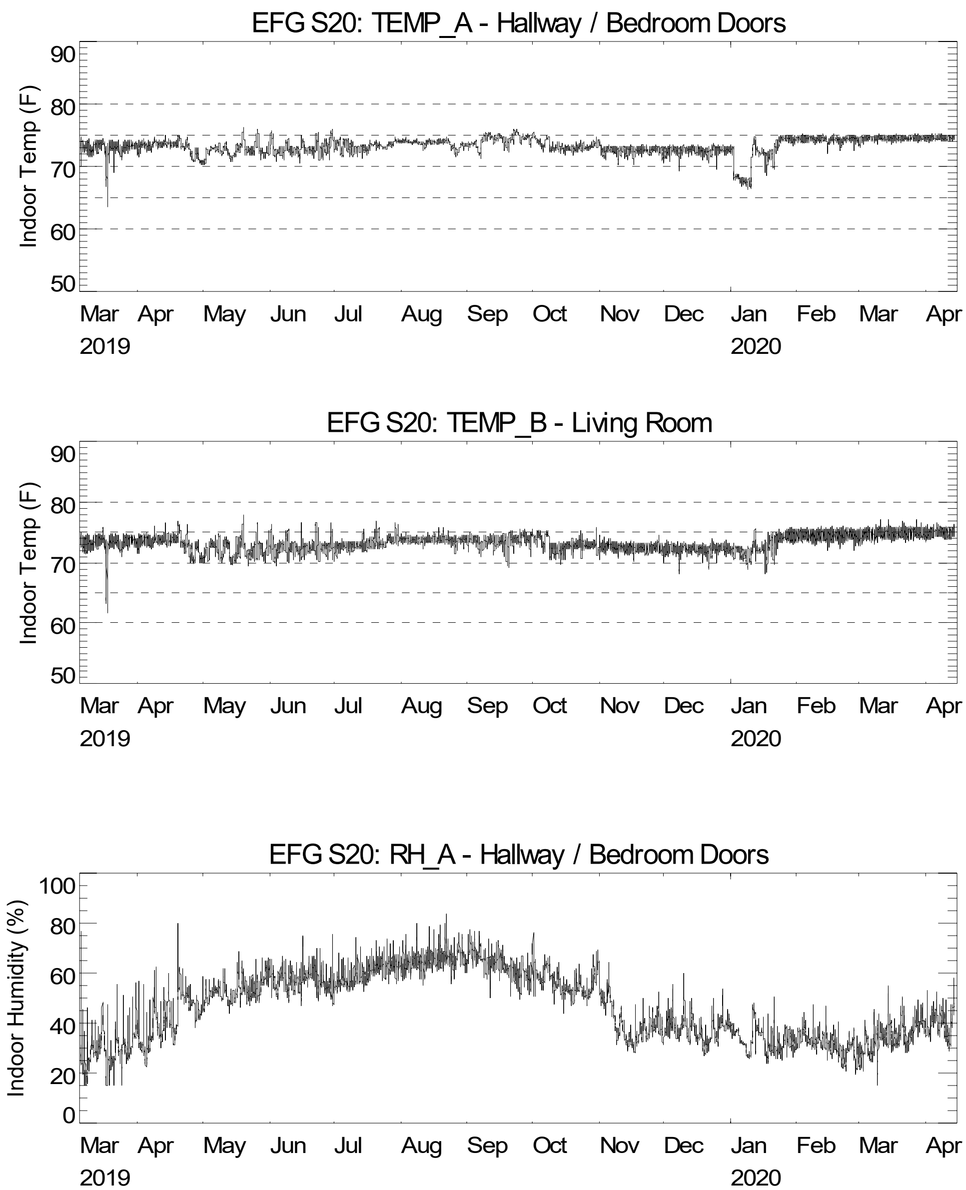


Figure 9. Space Temperatures and Humidity Levels

Appendix D. Performance Validation Plan

The following pages in this appendix provide the Performance Validation Plan.

Performance Validation Plan

for

Energy Futures Group:

Hudson Valley Heat Pump Project

under

NYSERDA PON 3127
Emerging Technologies Demonstration Projects –
Residential HVAC

October 18, 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

*Bill Mitchell		bill.mitchell@nyserda.ny.gov
*Scott Smith	518-662-1090 x 3344	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

Energy Futures Group
PO Box 587, Hinesburg, VT 05461
802-482-5001

*Richard Faesy, Principal		rfaesy@energyfuturesgroup.com
Gabrielle Stebbins		gstebbins@energyfuturesgroup.com

Bruce Harley	802-694-1719	bruceharleyenergy@gmail.com
Pasquale Strocchia	845-255-0418	pasquale@integralbuildingenergy.com
Ashley Nichols	802-862-8261	anicholls@ksvc.com
Mary Stewart	802-862-8261	mstewart@ksvc.com
Eric Dubin	617-939-1492	edubin@hvac.mea.com
Rick Nortz	617-489-2214	rnortz@hvac.mea.com
Michael Gamberoni	508-259-1543	mgamberoni@hvac.mea.com

Air-Source Heat Pump (ASHP) Advisory Group

Dave Lis		djlis@neep.org
Jonathon Comstock		jpc8@cornell.edu
Laura Tajima		ltajima@cityhall.nyc.gov
Jordan Dentz		jdentz@levypartnership.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

Validation Project Participants i

NYSERDA Staff i

Technical Consultant i

Applicant Team i

Air-Source Heat Pump (ASHP) Advisory Group i

Introduction 1

Background 1

Approach 1

Performance Validation Approach 2

Overview 2

Pilot Design 2

Site Selection Criteria (Sample Design) 3

Data Collected at Each Site 4

Data Collection Details 4

ASHP Monitoring at Each Site (Post-Retrofit) 4

Pre-Retrofit Utility Bills/Fuel Logs 5

Site Characteristics Data Collection 6

Customer Feedback Survey 7

Data Analysis 9

Pre-Retrofit Data Analysis 9

Post-Retrofit Data Analysis 10

Determining Energy Impacts and Cost Savings 11

Validation Results and Reporting 11

Cross Site Analysis and Comparisons 11

Validation Project Schedule 13

Introduction

Background

Energy Futures Group (EFG) has been awarded a project under NYSERDA PON 3127 (Residential HVAC) to install 20 mini-spilt, cold-climate air source heat pumps (ccASHPs) in single-family or two-family homes in the Hudson Valley (Kingston to Glens Falls). 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.

One emerging technology for northern climates is mini-split heat pumps, both ductless and ducted. 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. Ductless systems are often well suited as a retrofit technology for homes that do not have existing ductwork, and in homes with existing ductwork, mini-split heat pumps can be integrated into the system. Recent advancements in this heat pump technology means that it is now practical for heating in colder climates such as the Hudson Valley.

Energy Futures claims that the market for residential-class ductless heat pumps in New York averages over 47,000 units per year. However, up to three-quarters of those sales were within 25 miles of New York City and are likely installed in small commercial applications rather than in the residential market. As such, they hope that this effort will help to understand the magnitude and needs of the untapped market in the rest of the state.

Approach

The EFG team plans to demonstrate the application of highly-efficient mini-split heat pump technology as a supplement to old, inefficient heating and cooling systems. These systems will be installed in 20 homes within Mid and Upper Hudson Valley, New York (Kingston to Glens Falls).

At the same time, EFG will consider home performance energy efficiency measures. They will recommend participation in the NYS Home Performance with Energy Star (HPwES) program. The focus will be shell upgrades and relevant duct improvements identified through HPwES modeling software. Special attention will be given to ductwork located in vented, unconditioned buffer spaces such as attics and crawlspaces where existing ductwork will continue to be used.

EFG intends to install solar photovoltaic (PV) alongside half (10) of the air-source heat pump installations. Their aim in doing this is to test customer interest and uptake in packaging the two technologies together.

Alongside the demonstration projects, EFG will also conduct technology knowledge transfer activities for mini-split heat pumps, including conducting customer and contractor surveys, creating a consumer information fact sheet, coordinating with CDH and NYSERDA to produce case studies and other relevant materials, and marketing results to the community and public.

Performance Validation Approach

Overview

The EFG team will identify 20 single- or two-family homes in the Hudson Valley region (Kingston to Glens Falls) where they will install high-performance Mitsubishi air-source heat pumps (ASHPs). The ASHP systems installed will be selected from the NEEP list of equipment meeting the Cold Climate Air-Source Heat Pump (ccASHP) Specification.[1]

EFG will install a mix of ducted and ductless units. Most ASHP systems will have multiple indoor heads or sections. The existing heating system in each home will remain in place and provide peak backup to the ASHP system when needed. Base heating fuels are expected to be oil, propane, electricity, and possibly natural gas.

Only the most cost-effective building envelope improvements will be implemented in conjunction with the ASHP installation. Some installations will be heat pump only (with no envelope improvements) to focus directly on discerning ASHP impacts. At houses where envelope improvements are included in the retrofit, flip-flop testing may be used to separate annualized impacts through weather normalization (described below).

