Mini-Split Heat Pump Heating Load Shift Demonstration

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For

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Contents

Figures

Tables

1 Introduction

The project's purpose was to demonstrate the ability of the Mysa Smart Thermostat for AC and Mini-Split Heat Pumps to control mini-split heat pumps (MSHPs or mini-splits) in a load shifting (or demand response) context. The Mysa smart thermostat is a Wi-Fi enabled device that can be used to control an overwhelming majority of mini-split heat pumps. The thermostat can be mounted to a wall or placed on a table and it communicates wirelessly with the mini-split heat pump just like the proprietary product controllers. There is a corresponding smart phone application which can be used to define temperature setpoints – an operating schedule.

The typical user control for a mini-split heat pump, proprietary to the equipment, is a hand-held remote control (most common) or a wall mounted control. The interface usually lacks a scheduling capability (Cadmus 2019).[1] Further, the typical controller does not have the interface necessary for utilities to communicate with the mini-split and use them for demand response. Mysa fills in this capability gap while providing the utility a single, uniform method to communicate with a diverse array of equipment makes and models.[2]

The research questions addressed in the project are:

- Can the Mysa smart thermostat decrease mini-split power use over a specified time period?
- How effectively can the device reduce power use?
- When using setpoint to reduce power, how does it affect indoor air temperature?

To test the product, the project team explored heating load shifting ranging in duration from one to four hours. The project demonstrated the Mysa smart thermostat can increase and decrease heat pump power by altering the setpoint either up or down. The direct, in-field measurement of power draw showed that power increases and decreases were consistently and reliably achievable. Of note, in the first hour following a command to reduce setpoint by two degrees Celsius, the mini-splits decreased power consumption 50%, or 500 W, compared to baseline operation.

The specific case we explored was a heating load shaping/shifting activity. Importantly, because the thermostat demonstrated it could ramp up or down the heat pump power, it could be done on shorter time scales or used for an acute grid peak demand event when instructed to by a utility. Likewise, while the study conducted a four hour long shed event, the analysis focuses more on the first hour of the event. An occupant's tolerance for decreased temperature in the space is likely to decrease with duration although this was not specifically explored. Nevertheless, the data show a greater power reduction and lower temperature drop in the first hour which highlights the particular value of the shortened event. A recent project studying demand response in Oregon also highlights the value of the first-hour reduction.[3]

[1] *Residential Ductless Heat Pump Study*. Cadmus. 21 June 2019. Prepared for Energy Trust of Oregon. https://www.energytrust.org/wp-content/uploads/2019/10/Residential_Ductless_Heat_Pump_Study_Report.pdf

[2] Mysa thermostats use OpenADR protocols and can be accessed by utilities through AutoGrid platforms.

[3] *DHP Controls Coordinated Research Project Evaluation Final Report*. Evergreen Economics. 23 June 2022. Prepared for Energy Trust of Oregon. https://www.energytrust.org/wp-content/uploads/2022/07/DHP-Controls-Eval-Report-FINAL-wSR.pdf

To conduct the project, Mysa contracted with Larson Energy Research (LER) to devise the field demonstration, analyze the data, and document the results. Mysa employees installed the data loggers, deployed the test schedule at the sites, and provided the field data to LER.

2 Method

2.1 Participant Houses

Six homes (occupied by Mysa employees or associates) participated in the field study. All homes are located in the area of St. John's in Newfoundland, Canada. All sites have a mini-split controlled by a Mysa device. Some homes also have other heating equipment – primarily baseboard electric-resistance heaters – in place.

T1 Site Characteristics Overview

Site	Mini-split Make	Heating Capacity (Btu/hr)	Area Heated (approx. ft^2)	Supplemental Heating	Insulation Quality[4]
1	Ingersoll Rand	19,000	860	Infrequent use	Good
2	Senville	18,000	1,000	Rare use	Fair
3	LG	13,300	600	Not used	Good
5	Fujitsu	---	---	---	---
6	Fujitsu	16,000	1,000	Not used	Good
7	Daikin	13,500	550	Not used	Great

2.2 Measurement and Data Collection

The following values, measured for each site, were used in the analysis:

- Indoor air temperature
- Outdoor air temperature
- Temperature recorded by Mysa device
- Mini-split setpoint temperature
- Mini-split operating mode
- Heat pump power

The first two temperatures, "Indoor" and "Outdoor," were monitored by an independent measurement system, using Inkbird hardware and logged every hour. The Indoor temperature from this system is expected to vary from the Mysa temperature reading due to positioning of the devices within the home.

Heat pump power was measured with Emporia hardware installed on the circuit serving the outdoor heat pump unit. Power was logged every second and aggregated to the one-hour level for analysis.

The remaining values were collected from the Mysa device.

2.3 Load Shift Schedule

Load shifting events were simulated using a programmed thermostat setpoint schedule. Throughout the sampling period, this schedule was applied on alternating days and makes up the test data set. The remaining days, when occupants used their customary setpoints, make up the control, or baseline, data set.

At 5am The load shift schedule sets the thermostat one degree C above the home's typical setpoint; at 6am, two degrees C below; and at 10am to the typical setpoint. Specific values for each site are given in T2 .

[4] Subjective characterization provided by occupants.

