UCONS Ductless Heat Pump Demonstration: Interim Evaluation of Phase 2 Enhanced Controls and Operational Procedures for Manufactured Homes at Franklin Pierce Estates Mobile Home Park

Summary of Findings

April 2020

T. Eckhart
G. Sullivan
H. Reichmuth

UCONS, L.L.C.
Utility Conservation Services

Efficiency Solutions
Applied Energy Management

ORGANIZATION OF REPORT

Acknowledgments

The authors would like to thank Tacoma Public Utilities (TPU) for their support of the Franklin Pierce Estates demonstration program. Their staff were supportive of both phases of this important program, providing ongoing customer support and conducting important evaluations of the energy savings it produced.

This demonstration program also required and received the ongoing support of the manufactured home park owner and park manager over 30 months. The park manager, Debra Kraft, was instrumental in facilitating communications with both program participants and non-participants. Debra passed away last year but deserves special credit for this program.

The project team also appreciates the control equipment donation and marketing support by Gensco Services and Mitsubishi Electric. In addition, the project benefitted from collaboration with PNNL's separate project, coordinated by Cheryn Metzger. The project team greatly appreciated their tour of the PNNL evaluation site to learn of the systems, controls and zonal heaters employed for that regional study.

Finally, the Franklin Pierce demonstration program would not have been possible without the hard work of Dustin Breazeale, who coordinated all phases of field work during the program's 30 months. He addressed all customer inquiries, which resulted in the high level of customer satisfaction noted in the report.

I. Executive Summary

Introduction

In 2017, Tacoma Public Utilities (TPU) conducted a Pilot program in which no-cost ductless heat pumps (DHPs) were provided to their customers in manufactured homes in the utility's service area. The utility selected an experienced HVAC contractor in the manufactured home sector to install a single-head, 1-ton DHP in homes with existing electric forced air furnaces (eFAF). The objective of the program was to evaluate energy savings and the ability to meet customer's winter heating needs with a single-head DHP. This study was conducted in 2 Phases:

Phase 1: Single-head (1-ton) DHPs were installed in accordance with utility guidelines for qualifying customers (heated by eFAF) in 53 manufactured homes. The existing eFAF was left operational. Energy savings (following a single winter heating season) were found to be ~2,800 kWh annually and demonstrated a high level of separate (and concurrent) operation of both the DHP and the eFAF heating systems. When including an additional year of post-billing data, TPU has reported much higher energy savings for Phase 1 (3954 kWh).

Phase 2: Typically, larger DHPs were installed in 29 of the non-participant homes of the mobile home park based on size of living area and number of occupants. Additional controls were provided that precluded normal operation of the older eFAF. Supplemental bedroom space heaters were provided to those participants who requested them.

This report focuses on the data and lessons learned from Phase 2 and suggests direction for future studies. As part of the Phase 2 report, however, it is necessary to describe the process and findings of Phase 1.

Methodology

In order to enhance the data and information gained from this demonstration, multiple evaluation methodologies were conducted by TPU and UCONS. This report reviews the findings of pre- and post-billing history evaluations by both the utility and by UCONS consultant, Howard Reichmuth of each participant home over the winter heating season. UCONS also engaged Efficiency Solutions to conduct a process evaluation employing temperature-recording data loggers in multiple areas of each participant home over the winter heating season. The purpose of this evaluation was twofold: first, to evaluate how frequently the two heating systems (eFAF and DHP) operated following installation of the DHP; and second, to evaluate space temperatures in certain areas of each home following installation of a single-head DHP zonal heating system. The temperature recording evaluation provided insight into actual system use (run time) and when/if the eFAF, the DHP, or both systems were in use. The results of the Phase 1 and Phase 2 temperature evaluation highlight a significant decrease in eFAF use when the new controls were installed as part of the Phase 2 demonstration (illustrated in Section III).

There were 2 Basic Objectives and Findings from the 2nd Phase of this Pilot:

1. To install and evaluate new controls for the eFAF in order to mitigate the frequent use of the eFAF found in Phase 1. Allowing continued operation of the original heating system (when installing a new heating source) allows continued dependence on heating systems that are frequently over 30 years old.

   Findings: A single-head DHP in manufactured homes (with controls that mitigate continued operation of the eFAF heating system) proved successful for meeting winter heating in most applications when supplemental bedroom heating was provided. 2 of the 29 participant homes had 7 occupants and requested disabling the new controls within the 1st week of installation of the new single-head DHP.