A portion of the ASHP installations will be installed with solar photovoltaic (PV) systems, primarily to understand the marketing impact and customer appeal of the combined offering. These cases will also offer the ability to quantify the impact of ASHPs with solar PV on the homes' electric load shape and to discern the resulting utility impacts.

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 the 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).
- Policymakers 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.

[1] Northeast Energy Efficiency Partnerships (NEEP), Cold Climate Air Source Heat Pump, http://neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump

- 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 and policymakers want to understand the impact that ASHPs, and ASHPs installed in conjunction with solar PV, 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 are addressed below.

Site Selection Criteria (Sample Design)

All 20 sites will be retrofits of Mitsubishi brand mini-split ASHPs at single-family or two-family homes in the Hudson Valley, New York. Many of the homes will be two-story, with a living space downstairs and bedrooms on the upper floor. In general, homes with significant thermal problems that cannot be corrected within the scope of this program will be avoided.

It is expected that some of the homes will have an ASHP system with multiple heads, while some may have a single head or central ducted system. Approximately half of the systems will be ducted, approximately half will be ductless, and some may be a mix. Because the smallest heads are generally oversized for a single bedroom, upstairs bedrooms will likely either be ducted, have a fan to exchange air between bedrooms, or may not include ASHP distribution at all. The specific configurations will be based primarily on the best application for each home, rather than on trying to achieve the target mix of system types.

The ASHP systems will be sized to balance comfort, efficiency, and cost-effectiveness for the customer. EFG expects the ASHP system will displace between 75 and 90% of the load currently provided by the existing heating system, which will remain in place to provide supplemental heating. The ASHP system will typically offset heat from an existing furnace or boiler heating system, or from electric resistance baseboard heaters.

Some of the homes may have building envelope upgrades implemented as part of the ASHP system installation. The upgrades will be in keeping with the NYSERDA Home Performance with Energy Star (HPwES) program requirements. The heat pump will be sized to the new heating loads. Approximately half of the homes will have solar PV systems installed as part of the ASHP system installation. EFG is targeting a mix of installations by type, as indicated in Table 1.

Table 1. Number of Target Installations by Type

Total: 20 projects	Projects with PV installation	Projects without PV installation
Ductless ASHP	5	5
Ducted ASHP	5	5

Homeowners will voluntarily choose to participate in this study, will be offered a discount on their heat pump from Mitsubishi as an incentive, and ultimately make the final purchase decision for what is installed and retrofitted into their home. The EFG team and installing contractors will propose various options for each homeowner based on upfront estimates of cost effectiveness as well as homeowner interests and preferences.

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

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, and the ASHP system in conjunction with a solar PV installation, 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. Data will be collected for a minimum of one heating and one cooling season. 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 homes to quantify electric energy use. We expect all heat pump breakers to be in the basement, allowing for simplified monitoring. We will also measure the power of the boiler or furnace components to determine boiler or furnace runtime. We will use the runtime with the expected or measured firing rate to infer fuel use.[2] Data will be logged at 15-minute intervals at the most. Battery-powered data loggers will also be installed to measure temperature (and in some cases humidity) in various spaces in the home.[3]

At sites with solar PV installed, we will additionally measure the power produced by the solar PV system to allow for analysis of the combined solar PV-ASHP package. The monitoring equipment to be installed at each site are listed in Table 1.

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

[3] The budget accounts for space monitoring in an average of three (3) space locations (zones) per site.

EFG will provide eGauge data loggers for each site. These data loggers will remain in place at least until the end of the monitoring period (or longer, depending on agreements between EFG and the homeowner). CDH will provide the rest of the monitoring equipment. The battery-powered data loggers will be collected at the end of the monitoring period.

Table 2. Measured Data Points at Each Site (average across 20 sites)

Measured Quantity	Equipment
Heat pump electricity use	2 x CTs
Whole building electricity use	2 x CTs
Boiler/furnace runtime and inferred fuel use	1 x CT
Solar PV electricity generation (1-2 locations)	1 x CT
Data logger	1 x eGauge EG3010 (provided by EFG) 1 x powered enclosure (provided by CDH) 1 x TP Link Homeplug AV (HP200TPL) (EFG)
Space temperature and supply air temperatures (3 locations)	3 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 home

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. EFG 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 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 (from all fuel sources) 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[4]—where envelope improvements are made alongside the ASHP installation, and flip-flop testing is not possible—data loggers may be installed on the furnaces or boilers to develop a pre-retrofit correlation of furnace/boiler fuel use with outdoor temperature. 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.

Through the homeowner participation agreement, EFG will require 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, EFG will provide general information on the ASHP installation and other details about the existing facility at each site (Table 2).

Table 3. 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	
Heat pump ability to provide whole-house conditioning	House configuration, floor plan, % of space conditioning provided by heat pumps
Description of general thermal properties of building envelope	Generalized UA of the house components; and (when it differs) of the space served by the ASHP
Description of any envelope improvements	
Description of any distribution system improvements	Ductwork or distribution modifications

[4] The budget includes pre-monitoring at up to two (2) sites.

Parameter	Description
Existing heating system	Boilers/furnaces, supplemental heat: number, model, type, size, fuel source
Existing cooling system	Model, type, number, size
Boiler/furnace-ASHP control method	Are boilers/furnaces used as backup? Control settings for combined operation?
Other Considerations	Supplemental heater use, etc.
Solar PV system	Panel make/model, number of panels, total rated capacity, total installed cost and/or financing arrangement

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 home owners and occupants of each of the 20 homes 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 EFG 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 EFG will send customers an email informing them that they will be receiving a survey, CDH will work with NYSERDA and/or EFG to draft the email text. NYSERDA and/or EFG 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 ten of the customers (focusing on single-family homes) with a series of follow-on questions based on the responses provided in the web-based survey.

Table 4. 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 ASHP system Why customer decided to install solar PV alongside the ASHP system (where applicable)

Research Question	Topic(s)	Subtopic(s)
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 Satisfaction with new solar PV (where applicable)
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 of 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	At time of retrofit: 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 After retrofit: 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	Perceived comfort impacts or changes related to the building envelope retrofit Any aesthetic issues or changes

Research Question	Topic(s)	Subtopic(s)
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).

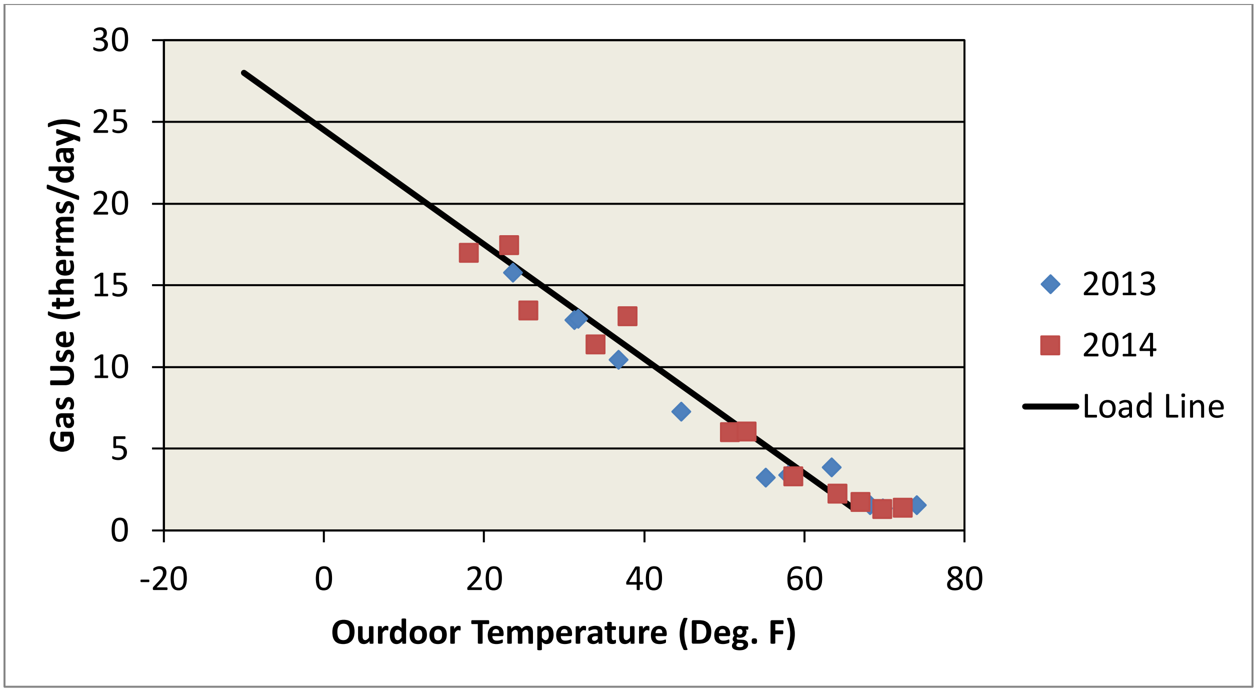


Figure 1. Example of Building Gas Use Correlated to Average Ambient Temperature in Monthly Billing Periods

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, or other accepted engineering analysis). From this analysis, we will be able to measure or infer:

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

Post-Retrofit Data Analysis

Boiler/Furnace Runtime and Energy Use

Status measurements using current switches or CT monitors on the boilers or furnaces will be used to ascertain boiler or furnace 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 some sites, envelope improvements will be included with the ASHP installation as part of the ASHP retrofit. In these cases, it would be desirable to separate the energy impacts of the ASHP and envelope measures. Alternating periods with and without ASHP operation in different parts of the heating season would provide a systematic way to discern ASHP impacts. Therefore, at sites with envelope improvements, we will initiate “flip-flop” testing by asking the homeowners to disable ASHP operation for several 1- to 2-week periods across the heating season (and potentially also across the cooling season). During this portion of the post-retrofit period, the home would be heated only by the original heating system, and any energy savings can be solely attributed to the envelope improvements. Homeowner compliance with these requests will be verified and monitored in real time via the eGauge data. An alternative method is to measure pre-retrofit boiler or furnace runtime before the heat pumps are installed (as described above) and develop a separate correlation with outdoor temperature.[5]

Determining Energy and Demand 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, net metering, etc.) will be applied as appropriate in the pre- and post-retrofit periods.