T2 Load Shift Schedules

Site	Load-Up Setpoint 5am - 6am	Shed Setpoint 6am-10am	Standard Setpoint from 10am
1	25° C / 77.0° F	22° C / 71.6° F	24 C / 75.2° F
2	25° C / 77.0° F	22° C / 71.6° F	24 C / 75.2° F
3	23° C / 73.4° F	20° C / 68.0° F	22 C / 71.6° F
5	24° C / 75.2° F	21° C / 69.8° F	23 C / 73.4° F
6	23° C / 73.4° F	20° C / 68.0° F	22 C / 71.6° F
7	25° C / 77.0° F	22° C / 71.6° F	24 C / 75.2° F

In homes with supplemental heating, occupants were instructed to keep the thermostats for such devices at least one degree C lower than the setpoint for the mini-split at all times, or to disable the equipment.

Data were collected from January 18 to April 3, 2023.

2.4 Data Processing

The data collected at each site for each day was reviewed for usability. Days were included in the analysis only if the thermostat setpoint matched the prescribed schedule for the day and all data points were successfully recorded between the hours of 12am and 12pm[5].

T3 Dataset Size

Site	Total Useable Days	Useable Load Shift Days	Useable Baseline Days
1	70	30	40
2	60	28	32
3	52	18	34
5	58	22	36
6	62	25	37
7	66	27	39
All	368	150	218

Most of the excluded days were a result of data logging failures. The remaining exclusions were mostly days when occupants either overrode the programmed load shift schedule (load shift days) or did not use a typical and stable setpoint from 12am to 12pm (baseline days). Because the goal of this study is to evaluate the Mysa device's ability to control mini-split operation and not user acceptance of demand response control events, these "opt out" instances were not included in the analysis.

[5] In all cases, the indoor temperatures recovered to normal by noon. Because our analysis is limited to the part of the day affected by the simulated load shift events, the quality of data after noon does not affect results.

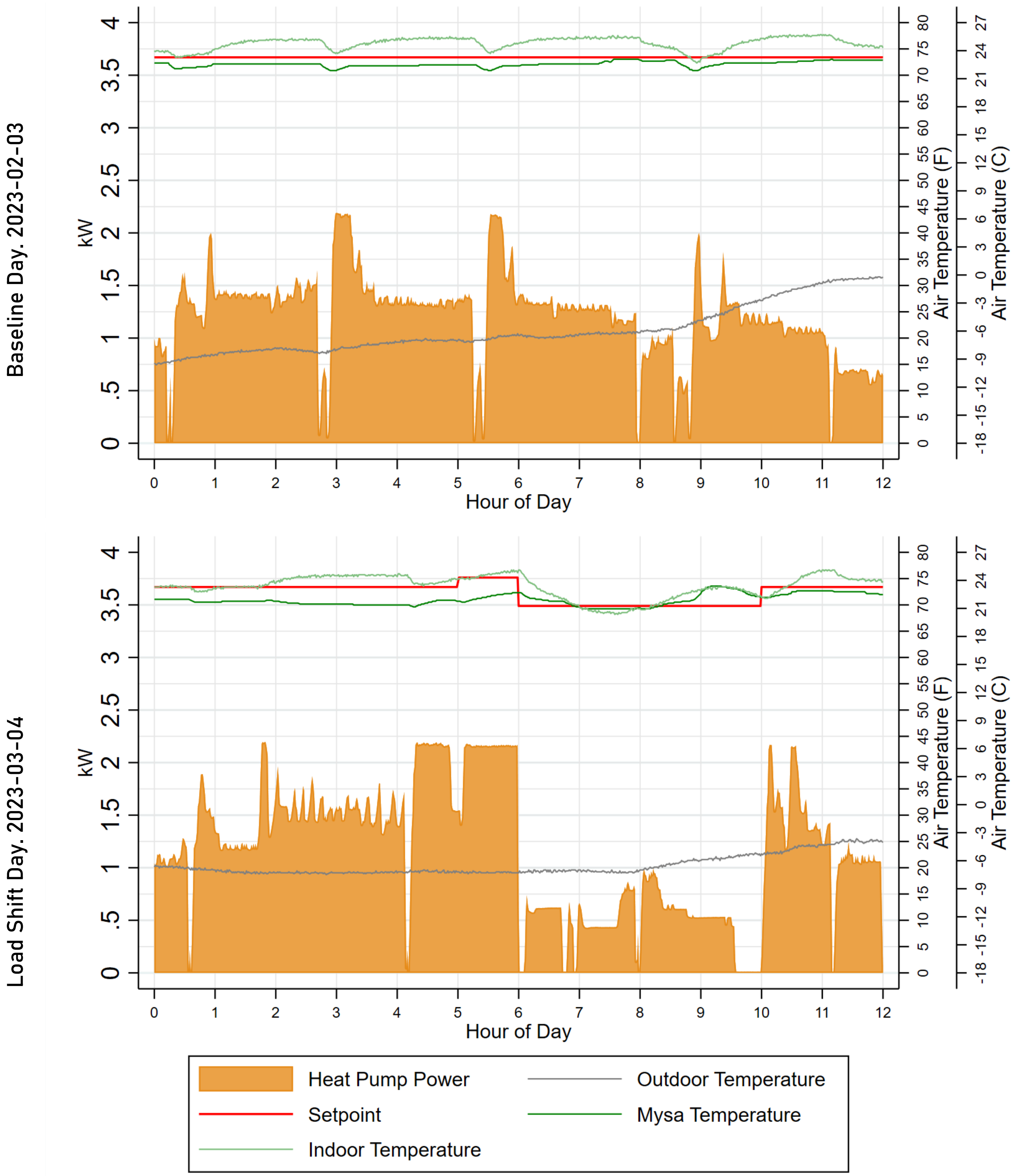
3 Analysis and Findings

3.1 Demonstrating Load Shifting Ability

3.1.1 Paired Day Comparison

Here we review the effect of the load shifting setpoint schedule for a single event, controlling for other variables. We compare data collected at a single site on two days with similar outdoor air temperatures but different setpoint schedules: One day with a constant setpoint and the other with the simulated load shift event schedule. The readings clearly show that the Mysa thermostat is able to influence the mini-split power use by altering the setpoint. F1 graphs the data.