   Customer satisfaction surveys of Phase 2 participants (following 2 winter heating seasons) demonstrated that all participants were both comfortable and satisfied with their new single-head DHP systems.

2. To obtain adequate pre- and post-billing data to evaluate if additional energy savings can be achieved through the installation of a single-head DHP in a manufactured home (when mitigating operation of an eFAF heating system).

   Findings: The energy billing histories of the participants in this relatively small project, consisting of only 29 participants, were reviewed and analyzed by Howard Reichmuth for evidence of energy savings. The preprocessed billing data supplied by TPU was sufficient to support the analysis of 17, (58%), of the participating sites. This data yield is typical and considered good for analysis projects of this type. The analysis used an IPMVP option C compliant protocol to develop site specific savings estimates at the monthly level. The results showed significant savings in excess of an average 3,300 kWh/yr. for most of the sites which also were notably sites with conspicuously high winter electric use in excess of 2,000 kWh/month.

   TPU reports its separate billing analyses of Phase 2 to be 3502 kWh.

Independent of this study, the Northwest Energy Efficiency Alliance (NEEA), BPA and other parties supported a research evaluation of DHP in the PNNL lab homes in Richland, Washington. The PNNL study was conducted employing similar DHP systems as in the TPU project and in lab modular homes similar in size and layout as the TPU Demonstration. The timing of these two evaluations over the same winter heating season provided a unique opportunity to compare data and lessons learned from unoccupied (but carefully monitored and controlled DOE lab homes in Richland, Washington), with 82 occupied manufactured home participants in the service area of TPU.

II. Overview of the Program and Measures Evaluated

The Northwest Power and Conservation Council's 7th Power Plan identified the manufactured home customer class as a hard to reach customer class with limited levels of participation in regional conservation programs. Duct sealing (and some lighting measures) have been the predominant measure offered this customer class. With this reality, Tacoma Public Utilities initiated a demonstration of DHPs with a focus on this underserved market. UCONS, working with TPU, facilitated the customer interaction, qualification, equipment installation and evaluation.

A. Phase 1 Design and Customer Selection

Prior to commencing the Pilot, TPU requested that UCONS embark on a review of the mobile home parks in their service area to identify homes that would provide a representative sample of this customer class. The 102-unit Franklin Pierce Estates was selected for its location, demographics and cooperative park management and park owners. The park consisted of predominately double-wide manufactured homes. Only those customers with eFAF qualified to participate. Tacoma randomly identified homes whose owners were asked to participate in the Pilot program. Nearly all of those asked in Phase 1 elected to participate for a sample size of 53 homes. Phase 1 non-participants in the park were candidates for the "control group" in the Phase 1 billing history evaluation.

The Phase 1 demonstration closely followed the regional and utility guidelines for the installation of a single-head, 1-ton DHP in a manufactured home. The low-income program at that time provided a fixed compensation to contractors for the installation of a 1-ton DHP system. While UCONS noted that a 1-ton system did not always meet manufacturer guidelines for sizing of DHP, TPU noted that an important objective of the demonstration project was to learn when (or if) there were situations requiring the installation of a larger DHP.

As part of the design, it was recognized that a billing history evaluation would capture the energy savings of the program, but would not capture the temperature distribution within each home, nor would this impact evaluation demonstrate the frequency of use by both heating systems. To separately evaluate these operational parameters, a temperature monitoring protocol was designed to use DHP and eFAF supply temperatures as a proxy for system run time. This portion of the program evaluation employed temperature recording data loggers in the supply-air streams from the two devices as well as loggers in primary living areas to record ambient space temperatures. Details of this evaluation are provided in greater detail in Section III.

Following the initial winter heating season of 2017/2018, results of the Phase 1 billing analysis were reported by TPU to be energy savings of about 2,800 kWh for the average of all participants. An independent evaluation performed by Howard Reichmuth provided similar results

B. Phase 2 Design and Customer Selection:

UCONS met with the staff of TPU in the summer and fall of 2018 to review the findings of Phase 1. While customer satisfaction was high and approximately 2,800 kWh savings had been achieved, the savings were not as great as the utility had hoped. In addition, the process evaluations demonstrated a significant use of the eFAF. Furthermore, during the Phase 1 portion, there were frequent customer inquiries on how best to use the multiple thermostats (their existing eFAF thermostat and the new DHP thermostat) during the colder winter months.