Determining Solar PV Impacts and Savings

To determine the coincidence of solar PV electricity production with heat pump electricity consumption, we will conduct an hourly analysis for the 1-2 sites that we collect PV generation data on. We will investigate daily demand profiles for each of the demand impact of the solar PV and ASHP package on the 1-2 sites we measure PV output on. We will also determine monthly, annual, and lifetime cost savings to the customer, forecasting to 15-20 years using projected increasing grid electricity rates. This will take into account the upfront installation costs and financial arrangements for the PV system, O&M costs, and savings via net metering.

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 5.

[5] The budget allows for pre-retrofit boiler or furnace monitoring at up to two (2) sites.

Table 5. 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/furnace runtime and fuel use, pre-retrofit
Total estimated boiler/furnace runtime and fuel use, post-retrofit (if any)
Average on-peak ASHP demand in each season
Average on-peak ASHP + PV net demand in each season
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 by season, and by coincident air temperature

The data 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 or furnace 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 create a case study on the 1-2 homes with additional monitoring and analysis on solar PV integration. We will work with EFG to gather information and materials necessary to develop the case study, and build in our findings from the performance analysis.

We will also combine the data from this 20-site study in the Hudson Valley with the results from the separate evaluation of 20 ASHP sites in Brooklyn and Queens. 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 P90 level.

Validation Project Schedule

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

Table 6. Validation Project Schedule - Individual Site

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

[1] Month from identification of site by EFG

Table 7. Validation Project Schedule - After All Data Collection Complete

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

[1] Month from date CDH collects final survey

Appendix E. Surveys

The following pages in this appendix provide the customer and contractor survey instruments.

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 Energy Futures Group 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)

Q5. (owners only) Is solar PV installed at this residence, or do you have plans to install solar in the next few months?

(yes/no)

Q6. (only where solar PV is installed) What are your reasons for deciding to install a solar PV system? Rank from most important to least important.

a. Lower operating costs (save on energy bills)
b. Reduced greenhouse gas emissions
c. Reduced peak load and need for more electric generating plants
d. Guaranteed electricity production for decades
e. Backup power source
f. Packaging with the heat pump upgrade made it simple
g. Net metering
h. Financial incentives (e.g. solar tax credit)
i. Attractive options to finance capital cost (upfront cost of system)
j. Improve value of home
k. Modern, trendy technology
l. Recommended by someone I trust

Heating

Q7. (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

Q8. (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).

Q9. (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

Q10. (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.

Q11. (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

Q12. (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

Q13-Q18: Questions will be the same as for heating, but with the word "cooling" replacing "heating", "cool" replacing "heat", and "summer" replacing "winter".

Other

Q19. (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

Q20. (owners only, if no solar PV yet installed) 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

Q21. (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

Q22. (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

Q23. (owners & occupants) Did you receive written instructions on how to operate the heat pump?

(yes/no)

Q24. (owners & occupants) Were you trained on how to use your new system?

(yes/no)

Q25. (owners & occupants) Was the information provided to you sufficient for you to operate your heat pump?

(yes/no, please explain why not)

Q26. (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. (owners with solar PV installed) Overall, how satisfied or dissatisfied are you with your solar PV system (if applicable)?

(same options as corresponding question from Survey 1)

Q6. (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

Q7. (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)

Q8. (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)

Q9. (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.

Q10. (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)

Q11. (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)

Q12. (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

Q13. (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)

Q14. (owners & occupants) Briefly describe any unexpected benefits that you have gained from the air-source heat pump system, if any.

(text box, optional)

Q15. (owners & occupants) Describe any unexpected problems that you have experienced with the air-source heat pump system, if any.

(text box, optional)

Q16. (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)

Q17. (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)

Q18. (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)

Q19. (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)

Q20. (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)

Q21. (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

Q22. (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

Q23. (owners & occupants) Would you switch back to your old heating and cooling systems? If yes, please explain why.

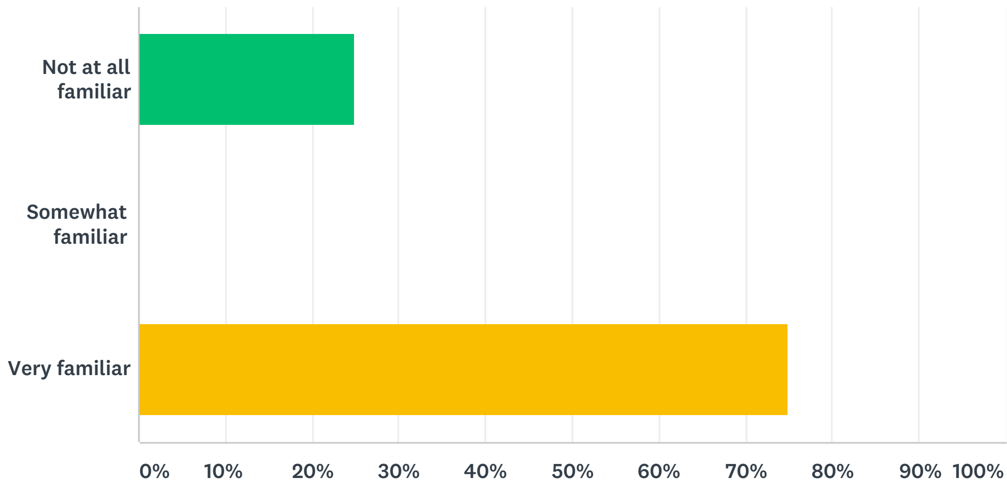
c. No
d. Yes (please explain why)

Q24. 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)

Q2 Prior to participating in the Hudson Valley Heat Pump Project, how familiar would you say you were with air sealing and insulation?

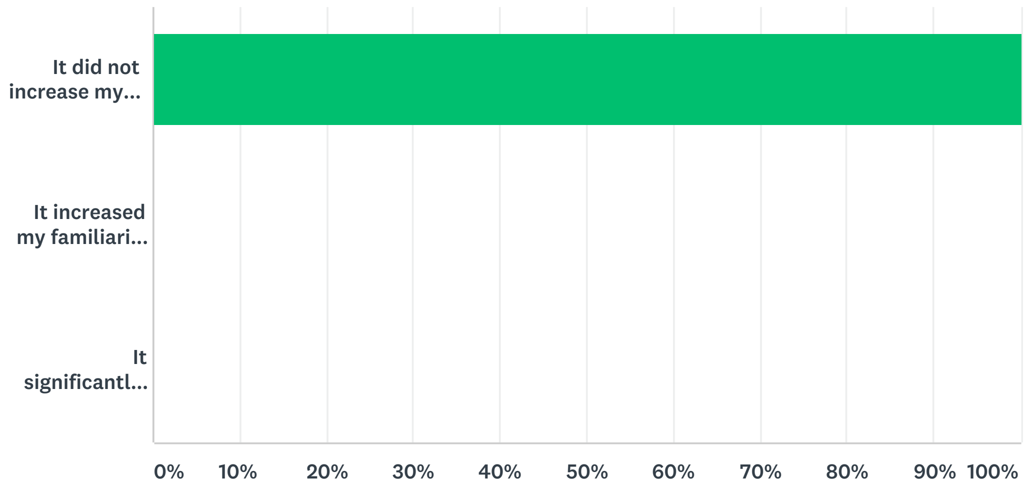
Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Not at all familiar	25.00%	1
Somewhat familiar	0.00%	0
Very familiar	75.00%	3
TOTAL		4

Q3 Did participation in this program increase your familiarity and experience with air sealing and insulation?

Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
It did not increase my familiarity / experience	100.00%	4
It increased my familiarity / experience somewhat	0.00%	0
It significantly increased my familiarity / experience	0.00%	0
TOTAL		4

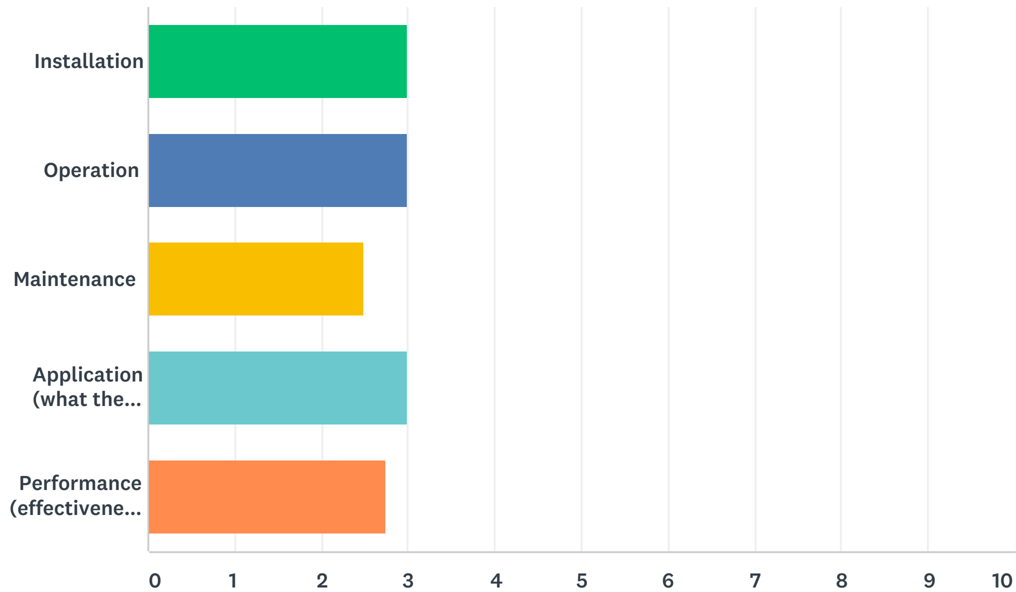
Q4 Please elaborate on your response to the previous question. How did this program increase your familiarity / experience with air sealing and insulation or why didn't it?

Answered: 4 Skipped: 0

#	RESPONSES	DATE
1	I had six years of experience in residential energy efficiency and weatherization retrofits prior to participating in the HVHPP.	9/24/2018 12:05 PM
2	Did not have the opportunity to participate in any air sealing	9/21/2018 4:07 PM
3	we did not do a job in this program that required air sealing or insulation.	9/21/2018 3:13 PM
4	BPI Training in 2001	9/21/2018 12:31 PM

Q5 Prior to your involvement in this program, how familiar were you were with the following aspects of cold climate air source heat pumps (ASHPs)

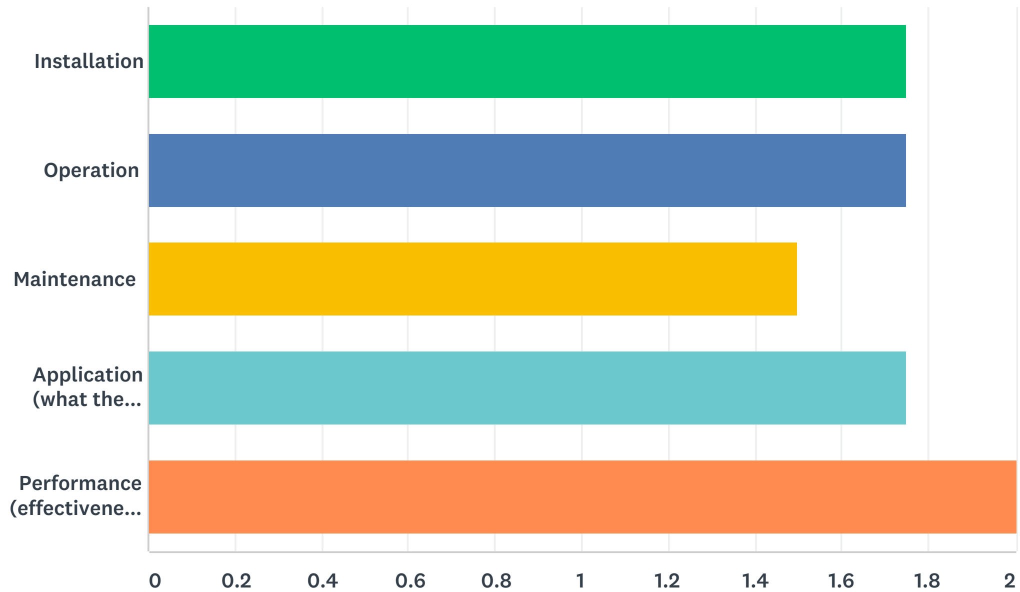
Answered: 4 Skipped: 0



	NOT AT ALL FAMILIAR	SOMEWHAT FAMILIAR	VERY FAMILIAR	TOTAL	WEIGHTED AVERAGE
Installation	0.00% 0	0.00% 0	100.00% 4	4	3.00
Operation	0.00% 0	0.00% 0	100.00% 4	4	3.00
Maintenance	0.00% 0	50.00% 2	50.00% 2	4	2.50
Application (what the purpose is: e.g., whole home heat, supplemental heat)	0.00% 0	0.00% 0	100.00% 4	4	3.00
Performance (effectiveness, efficiency)	0.00% 0	25.00% 1	75.00% 3	4	2.75

Q6 Did your involvement in this program increase your familiarity and experience with the following aspects of cold climate ASHPs?

Answered: 4 Skipped: 0



	DID NOT INCREASE	SOMEWHAT INCREASED	INCREASED SIGNIFICANTLY	TOTAL	WEIGHTED AVERAGE
Installation	25.00% 1	75.00% 3	0.00% 0	4	1.75
Operation	25.00% 1	75.00% 3	0.00% 0	4	1.75
Maintenance	50.00% 2	50.00% 2	0.00% 0	4	1.50
Application (what the purpose is: e.g., whole home heat, supplemental heat)	25.00% 1	75.00% 3	0.00% 0	4	1.75
Performance (effectiveness, efficiency)	0.00% 0	100.00% 4	0.00% 0	4	2.00

Q7 Please explain how your participation in this program increased your familiarity and experience with cold climate ASHPs or why it did not.

Answered: 4 Skipped: 0

#	RESPONSES	DATE
1	I learned a few performance and application tips from Pasquale Strocchia while working with him and his team in this program.	9/24/2018 12:08 PM
2	We have been installing heat pumps only as a solution for primary heat in the Hudson die for the last 10 years. So it would not increase my awareness on these items very much. We were already very aware	9/21/2018 4:08 PM
3	I would have learned more if the results of some of the test were shared.	9/21/2018 3:16 PM
4	Looking forward to reading results on operating costar	9/21/2018 12:34 PM

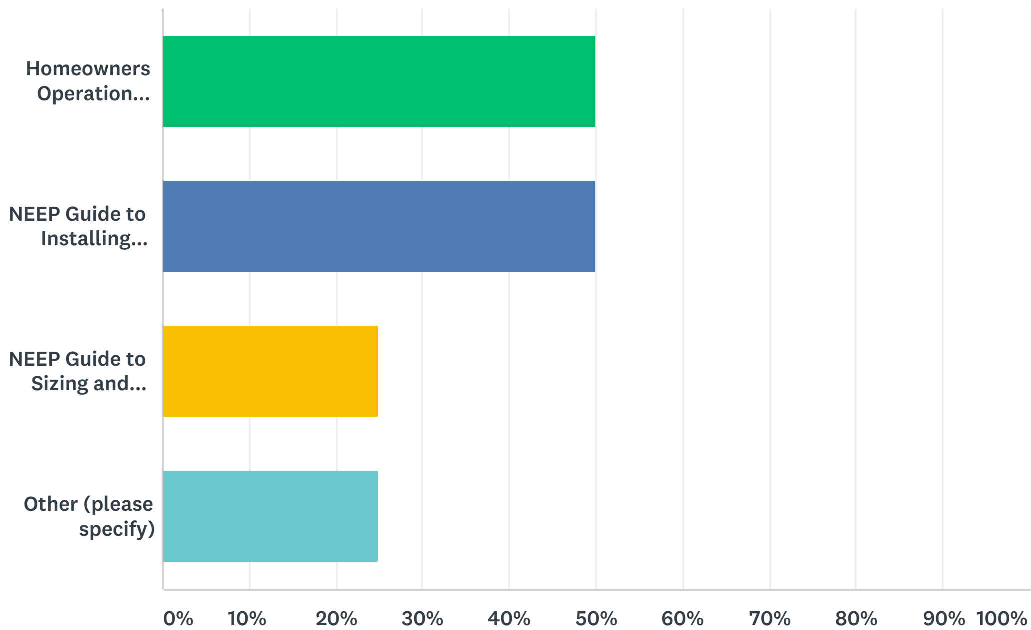
Q8 What do you think you will do differently regarding cold climate ASHP installations as a result of participating in this program?