F1 Baseline and Load Shift Day Example Comparison



Data from mornings of two days at site 5 comparing baseline (top) and load-shift (bottom) schedule effects.

The setpoint, graphed in red, shows a constant value of 73.4° F (23° C) on the baseline day. On the load shift day, the setpoint increases to 75.2° F (24° C) at 5am for the load-up period, decreases to 69.8° F (21° C) at 6am for the shed period, and then returns to the standard setpoint at 10am. The outdoor air temperature, graphed in gray (grey), is similar between the two days.

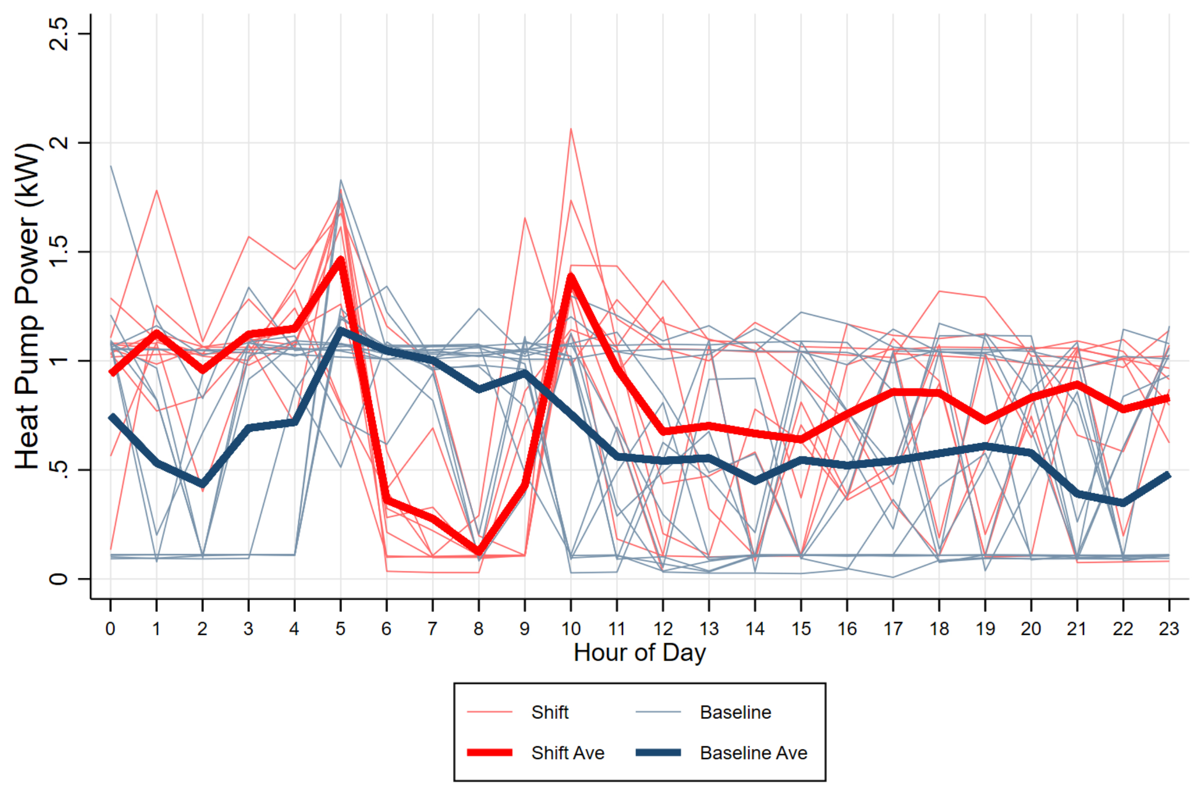
On the baseline day, the heat pump has a fairly even power draw, operating between 1.0 and 1.5 kW most of the time.[6] On the load shift day, each of the three setpoint changes induces a noticeable effect:

- **Load Up:** Just before 5am, the heat pump reduced power from its typical highest power of about 2.1 kW to 1.5 kW. When the setpoint increased at 5am, the mini-split responded by returning to the higher power level.
- **Shed:** When the setpoint is decreased at 6am, the mini-split idled briefly, and then resumed operating at a low-power level, about 0.6 kW. The heat pump operated for most of the shed period, but around that 0.6 kW level, rather than the 1.0 kW and higher that is seen in the baseline day during the same hours.
- **Recovery:** When the setpoint was returned to the standard temperature at 10am the mini-split ramped up – including two brief periods at its highest power level. Around 11am the indoor temperature was recovered and the heat pump settled into the moderate, ~1.0 kW operating range.