Phase 2 benefitted from a prior DHP Pilot conducted in California the previous year. In that pilot, UCONS installed similar DHPs as employed for the TPU Demonstration. An outcome of the California pilot was the realization of the challenges of a zonal heating system installed with an existing central eFAF system. These challenges include:

- The two systems are not compatible operationally. The eFAF system tends to recover and heat much more quickly than the single-head DHP. Most customers “set back” their new DHP at night, but have found they do not recover quickly in the morning. The consequence is a high morning demand on the eFAF. This problem was minimized by educating new customers to not setback their DHP at night.
- There are no “off the shelf” (and low cost) thermostats to optimize operation of zonal systems and whole house eFAF in manufactured homes. This customer class requires a simple and low cost approach to heating their homes.
- Often the two systems “compete” with each other, particularly if the thermostats are not located optimally.
- Research also found that some customers left their eFAF systems “on” in the summer. As such, when the occupants placed their DHP into a cooling mode, this set up a very inefficient simultaneous heating and cooling scenario.

Education has been found to mitigate some of these challenges but would need to be provided on an ongoing basis and would not be practical on a large-scale program.

In the Northwest, the removal of an eFAF (when replacing with a single-head DHP) can present problems during the winter heating season. UCONS and TPU reviewed options to reduce the operation of the eFAF, except when the DHP could not maintain living room and kitchen temperature above 65 degrees. In Phase 2, UCONS recommended installing a new eFAF thermostat capable of allowing operation when ambient temperatures dropped below the lock-out set point of 65 F. The objective for employing the new thermostat to the older eFAF was to:

- Minimize eFAF usage except when the DHP could not maintain a comfortable temperature.
- Maximize the energy saving benefits of the single-head DHP.

To mitigate any potential comfort issues in back bedrooms/areas, Tacoma Public Utilities and UCONS agreed that stand-alone space heaters (wall-mounted and upright portable oil-filled heaters, 400 W and

700 W respectively) would be provided to Phase 2 participants who requested them. Table 1 summarizes the homes (size and age) and key measures provided each Phase 2 Participant.

Home #	Width	Size (sq. ft.)	Age (year)	# occupants	DHP Size (in tons)	Heater	
						Wall	Oil
	DW	1188	1988	5	1.25	2	
	SW	932	1989	1	1	1	1
	DW	1188	1991	4	1.25	1	1
	DW	1077	1999	3	1.25	0	0
	SW	871	1989	5	1	1	1
	DW	1144	1983	1	1.25	1	
	DW	1080	1996	4	1.25	0	0
	DW	1080	1990	4	1	0	0
	DW	1296	1989	4	1.25	0	0
	DW	1179	1997	3	1.25	0	0
	DW	1404	1990	2	1.25	0	0
	DW	1782	1997	6	1.25		0
	DW	1404	1991	6	1.5	0	1
	DW	1765	1990	3	1	1	
	DW	1152	1982	3	1		0
	DW	1215	2002	1	1.25	1	1
	DW	1176	1990	1	1.25	1	1
	DW	1188	1994	9	1.25	1	1
	SW	780	2005	4	1	1	1
	DW	1404	1991	7	1.25	1	2
	DW	1188	1989	4	1.25	0	0
	DW	1296	1993	2	1.25		2
	DW	1478	1989	1	1.25		1
	DW	1624	2000	6	1.25	1	1
	DW	1188	1991	4	1.25		2
	DW	1296	1992	3	1.5		2
	DW	1293	1996	5	1.5	1	2
	DW	1320	1991	3	1.25		2

Table 1. Attributes of Phase 2 Participants

The primary equipment changes made in Phase 2 were:

1. Installation of controls for mitigating the reliance by the customer for continued use of a heating system (typically far past it's reliable or useful life).

2. Providing bedroom space heaters for those participants who requested them.

3. Installation of larger (1.25 and 1.5 ton) DHPs in most Phase 2 homes. While these were slightly more expensive, they were in accordance with the standard design specs recommended by most manufacturers.

4. Indoor head location. In Phase 1, the park owner required all DHP outdoor units to not be visible from the street. This required some of the indoor head placements to be less-than optimal. In Phase 2, the park owner waived this requirement, resulting in more optimal placement of the indoor head. This configuration also allowed better placement of the separate thermostats for the eFAF and for the DHP.