Answered: 4 Skipped: 0

#	RESPONSES	DATE
1	I will slightly under-size BTU capacity of multi-zone outdoor ASHP condenser units by sizing total indoor unit BTU demand to ~130% of outdoor unit BTU capacity. This was a helpful tip from Pasquale. He found it increases the overall operating efficiency of the systems. It also reduces our material costs slightly.	9/24/2018 12:16 PM
2	Mount had units lower from ceiling	9/21/2018 4:08 PM
3	Not much. Once results are out maybe it will change.	9/21/2018 3:17 PM
4	Better information for clients.	9/21/2018 12:35 PM

Q9 This program offered a variety of materials to assist in increasing the most effective installation and usage of cold climate ASHPs.Of the below listed materials, what did you find most informative and helpful? (Check all that apply)

Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Homeowners Operation Checklist	50.00%	2
NEEP Guide to Installing ASHPs in Cold Climates	50.00%	2
NEEP Guide to Sizing and Selecting ASHPs in Cold Climates	25.00%	1
Other (please specify)	25.00%	1
Total Respondents: 4		

#	OTHER (PLEASE SPECIFY)	DATE
1	Nothing listed that hasn't been done since installations began in 2008.	9/21/2018 12:37 PM

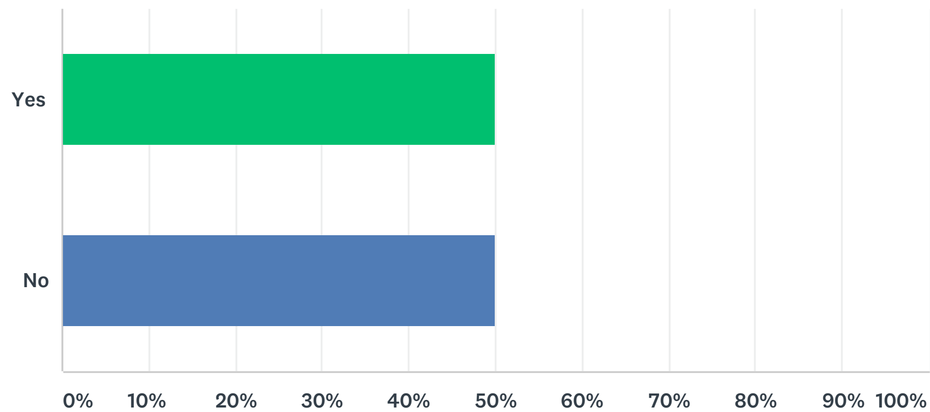
Q10 Why were these materials helpful and informative or why weren't they?

Answered: 4 Skipped: 0

#	RESPONSES	DATE
1	The NEEP / NYSERDA average snow depth and condenser install height map / instructions were helpful. Some of the other guides were a good refresher for me. They seemed quite thorough and well written overall.	9/24/2018 12:20 PM
2	Help me understand things I should point out to the customer	9/21/2018 4:09 PM
3	N	9/21/2018 3:18 PM
4	All info has been available to us for years.	9/21/2018 12:37 PM

Q11 Prior to participating in the Hudson Valley Heat Pump Project (and prior to receiving the various materials provided to you in this program), did you leave educational materials with homeowners regarding how best to operate a cold climate ASHP?

Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	50.00%	2
No	50.00%	2
TOTAL		4

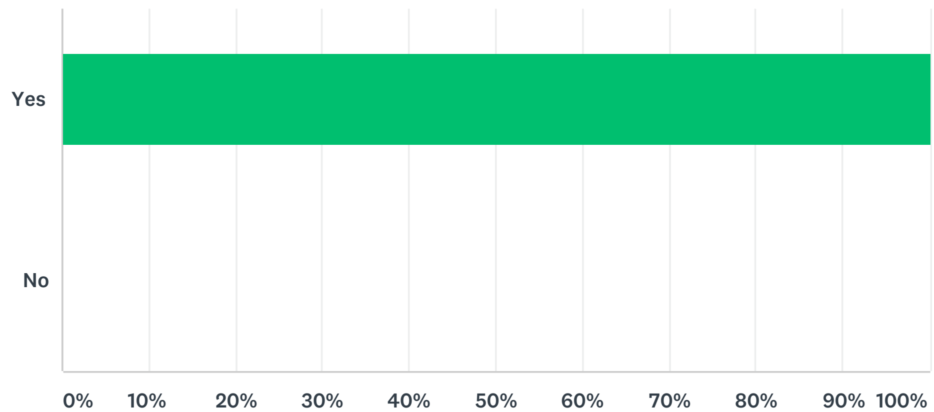
Q12 What types of educational materials would you leave with homeowners prior to participating in this program?

Answered: 2 Skipped: 2

#	RESPONSES	DATE
1	The manufacturer operation and installation manuals for the system.	9/24/2018 12:21 PM
2	Product brochures provided by manufacturer	9/21/2018 4:09 PM

Q13 Thinking of the materials provided to you as part of this program to share with homeowners, will you continue to provide these to your future customers after completion of this program?

Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	100.00%	4
No	0.00%	0
TOTAL		4

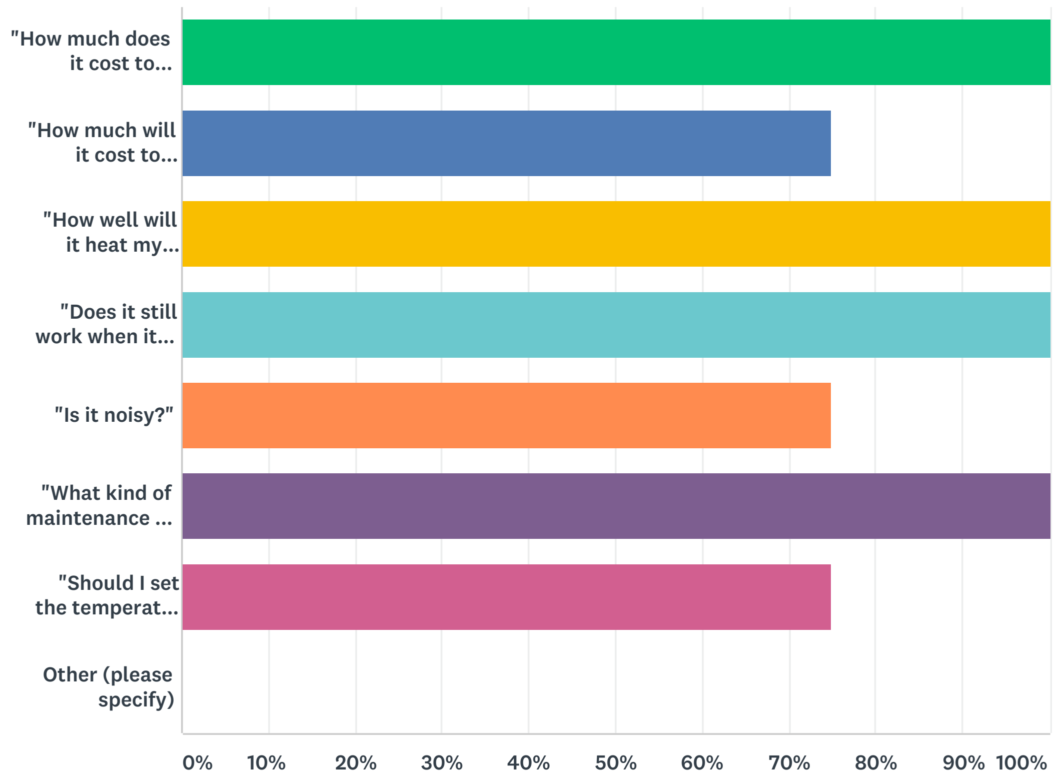
Q14 What other materials, handouts, resources, or tools do you wish you had at your disposal to offer to customers regarding cold climate ASHPs? What value could they provide?

Answered: 4 Skipped: 0

#	RESPONSES	DATE
1	An annual energy savings calculator that compares heating and cooling operating costs for ASHP systems vs. other common heating and cooling systems. We have modeled these systems in Optimiser and the energy savings estimates seem to be way too bullish. A simple calculator that takes in average annual energy usage, existing HVAC system types, square footage and % of home to be conditioned with ASHPs could be a very effective way to convey the savings to a client without getting lost in the details. These systems use a fraction of the amount of energy that many existing HVAC systems use but it is currently hard to back that statement up due to a gap in quick energy modeling tools for ASHPs. If homeowners could see more accurate annual energy savings totals to help cost justify the initial investment in ASHPs, I believe they would be more widely adopted.	9/24/2018 12:32 PM
2	Case studies of homes average savings	9/21/2018 4:09 PM
3	None	9/21/2018 3:19 PM
4	Research program results. Helpful in educating future clients.	9/21/2018 12:39 PM

Q15 What questions do your customers typically ask before or after installing a cold climate ASHP?