3.1.2 Aggregate Results

To understand the effect of the simulated load shift event setpoint schedule on heat pump power in aggregate, we grouped days from each site by their average outdoor temperature from 12am to 12pm. F2 is an example of one of those groups, graphing the hour-by-hour power use at site 3 for days with an average morning temperature of 30 to 40° F (-1.1 to 4.4° C).

F2 Heat Pump Power Profile for 30F-40F Days, Baseline and Shifted. Site 3.



Baseline data are graphed in blue, load shift data in red. The thin lines represent individual days; the thick lines their averages.

The average power for load shift days exhibits the expected profile for a load-shifting event and varies from the baseline average as would be expected:

[6] We suspect the dips in power, followed by increases to 2.1 kW around 3am, 5:30am, and 9am to be defrost cycles and subsequent recovery.

Load Up

Power is highest during the load-up period, hour 5. This hour uses the highest setpoint of the day and is typically one of the coldest hours of the day. (The outdoor temperature is the primary reason that the baseline average peaks at the same time.)

Shed Period

Power drops significantly during the shed period, hours 6-9. These four hours have the lowest power use of the day. By comparison, on baseline days, they are four of the five highest hours for power use.

Fourth Shed Hour

In the last hour of the shed, hour 9, power increases somewhat. At the beginning of the shed, the indoor temperature begins “coasting” down from the load-up temperature toward the shed-period setpoint. Because there is insufficient heat to coast for a full four hours, the average power is higher at the end of the shed than the beginning. Note that it is still well below the baseline average.

Recovery

At the end of the shed, at hour 10, power spikes as the mini-split reacts to the higher setpoint sent to it from the Mysa thermostat and begins recovering the temperature to the normal setpoint.

Similar patterns are seen across all sites and in different outdoor temperature groups.

3.2 Load Shifting Effectiveness

The preceding examples demonstrate that the Mysa thermostat is capable of reducing the electrical load of mini-split systems in heating mode. The question that naturally follows is how much the load can be reduced. While an important part of the answer depends on what mini-split the Mysa thermostat is connected to, the data from this study demonstrate a meaningful reduction in power across several mini-split models.

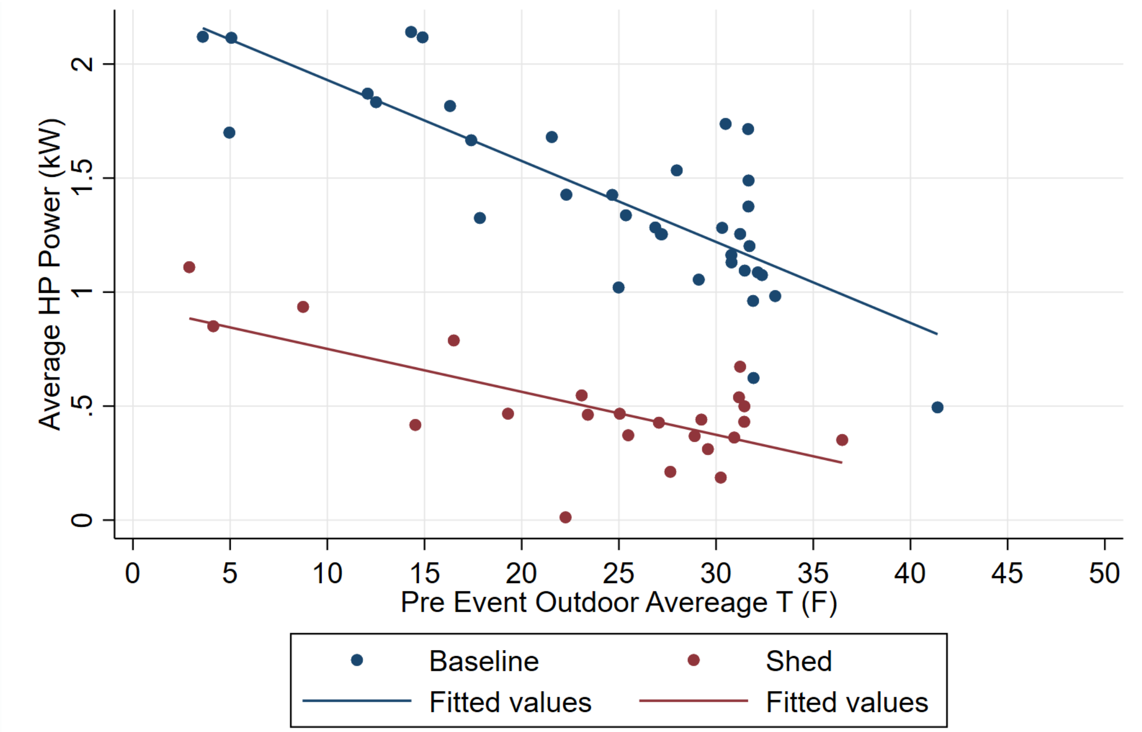
While the event in this study had a duration of four hours, much of our analysis focuses on the first hour of the event as we believe it will have more practical utility.

3.2.1 First-Hour Power Reduction

The study data reveal a clear relationship between use of the load shift setpoint schedule and a reduction in power during the first hour of the shed.