III. Evaluation Protocols Employed and Energy Impacts

The study (both Phase 1 and Phase 2) was designed to evaluate the practicality and benefits of high-efficiency DHP heating, improved control strategies, and occupant comfort, while minimizing the usage of existing eFAF and (often compromised) ducted delivery systems. Appendix A provides the technical details of the DHP used in this demonstration.

One overall objective was to evaluate the ability of DHPs to offset existing eFAF usage in the manufactured home setting. The study included 82 manufactured homes located at the Franklin Pierce Estates manufactured home park in Tacoma, Washington, and was conducted in two phases. Phase 1 (53 homes/winter months of 2018) included DHP installation (with DHP thermostat), commissioning, and occupant education. Phase 2 (29 homes/winter months of 2019) included the same installation, commissioning, and education but also included a new eFAF thermostat with an ability to lock-out (with occupant concurrence) the eFAF usage at temperatures above 65 F. In Phase 2, occupants were allowed/provided with small auxiliary space heaters (if requested) for supplemental comfort heating in back bedroom areas.

The evaluation design included multi-zone temperature data logging to assess DHP performance compared with the existing eFAF usage. Appendix B provides the technical details of the data logging devices used.

The evaluation also included a utility billing analysis for all participants (and a separate impact evaluation for each Participant).

In addition to monitoring, the evaluation design included ex-post participant surveys. These surveys were designed to determine satisfaction, challenges, overall comfort, and any operational or other issues encountered. Appendix C presents the survey instrument used.

A. Process Evaluation

This demonstration and evaluation were designed to assess the temperature distribution, displaced eFAF runtime, and thermal comfort resulting from the DHP installation. For a number of reasons, cost being primary, this analysis did not collect end-use energy data. In lieu of this, TPU and UCONS have conducted a pre- and post-billing analysis.

In each home, both Phase 1 and Phase 2, zonal temperature monitoring was completed. Each home was instrumented with four or five stand-alone temperature data loggers recording 5-minute interval temperature data. The temperature loggers were placed in zones both directly served (e.g., the main living area) and indirectly served (e.g., back bedrooms) by the DHP. In addition, each home had a logger placed in an eFAF duct register (records temperature profile of eFAF activity) and the DHP supply head (records temperature profile of DHP activity). While installation schedules varied, the Phase 1 data collection period was approximately 6 weeks during the months of January, February and March of 2018. The Phase 2 period encompasses a similar duration in the months of February and March of 2019.

All the demonstration homes had existing heating systems comprising a central eFAF. Figures 1-6 highlight the DHPs and the thermostats installed as part of the demonstration. Refer to Appendix A for the technical details on both the DHPs and thermostats systems installed.

Figure 1. Demonstration DHP Outdoor Unit

Figure 2. Demonstration DHP Indoor Head

Figure 3. DHP Thermostat and Temperature Logger

Figure 4. Updated eFAF Thermostat with Lock-out Capability

Figure 5. DHP Indoor Head with Temperature Logger

Figure 6. Temperature Logger as Installed in eFAF Duct–Register Removed

Evaluation Objectives. The evaluation objectives for this demonstration were threefold.

Objective 1. Determine the eFAF offset (i.e., reduction in system use via runtime temperature proxy) resulting from DHP installation in common areas of occupied manufactured homes. This was Phase 1 of this demonstration.

Objective 2. Identify opportunities for additional savings via better system control of eFAF and/or DHP.

Objective 3. Implement improved control strategy and determine performance via the same evaluation protocol used above. This activity constituted Phase 2 of this demonstration.

To accomplish these objectives, the multi-point temperature metering approach and billing analysis protocols were developed.

Metering Points

- Space temperature. Multiple point temperature logging of affected zones. Monitored locations included:
    - Main living space/thermostat
    - Partitioned zones (bedrooms/other)
- Air delivery temperature.
    - Existing eFAF system diffuser supply temperature (proxy for run/on time)
    - DHP head delivery temperature (proxy for run/on time)

The installation included 4-5 loggers per home, 2 focused on systems (DHP and eFAF) and 2-3 focused on space temperatures. Table 2 lists the temperature point locations and Figure 7 presents typical placement points. All metering used 5-minute sampling intervals for a higher resolution data set.