Answered: 4 Skipped: 0

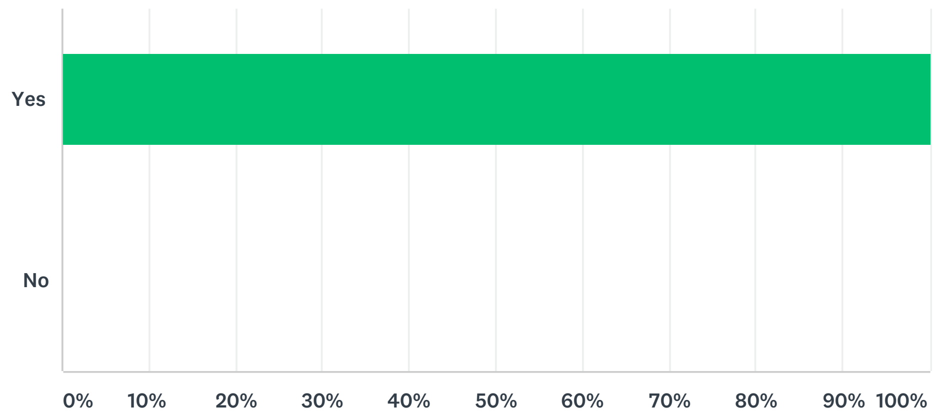


ANSWER CHOICES	RESPONSES	
"How much does it cost to install?"	100.00%	4
"How much will it cost to operate?"	75.00%	3
"How well will it heat my home?"	100.00%	4
"Does it still work when it's extremely cold or hot outside?"	100.00%	4
"Is it noisy?"	75.00%	3
"What kind of maintenance do I need to do?"	100.00%	4
"Should I set the temperature back at night or when no one is home?"	75.00%	3
Other (please specify)	0.00%	0
Total Respondents: 4		

#	OTHER (PLEASE SPECIFY)	DATE
	There are no responses.	

Q16 Do you think the awareness and education of your customers regarding how to operate cold climate ASHPs has changed as a result of the materials and training you have received during this program?

Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	100.00%	4
No	0.00%	0
TOTAL		4

Q17 How do you think your customers' awareness and education of cold climate ASHPs has changed as a result of the materials and training provided to you?

Answered: 4 Skipped: 0

#	RESPONSES	DATE
1	The materials have helped to re-iterate the need to "set it and forget it" when it comes to temperature set points with these systems. They work very efficiently without homeowner temperature setbacks to try to increase efficiency.	9/24/2018 12:37 PM
2	They realize that it is a product supported by NYSERDA and local utility companies which adds more credibility	9/21/2018 4:11 PM
3	Can’t say	9/21/2018 3:20 PM
4	Regarding Set Back temperatures and zoning operation.	9/21/2018 12:41 PM

Q18 Why don't you think your customers' awareness and education has changed given the materials and training provided to you?

Answered: 0 Skipped: 4

#	RESPONSES	DATE
	There are no responses.	

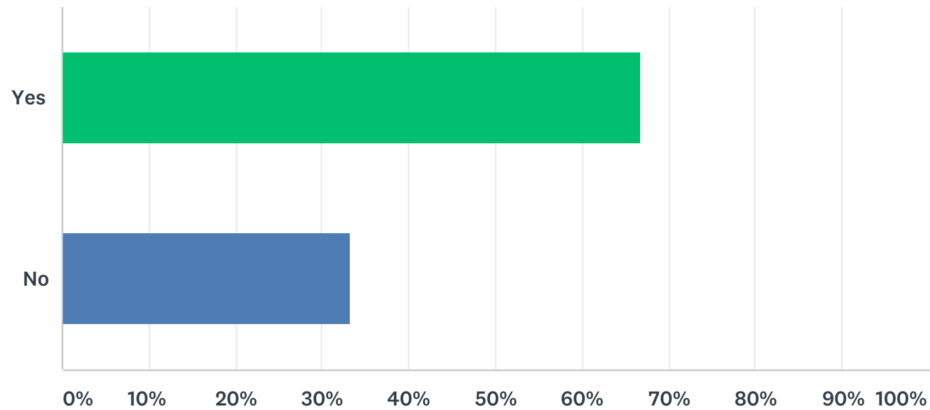
Q19 What do you wish homeowners in New York State knew about cold climate ASHPs? What education needs to happen in the market? What perceptions need to be overcome?

Answered: 3 Skipped: 1

#	RESPONSES	DATE
1	I wish homeowners knew that ASHPs were one of, if not the most cost effective option for heating and cooling their homes. This applies to both the initial investment as well as lifetime operating costs. The perceptions that they cannot heat in very cold temps and that ductless wall units are too obtrusive both need to be overcome.	9/24/2018 12:41 PM
2	They need to recognize low ambient operation and that they are an effective Northeast solution	9/21/2018 4:11 PM
3	Proven results.	9/21/2018 12:42 PM

Q20 Do you recommend a comprehensive approach that pairs a heat pump installation with weatherization and/or solar to your clients?

Answered: 3   Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	66.67%	2
No	33.33%	1
TOTAL		3

Q21 For what reasons do you recommend a comprehensive approach that would pair weatherization and/or solar with a heat pump?

Answered: 1 Skipped: 3

#	RESPONSES	DATE
1	The ASHP system will perform better for heating and cooling while using less energy.	9/24/2018 12:43 PM

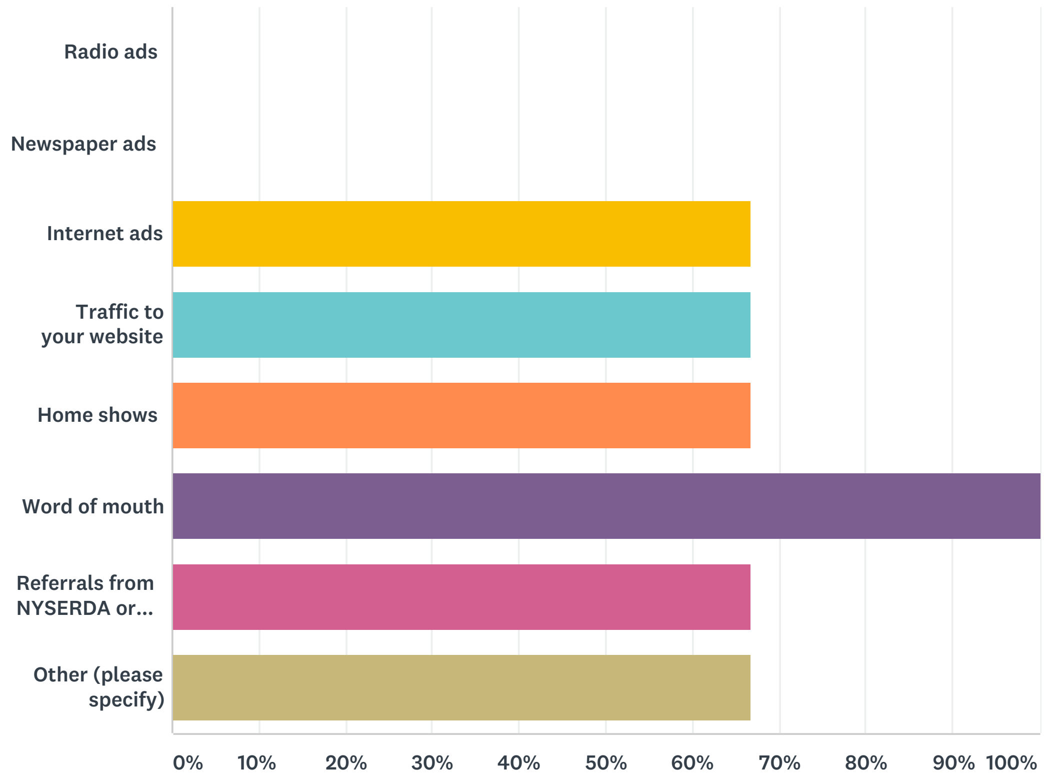
Q22 Why don't you recommend a comprehensive approach that would pair weatherization and/or solar with a heat pump?

Answered: 1 Skipped: 3

#	RESPONSES	DATE
1	Too much for a person to digest at once	9/21/2018 4:12 PM

Q23 How do you typically generate leads for your business? (Check all that apply)