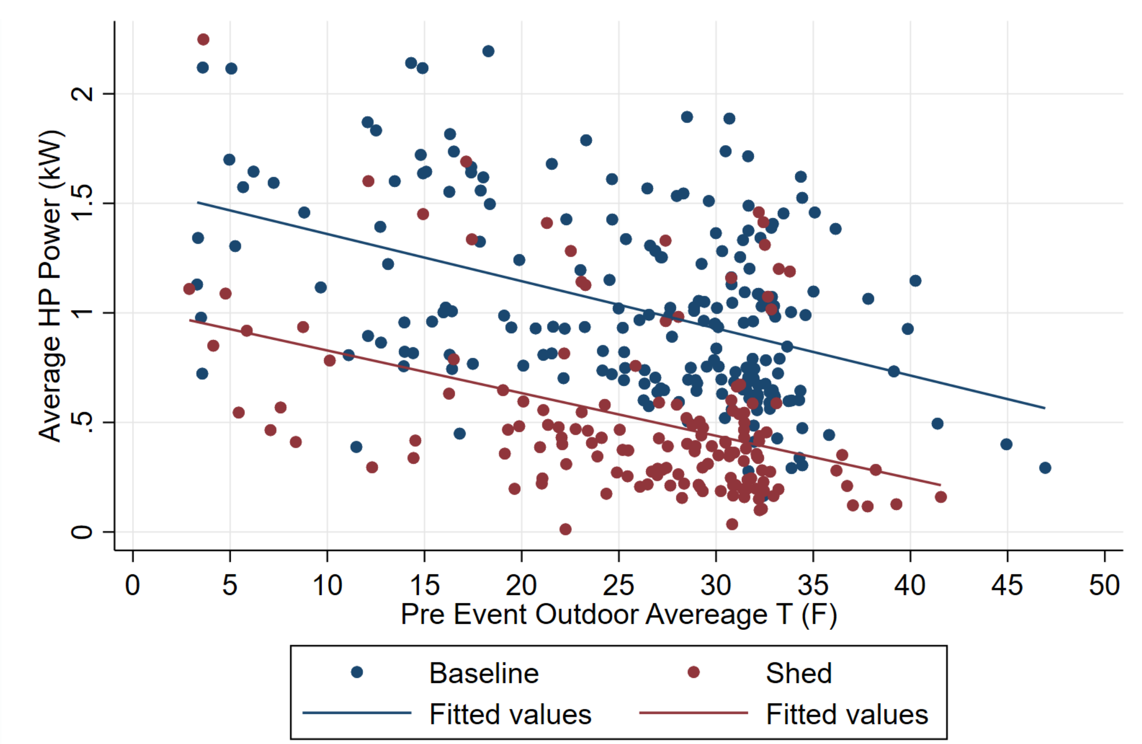
That relationship is demonstrated with site 5 in F3 . Average heat pump power over the 6am-7am hour of each day are arranged by the average morning outdoor temperature. Again, days with the baseline schedule are in blue, and load shift days in red.

F3 Example of Average Power During First Hour of Shed. Site 5.



Combining the data from all sites shows the same general patterns and relationships, as demonstrated in F4 . This graph does not control for site-specific factors (mini-split size, volume of conditioned space, insulation quality, etc.) that affect power requirements. Nevertheless, the pattern of reduced power during the load shift event is plainly evident despite all the variability across sites.

F4 Average Power During First Hour of Shed, All Sites



3.2.2 Outdoor Temperature and Load Reduction

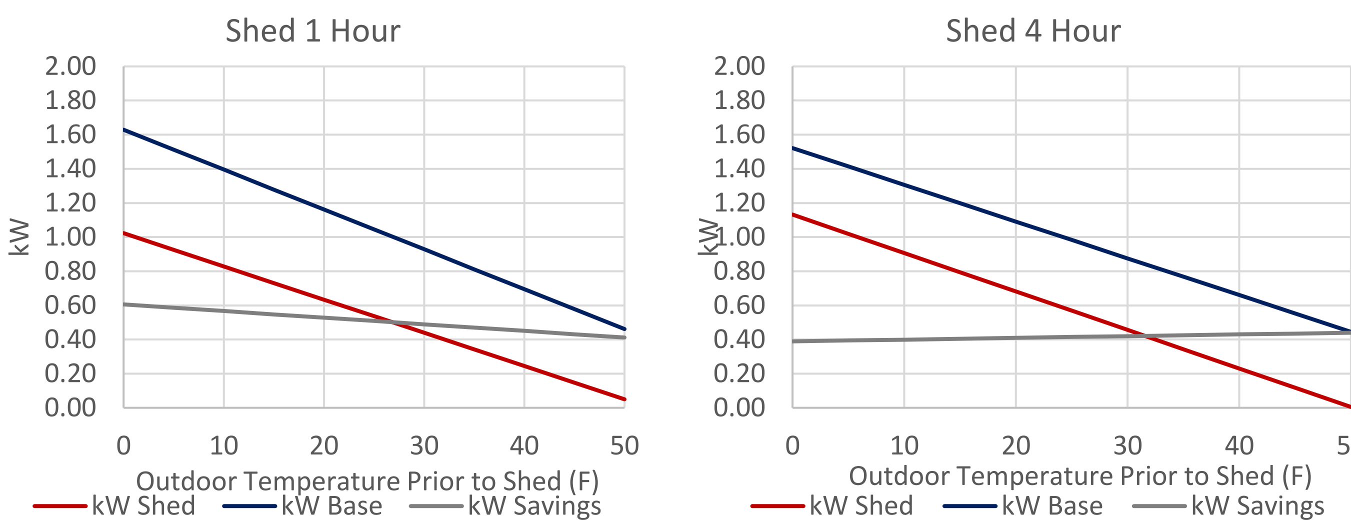
The data also demonstrate the effect of outdoor air temperature on load reduction.