Point name	Measurement	Notes
T1	Existing/new thermostat temperature main living space temperature	Control point of occupant setting and space temperature
T2	Bedroom 1 temperature	Bedroom temperature
T3	Bedroom 2 temperature (where possible)	Bedroom temperature
T4	Existing system (eFAF) delivery temperature	Delivery air temperature of eFAF/proxy for run time
T5	DHP delivery temperature	Delivery air temperature of eFAF/proxy for run time

Table 2. Temperature Metering Points and Locations

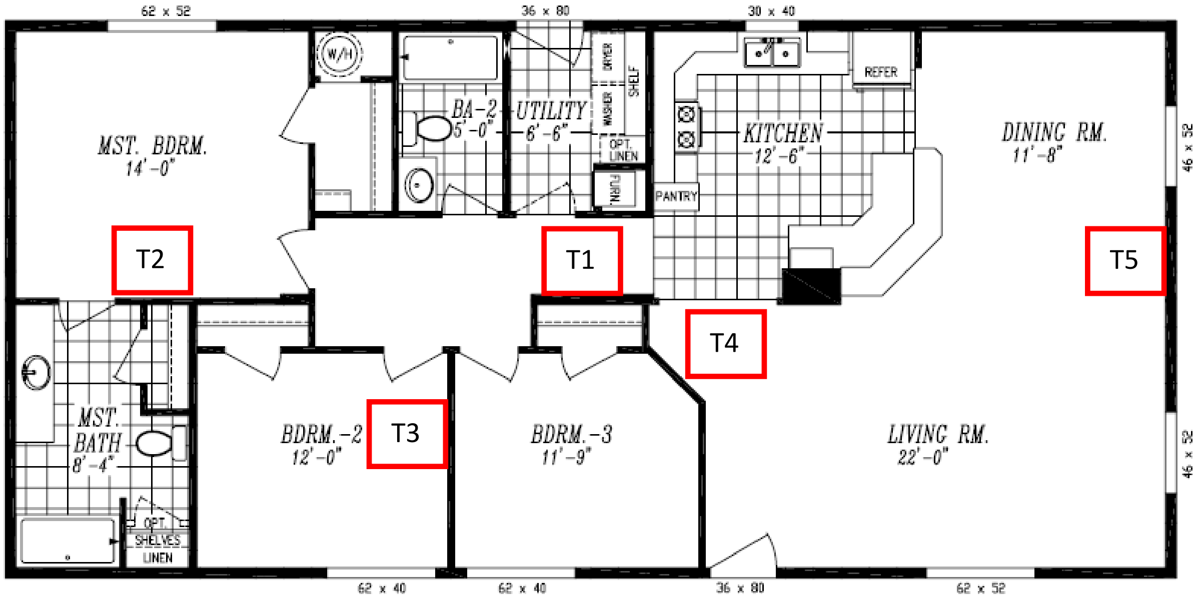


Figure 7. Temperature Logger Placement Points – Typical Manufactured Home (Marlette Homes, Hermiston, OR)

B. Evaluation Findings: Operational Impacts

Phase 1 (winter months of 2017/2018), the 53 manufactured homes received 1-ton Mitsubishi DHPs with standard Mitsubishi wireless hand-held (or wall-mounted) thermostats. In this phase, the existing eFAF was controlled via the existing thermostat.

Phase 2 (winter months of 2018/2019) the 29 manufactured homes in the same manufactured home park, received a slightly larger DHP, in most cases 1.25-tons. This phase included the same installation, education, and operational instructions. However, the existing eFAF thermostat was replaced with a modern programmable thermostat. With the occupant's concurrence, these new thermostats were set with an eFAF lock-out set at 65 F. In other words, the eFAF would not/could not be enabled unless the thermostat sensed a temperature at, or less-than, 65 F. Phase 2 also included the installation/use of 400 watt or 700 watt space heaters and were installed primarily in the bedroom areas where the DHP was less effective in heating the area. These were installed only at the occupant's request and the occupants used them at their discretion.

The charts below present the results of the multi-point temperature assessment. These data loggers allow for time-series (5-minute interval) recording of space temperature profiles and system delivery air temperatures. The data were processed to show which system (eFAF, DHP, both, or neither) were operating in any 5-minute interval.

Figure 8 presents the Phase 1 percentage of total heating time that the eFAF was engaged. The data are presented by participating home number (a surrogate number was used to maintain customer privacy). The data show, in most cases, a significant offset in eFAF usage. The actual number of total heating hours incurred varied by home, as expected. The difference between the percentage shown and 100%, represents the percentage of time the DHP served the requisite heating load.