Answered: 3 Skipped: 1

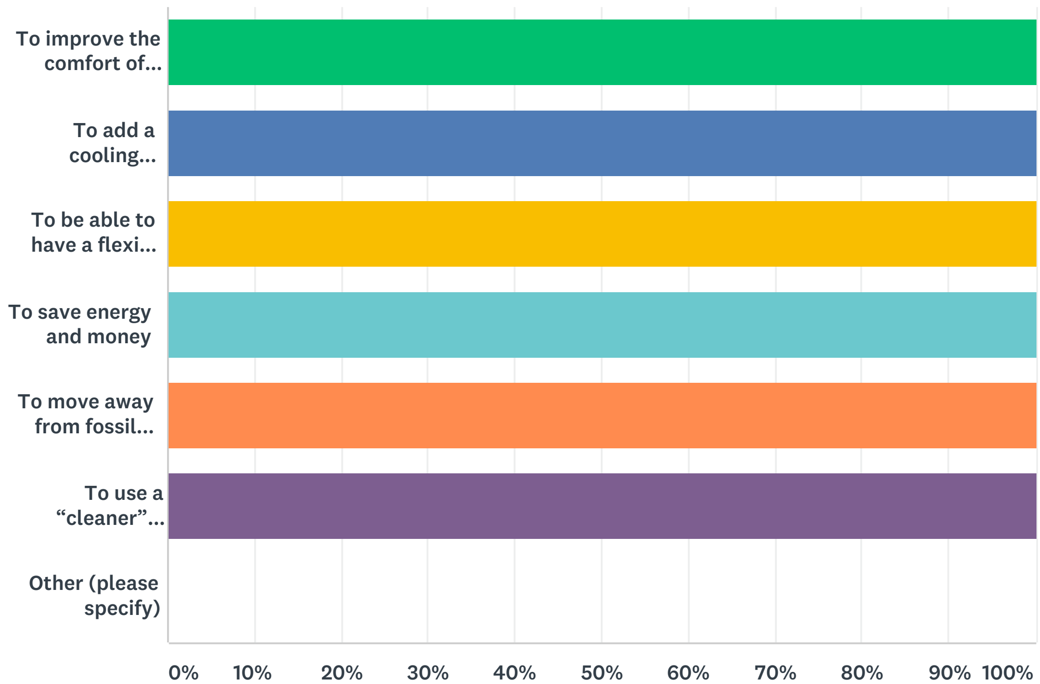


ANSWER CHOICES	RESPONSES	
Radio ads	0.00%	0
Newspaper ads	0.00%	0
Internet ads	66.67%	2
Traffic to your website	66.67%	2
Home shows	66.67%	2
Word of mouth	100.00%	3
Referrals from NYSERDA or utility programs	66.67%	2
Other (please specify)	66.67%	2
Total Respondents: 3		

#	OTHER (PLEASE SPECIFY)	DATE
1	Mailers	9/21/2018 4:13 PM
2	Need more from NYSERDA and Utility Companies	9/21/2018 12:44 PM

Q24 For what reasons do customers want to have a cold climate air source heat pump installed? (Check all that apply)

Answered: 3 Skipped: 1

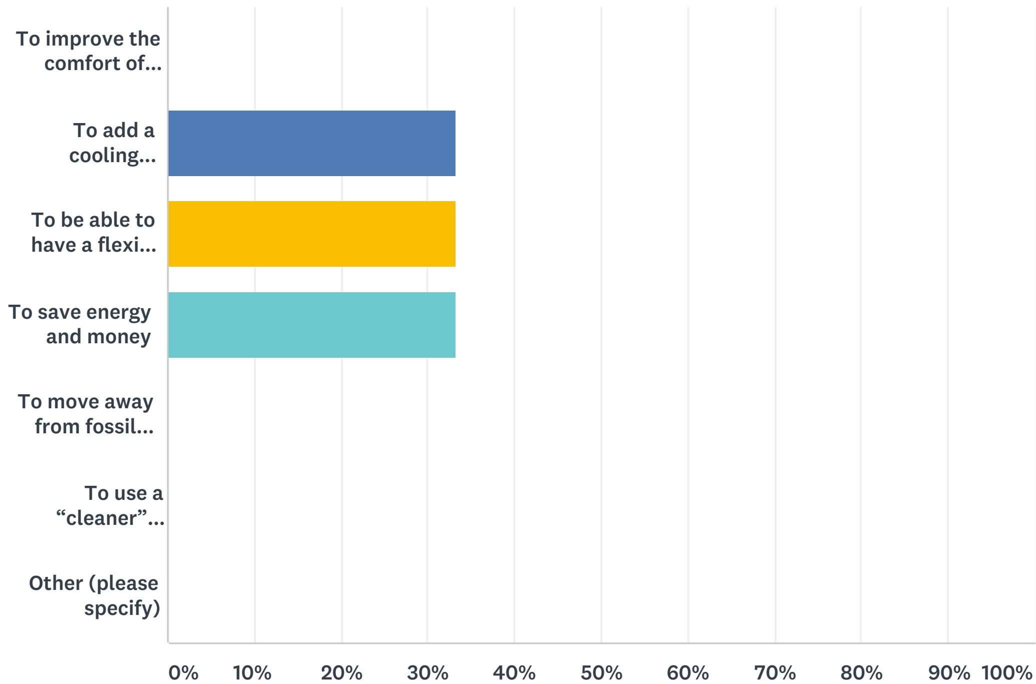


ANSWER CHOICES	RESPONSES	
To improve the comfort of their home	100.00%	3
To add a cooling solution to their home	100.00%	3
To be able to have a flexible solution that can both heat and cool	100.00%	3
To save energy and money	100.00%	3
To move away from fossil fuels	100.00%	3
To use a "cleaner" energy source	100.00%	3
Other (please specify)	0.00%	0
Total Respondents: 3		

#	OTHER (PLEASE SPECIFY)	DATE
	There are no responses.	

Q25 What is the most common reason why customers want to have a cold climate air source heat pump installed? (Select one)

Answered: 3 Skipped: 1

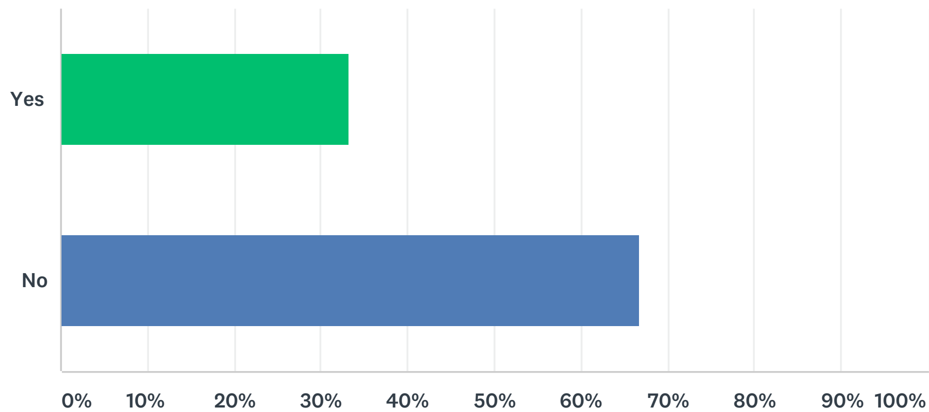


ANSWER CHOICES	RESPONSES	
To improve the comfort of their home	0.00%	0
To add a cooling solution to their home	33.33%	1
To be able to have a flexible solution that can both heat and cool	33.33%	1
To save energy and money	33.33%	1
To move away from fossil fuels	0.00%	0
To use a “cleaner” energy source	0.00%	0
Other (please specify)	0.00%	0
TOTAL		3

#	OTHER (PLEASE SPECIFY)	DATE
	There are no responses.	

Q26 Do you think your peers/competitors in the residential HVAC space are generally informed about the benefits of cold climate ASHPs and interested in installing them?

Answered: 3 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	33.33%	1
No	66.67%	2
TOTAL		3

Q27 Why don't you think your peers/competitors are interested in cold climate ASHPs or knowledgeable about the benefits?

Answered: 2 Skipped: 2

#	RESPONSES	DATE
1	Lack of dedication to excellence	9/21/2018 4:13 PM
2	Because they are my competitors	9/21/2018 12:45 PM

Q28 For each installation situation below, please give a rough percentage that represents your cold climate ASHP installations. For example, 35% of the installations you do replace a failed heating system, while 10% are add-ons to existing equipment, etc.

Answered: 3 Skipped: 1

ANSWER CHOICES	RESPONSES	
Complete replacement of failed (or failing) heating/cooling system	100.00%	3
Complete replacement of heating/cooling system that is in working order	100.00%	3
Add-on to existing heating/cooling system	100.00%	3
New home installation	100.00%	3
Addition to home	100.00%	3
Solve for localized comfort problems (e.g., a room that is too warm / cold)	100.00%	3

#	COMPLETE REPLACEMENT OF FAILED (OR FAILING) HEATING/COOLING SYSTEM	DATE
1	5	9/24/2018 12:46 PM
2	10	9/21/2018 4:15 PM
3	20	9/21/2018 12:47 PM

#	COMPLETE REPLACEMENT OF HEATING/COOLING SYSTEM THAT IS IN WORKING ORDER	DATE
1	3	9/24/2018 12:46 PM
2	25	9/21/2018 4:15 PM
3	30	9/21/2018 12:47 PM

#	ADD-ON TO EXISTING HEATING/COOLING SYSTEM	DATE
1	60	9/24/2018 12:46 PM
2	35	9/21/2018 4:15 PM
3	20	9/21/2018 12:47 PM

#	NEW HOME INSTALLATION	DATE
1	2	9/24/2018 12:46 PM
2	15	9/21/2018 4:15 PM
3	15	9/21/2018 12:47 PM

#	ADDITION TO HOME	DATE
1	10	9/24/2018 12:46 PM
2	0	9/21/2018 4:15 PM
3	15	9/21/2018 12:47 PM

#	SOLVE FOR LOCALIZED COMFORT PROBLEMS (E.G., A ROOM THAT IS TOO WARM / COLD)	DATE
1	20	9/24/2018 12:46 PM
2	15	9/21/2018 4:15 PM
3	15	9/21/2018 12:47 PM

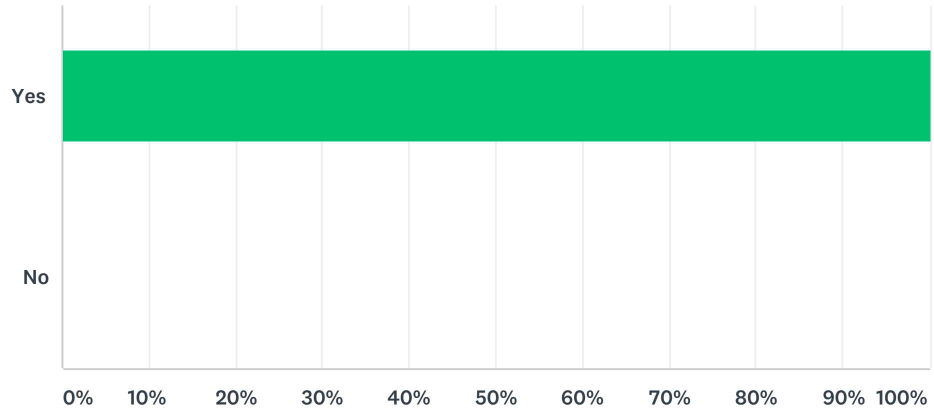
Q29 What is the biggest challenge you have in promoting, selling, and installing cold climate air source heat pumps?