A linear regression of power against outdoor temperature shows that over the first hour of the shed, the savings has a mild outdoor temperature dependence. Overall, this amounts to 3.8W per degree F (6.8W per degree C). Put another way, every 26 degrees F (14.4 degrees C) colder, there is an additional 0.1 kW of power to shed. This makes sense because the heat pumps operate at higher power when it is colder outside so there is more power to drop.

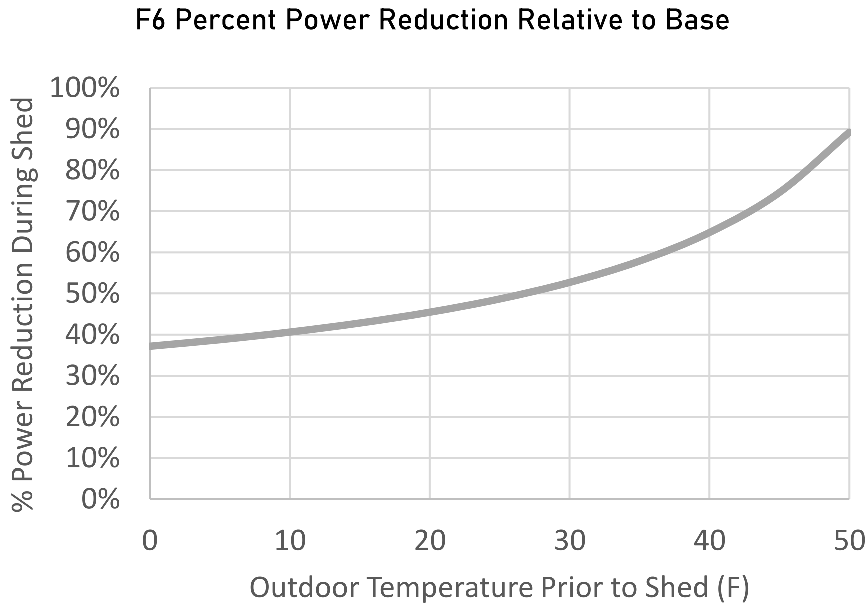
Over the four-hour period, we do not see evidence of temperature dependence of the power reduction. It is mostly constant at 0.4 kW over a 50 degree F (28 degree C) temperature range. Based on heat-loss principles, we would expect some temperature dependence. We speculate that the relationship is not apparent in our dataset due to its relatively small size and because it is dominated by temperatures in the 20 to 33° F (-7 to 1° C) range where the effect is muted.

F5 shows the linear estimates of baseline, shed, and savings power use for both event durations.

F5 Power Savings by Outdoor Temperature, 1- and 4-hour Sheds



The fraction of load reduced relative to the baseline use is highly dependent on temperature. This is because the baseline load increases as the outdoor temperature cools but the power reduction is fairly constant. Restated, at warm temperatures like 40° F (4.5° C) the mini-splits are running at a lower power and they are able to almost completely shut off. In contrast, at low temperatures, the mini-splits are running under higher power and only reduce input so much. F6 shows the relationship. This finding is based solely on the six mini-splits under study. Other mini-splits in other houses will likely have other behavior. Still, the amount of relative power reduction is expected to be higher at warmer temperatures and lower at cooler ones.



3.2.3 Power Reduction

The average power shed by the mini-splits during the events, across all temperatures, is summarized in T4 . The average first hour reduction was 50% of the baseline usage, or 0.5 kW, while the average over four hours was 45%, or 0.4 kW. During the first hour of the event, the setpoint is reduced and the mini-split can coast down to the lower temperature. As the event progresses, the indoor temperature approaches the setpoint and the mini-split must operate again which explains why the average reduction, per hour, is less over a longer period.

The first hour average power reduction ranged from 33% to 70% of the load, or 0.2 to 0.9 kW across the sites. In-depth analysis revealed no apparent relationship between the mini-split nominal size (heating output capacity) and power reduction. Further investigation showed similarly no apparent relationship between floor area served by the mini-split, use of temperature setback, overnight temperature, or the indoor temperature drop experienced during the event. We expected there to be a correlation between the power reduction and a combination of the mini-split size and floor area served, since these two factors strongly relate to baseline power use. We speculate that the sample size is too small for such a correlation to be evident. Further, the diversity of equipment makes may also lead to a diversity of savings. The way that a particular product responds to a change in the setpoint is specific to that product. Some spin down the compressor more slowly than others, for example.

We note that site 1 maintained a deep overnight temperature setback throughout the study. The temperature was typically set to increase around the load up time period. Since the house was warming up, we think this had the effect of dampening the ability of the mini-split to drop load during the shed period. However, this explanation is not universal across the dataset because site 3 also used an overnight setback about half of the days yet showed large power reductions.