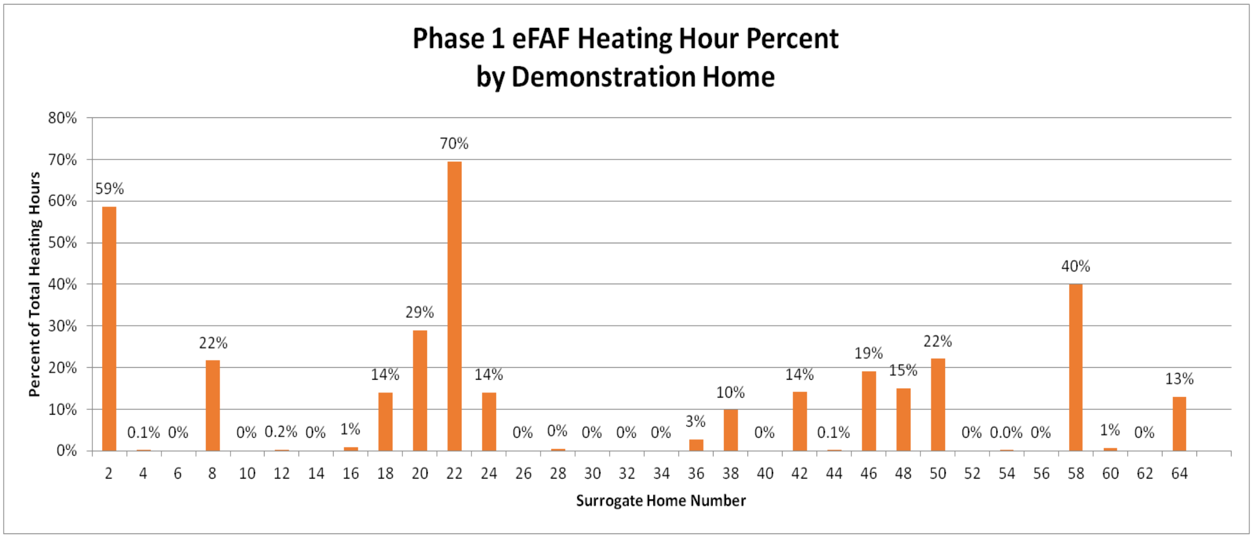


Figure 8. Phase 1 eFAF Heating Use Percentage by Surrogate Home Number

Figure 9 presents the same results, but for Phase 2 of this demonstration. Highlighted in Phase 2 is the marked decrease in the percentage of time the eFAF was engaged. In fact, the temperature data suggest, with two notable exceptions, that the eFAF saw little to no usage during this period. Upon further research with site installation staff, one of these homes had no lock-out enabled (per occupant request) and the other was found that the lock-out was defeated and site staff removed the lock-out.