Answered: 3 Skipped: 1

#	RESPONSES	DATE
1	Initial investment cost.	9/24/2018 12:46 PM
2	Aesthetics	9/21/2018 4:15 PM
3	Potential customers education. Rebates for proven excepted technologies	9/21/2018 12:49 PM

Q30 Should cold climate ASHPs be promoted to New Yorkers?

Answered: 3 Skipped: 1



ANSWER CHOICES	RESPONSES	
Yes	100.00%	3
No	0.00%	0
TOTAL		3

Q31 Why did you select the answer you did above?

Answered: 3 Skipped: 1

#	RESPONSES	DATE
1	They work very well and will help to reduce home energy waste.	9/24/2018 12:47 PM
2	Saves money increases comfort	9/21/2018 4:15 PM
3	Education for proven technologies	9/21/2018 12:50 PM

Q32 What tools, resources, or marketing support could NYSERDA provide to help your business sell more cold climate air source heat pumps? (Please note, this does not represent a commitment by NYSERDA to provide any support or resources.)

Answered: 3 Skipped: 1

#	RESPONSES	DATE
1	Homeowner rebates and low interest financing.	9/24/2018 12:47 PM
2	More comprehensive materials demonstrating the advantages and capabilities of heat pumps in this region	9/21/2018 4:22 PM
3	Saving tools	9/21/2018 12:51 PM

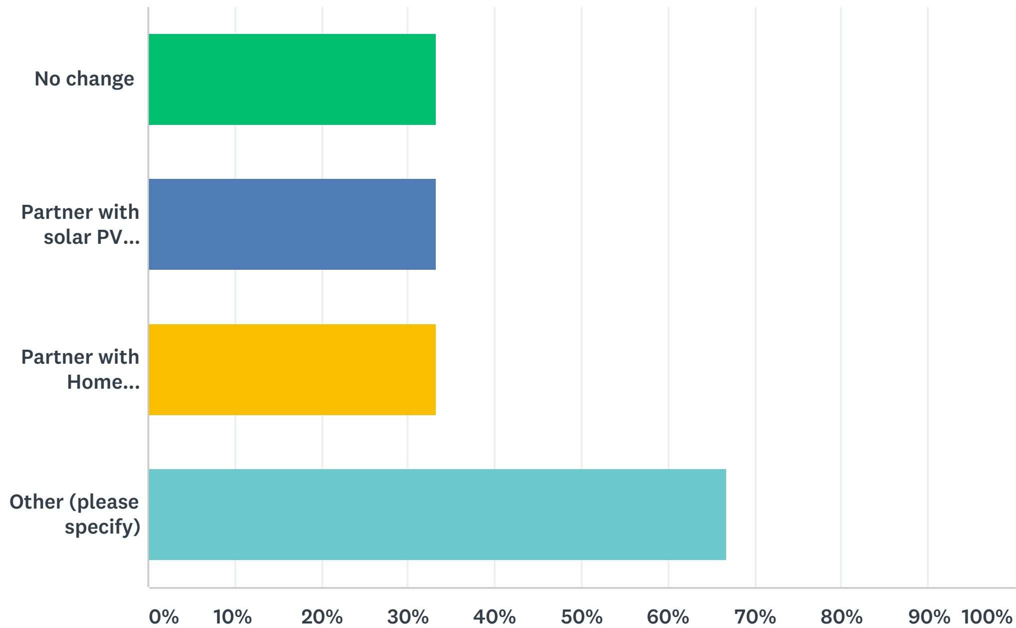
Q33 What would you do differently if there were more incentives for, and promotion of, cold climate ASHPs in New York?

Answered: 3 Skipped: 1

#	RESPONSES	DATE
1	Install more ASHPs systems in response to the increased consumer demand.	9/24/2018 12:48 PM
2	I would advertise more	9/21/2018 4:28 PM
3	Advertising and cost reductions	9/21/2018 12:51 PM

Q34 What do you think your business model will be going forward with respect to cold climate air source heat pump installations?

Answered: 3 Skipped: 1



ANSWER CHOICES	RESPONSES	
No change	33.33%	1
Partner with solar PV contractor	33.33%	1
Partner with Home Performance with ENERGY STAR contractor	33.33%	1
Other (please specify)	66.67%	2
Total Respondents: 3		

#	OTHER (PLEASE SPECIFY)	DATE
1	It will continue to be our primary product	9/21/2018 4:29 PM
2	Marketing	9/21/2018 12:52 PM

Q35 Do you have a memorable, positive customer experience of a completed cold climate air source heat pump installation (e.g., an enthusiastic customer response or a compelling stat/result)? What was memorable about it? Please specify whether it was part of the Hudson Valley Heat Pump Project or outside of this program.

Answered: 2 Skipped: 2

#	RESPONSES	DATE
1	Yes, we have many clients who are extremely happy with their ASHP systems. One in the HVHPP and many others outside of it.	9/24/2018 12:50 PM
2	Every person we have included in the Hudson Valley heat pump project has been elated about what they're getting for their participation. Outside of the project we have had many many reviews surrounding energy savings being higher than anticipated comfort being better than expected all positive feedback across the board	9/21/2018 4:30 PM

Q36 Is there anything else you would like to add?

Answered: 3 Skipped: 1

#	RESPONSES	DATE
1	Please try to improve NYSERDA homeowner rebates & low interest financing for these systems. Thank you for all your hard work!	9/24/2018 12:50 PM
2	We truly appreciate being part of this program and we hope we are invited to enjoying in on any huger programs. You have our full support moving forward as we would love to partner with you.	9/21/2018 4:30 PM
3	Thank you	9/21/2018 12:52 PM

Endnotes

[1] The "Performance Validation Plan" is available at https://cloud.cdhenergy.com/ashp_ef/ and in appendix D.

[2] There was also interest in understanding the peak demand interactions of combining solar and heat pumps in a home. Observations regarding solar generation and heat pump demand impacts are made throughout the report.

[3] This document can be found at https://www.mitsubishicomfort.com/articles/personalized-comfort/the-diamond-contractor-a-homeowners-best-friend

[4] S5 was sold to a new homeowner who was unable to obtain the costs paid by the previous homeowner. The cost for S15 is not representative as it does not include all labor costs (the homeowner was a licensed HVAC installer).

[5] Founded in 1996, NEEP is one of six Regional Energy Efficiency Organizations (REEOs) funded, in part, by the US Department of Energy to support state efficiency policies and programs. NEEP focuses on the Northeast and Mid-Atlantic states.

[6] These conditions were ultimately not satisfied at several sites. This and other confounding issues limited our ability to complete the analysis at five of the 20 sites, as indicated by the notes under Table 25. Behavior or setpoint changes in the post-retrofit period at other sites (e.g., S4) may have led to conservative savings estimates.

[7] This can be found at: https://www.epa.gov/sites/production/files/2020-01/documents/egrid2018_summary_tables.pdf

[8] This can be found at https://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf

[9] For example if the daily average temperature is 64°F, use 60% of the hourly profile values at 60°F and 40% of the hourly profile values at 70°F to create the profile for that day.

[10] Sites S9 and S16 did not answer the question regarding installation experience.

[11] This particular HVHPP participant is a builder focused on net zero design and construction.

[12] Available at https://neep.org/high-performance-air-source-heat-pumps/air-source-heat-pump-installer-and-consumer-resources

[13] Note that by this question in the survey, one contractor ceased responding to the questions.

[14] Further, contractor number 3 responded such that his total installations achieve 115% and not 100%.

[15] Note that another awardee of the original PON, the Levy Partnership, focused on messaging targeted to contractors, distributors, and manufacturers.

[16] Because of the low price of natural gas, the three customers who used natural gas for heating spent a bit more to heat with the heat pumps, but saved an average of 1181 lb/year of CO_2 (equivalent).

[17] Fact sheets are available on NYSERDA's website, nyserda.ny.gov/about/publications/factsheets.

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