T4 Average Power Reduction Summary

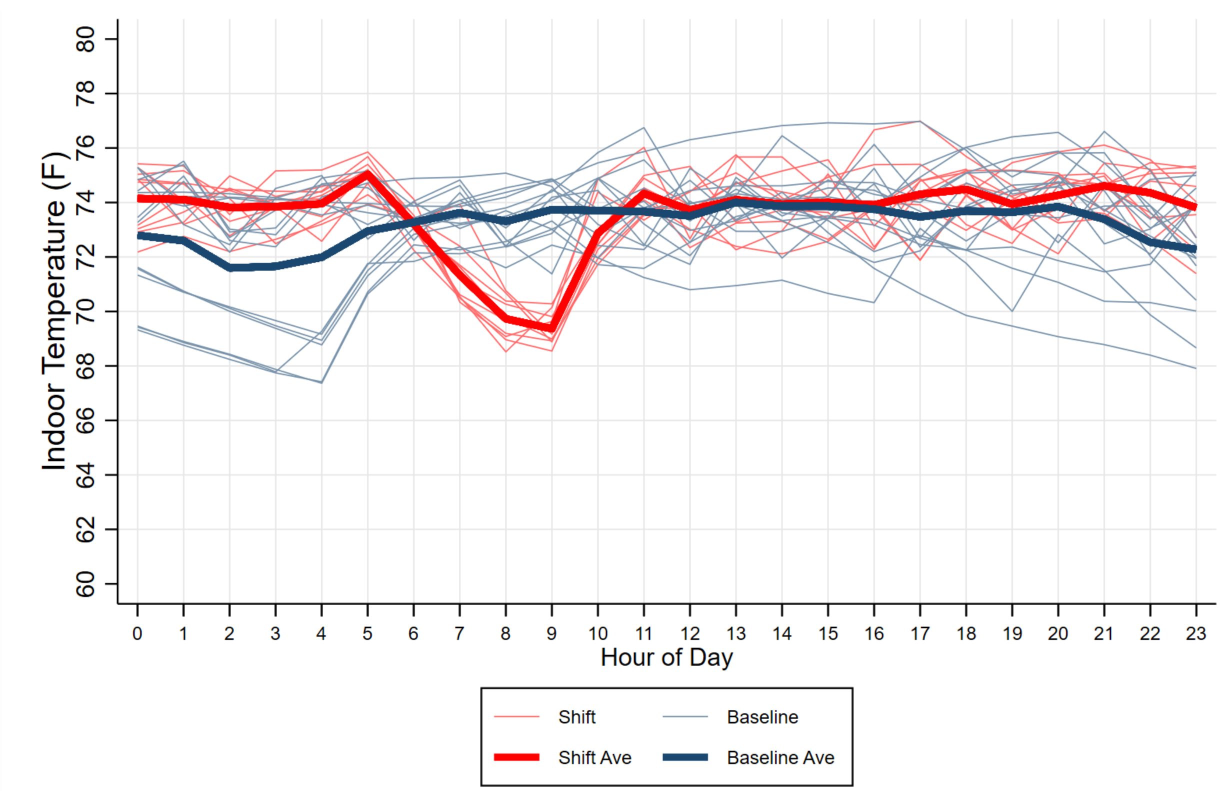
	Mini-split Size	Average kW Reduction		Percent Reduction		
Site	**Nominal Tons**	**1 Hour Shed**	**4 Hour Shed**	**1 Hour Shed**	**4 Hour Shed**	**1 hr kW/ton**
1	1.58	0.23	0.12	33%	18%	0.15
2	1.50	0.50	0.53	33%	36%	0.33
3	1.11	0.63	0.61	53%	56%	0.57
5	---	0.92	0.66	65%	53%	---
6	1.33	0.52	0.44	70%	63%	0.39
7	1.13	0.40	0.32	54%	45%	0.35
Average		**0.51**	**0.42**	**51%**	**45%**	

3.3 Setpoint and Indoor Temperature Relationship

An important practical matter for any heating load shifting program is the impact on indoor air temperature. While this study was not designed to test occupant acceptance of events, the temperature data collected are nonetheless informative. One important finding is that lowering the setpoint to reduce mini-split power use does not necessarily result in a drop of indoor air temperature.

F7 demonstrates a typical expected indoor temperature profile. It includes data from days at site 3 with an average morning outdoor temperature between 30 and 40° F (-1.1 and 4.4° C). Indoor temperature increases slightly during the load-up period (hour 5) and then drops throughout the shed period (hours 6-9). The rate of temperature drop is noticeably slower in the fourth hour of the shed, as the mini-split resumes heating. At the end of the event, the indoor temperature recovers within an hour. In comparison, the average indoor temperature is mostly steady on baseline days.

F7 Example Indoor Temperature Profile for 30F-40F Days, Site 3



While the preceding example demonstrates that the expected effect on indoor temperature does occur, reviewing the full dataset shows that is not the case for every day at every site. T5 reflects indoor temperature data from all sites on load shift days. Among the unexpected outcomes is that the load-up setpoint does not consistently produce an increase in indoor temperature. We hypothesize that the 1 degree C (1.8 degrees F) increase may not be large enough to induce a meaningful change in the mini-split operating behavior in all cases. Consequently, we recommend a future trial where the load up temperature is at least 3.6 degrees F (2 degrees C).

The temperatures in the first hour of the shed dropped in four of the sites and, in the full four-hour length, in five sites. The amounts varied from site to site likely due to the house insulation, thermal mass, and mini-split operational differences.

T5 Average Indoor Temperature Changes During Events

Site	Reference 12-5am	Load Up 5-6am	First Hour 6-7am	Full Shed 6-10am
1	68.8° F 20.4° C	+2.3° F +1.3° C	+2.7° F +1.5° C	+2.0° F +1.1° C
2	69.4° F 20.8° C	+0.9° F +0.5° C	+1.4° F +0.8° C	+1.7° F +0.9° C
3	72.9° F 22.7° C	+1.3° F +0.7° C	-0.1° F -0.1° C	-2.3° F -1.3° C
5	75.5° F 24.2° C	0.0° F 0.0° C	-3.0° F -1.7° C	-3.8° F -2.1° C
6	73.7° F 23.2° C	-0.2° F -0.1° C	-2.8° F -1-6° C	-4.0° F -2.2° C
7	77.6° F 25.3° C	-0.2° F -0.1° C	-2.1° F -1.2° C	-3.3° F -1.8° C

Average temperatures during various segments of the event schedule are given relative to the average temperature recorded in the five hours before the load up.

Because the homes in the study have supplemental heating equipment (see 2.1) we also made an effort to eliminate them as a potential explanation for indoor temperatures and confirm they were not, unknown to us, being used to maintain indoor temperature while the mini-split was in shed mode. The heaters were typically in separate rooms from the mini-split and occupants were instructed to control them so setpoints were below the mini-split setpoints. Still, since the heaters were not metered directly, to ascertain operation profiles, we surveyed the occupants on their use. Across the board, those heaters were rarely used. Further, we observed a temperature drop in the space served by the mini-split heat pump in the shed period. This is clear, indirect evidence, that other heating systems did not run or, at least, did not run much during the shed period. Consequently, we remain confident in the ability of the Mysa thermostat to shed load even in houses with multiple heating sources. Importantly, however, we suspect that to effectively shift loads in a large population of houses, the additional heating sources need to be either separately set to always be below the mini-split temperature or jointly controlled by the smart thermostat in conjunction with the mini-split.

In qualitative terms, four occupants reported noticing lower temperatures on load shift days. Three of them found it uncomfortably cool.

4 Conclusions

The project demonstrated the Mysa thermostat effectively control the operation of multiple brands of mini-split heat pumps according to a schedule. Further, the demonstrated behavior showed the approach can shift and shed load during heating operation in the morning hours. This is especially notable because the Mysa thermostat interacts with the heat pump only by sending setpoint signals. It is not directly instructing the variable speed compressor to “ramp-up” or “turn-down”. The setpoint control method clearly works.

The project did not exercise the ability of Mysa to dynamically send control signals to the thermostat as would be more typical of an “active” demand response program. Mysa has demonstrated that capability elsewhere.

Across the six sites studied, which had heat pump sizes nominally ranging from 1-1.5 tons, an average power reduction, compared to the baseline, of 50%, or 500 W, during the first hour was achieved. The amount varied with outdoor temperature ranging from 450 W (65%) at 40° F to 570 W (41%) at 10° F. The percentage reduction decreased as temperature dropped, but the absolute amount increased. This follows due to the increasing house heating load.

The data show that the two degree C setpoint decrease was clearly enough to induce the mini-split to reliably operate at lower power. In contrast, the one degree C setpoint increase for the load up period appeared to be only mildly successful in inducing more power consumption, at least in the one-hour period. Only half of the sites showed an obvious, immediate change in mini-split operation in response to the load up setpoint. For future studies or programs, we recommend exploring at least a two degree C (or 3+° F) increase.

Additionally, the data show overnight temperature setback potentially dampens ability to shed load in the morning. With the house being cooler overnight, the mini-split is working to bring it up to temperature in the early morning. Essentially, the house is not pre-heated. This implies that a longer pre-heating period than one hour used in this test is needed. An overnight setback could still be used, but the pre-heating period may need to be two to three hours long instead of just one. Future studies could explore this option.

In dwellings heated solely by a mini-split heat pump, the Mysa thermostat can clearly control the equipment to increase or reduce power consumption for the dwelling as a whole. For dwellings with multiple heating sources, such as additional electric resistance baseboard heaters, those must be controlled to stay below the mini-split setpoint to realize load shifting. In addition to a thermostat for AC and mini-splits, Mysa also makes a thermostat for electric baseboard heaters with line-voltage controls. Integrating these two thermostats into a control system for the whole dwelling is a way to guarantee that the mini-split is used preferentially to condition the space, ensuring that inefficient heat sources do not erode the gains made by scheduling the mini-split alone.

As planned by the thermostat, the indoor temperature during the shed period generally declined compared to the load up and the pre period. If other analysis finds the temperature drop seen in the four-hour, two-degree shed event to be too great to implement at a large scale, there remain myriad demand response control strategy implementation possibilities. These include shorter shed periods and adjusting the indoor setpoint by fewer degrees. These strategies could potentially achieve the same power reduction observed in this demonstration. For instance, if the setpoint is decreased for 15 minutes, the mini-split will operate at lower power for that period – potentially the same drop as the one-hour period. Carrying this example further, in a full-scale demand response program, one can imagine four groups of houses (with thousands in each) and sending the signal to drop load in succeeding 15-minute intervals. The result would effectively be a continuous load drop for one hour across one quarter of the participating houses.

The results from the demonstration are clearly encouraging. They show the Mysa thermostat has opened the door to allow mini-split heat pumps of a large range of makes and models to participate in demand response and load shifting programs. Larger-scale field trials are now needed to more fully explore and quantify the benefits of load shifting mini-split heat pumps with the Mysa thermostat.