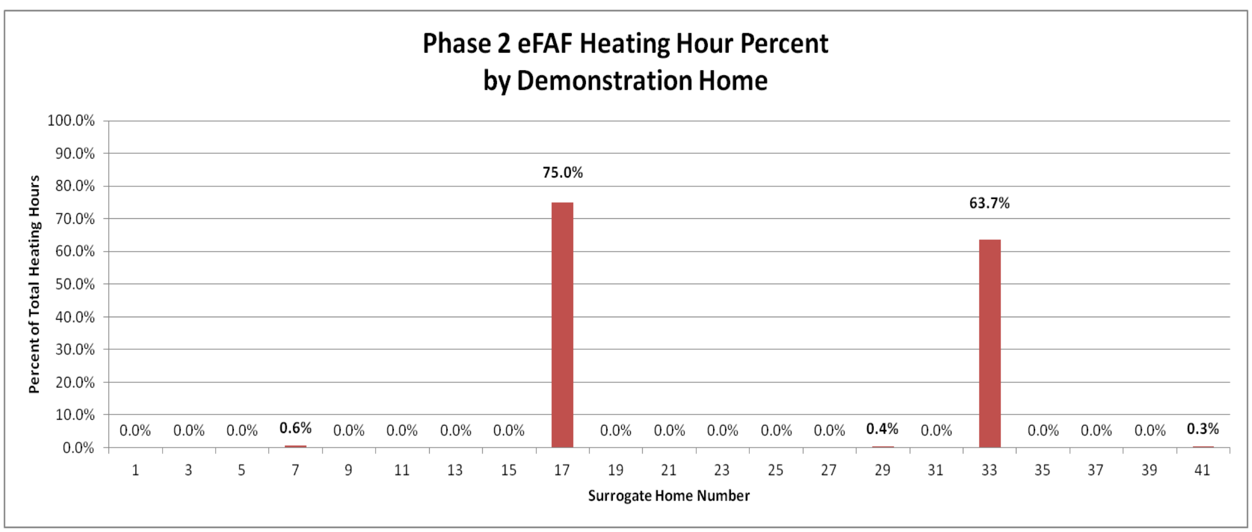


Figure 9. Phase 2 eFAF Heating Use Percentage by Surrogate Home Number

One of the drivers for this demonstration was to better understand how (or if) two heating systems can function properly (and efficiently) while serving the same zone or zones. Phase 1 of this demonstration provided evidence that indeed the DHP can offset a significant portion of the eFAF energy use. The

Phase 1 results presented in Figure 10 highlight this significant displacement of the eFAF. The Phase 2 results, taking advantage of enhanced control of the eFAF, further offset eFAF energy use in many homes.

An artifact within the temperature data also reveals how the two systems interact when their use is coincident. Figure 10 presents the Phase 1 percentage of heating hours when both systems were engaged–coincident heating system use. By way of example, in Home 8 (Figure 10 below) both systems (DHP and eFAF) were on together for 11% of the total heating hours.

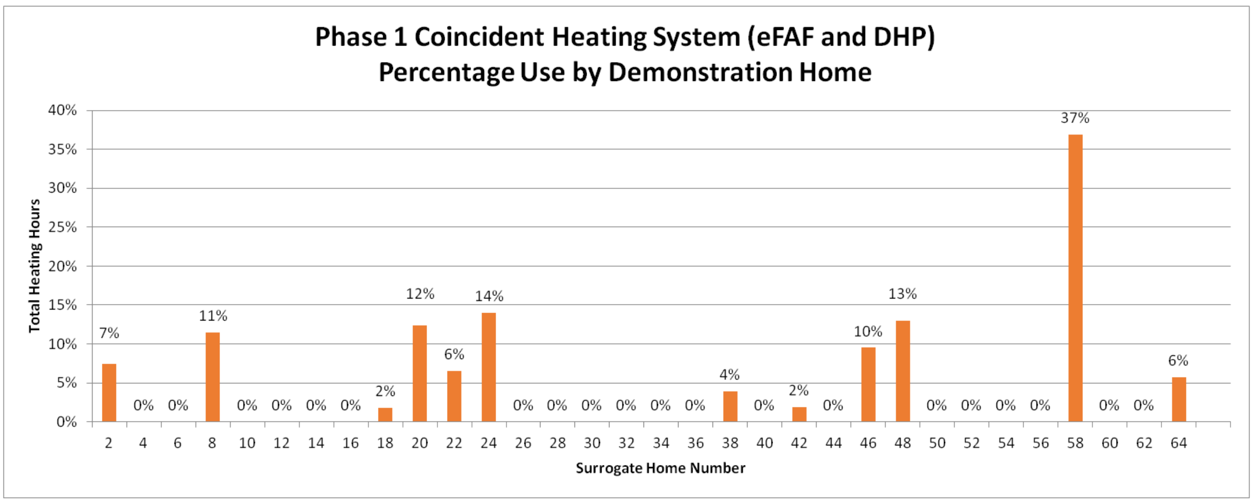


Figure 10. Phase 1 Coincident Heating System Use (eFAF and DHP) by Percentage and Home

A closer look at the actual transition between heating systems reveals an interesting, albeit intuitive, finding. In many cases when the DHP is operational and then the eFAF cycles on, the DHP will become "satisfied" and will power off. This is not unexpected as a typical eFAF system is designed to rapidly increase zone temperatures with higher flows of warm air (warmer and at a higher flow rate than a DHP) until set-point is reached. Figure 11 below highlights this transition from DHP to eFAF.

In Figure 11, starting in the upper left with the "green" DHP temperature profile, the DHP operates (providing ~ 108 F air) until about 9:00 PM when the eFAF (red line) cycles on; the saw-tooth pattern represents the eFAF cycling on and off over this period. This cycle continues for the next few hours, whereby the eFAF now has completely displaced the high efficiency DHP. In this particular case, it is not clear why the eFAF cycled on, but because it was Phase 1, there was no system lock-out to prevent it.

Figure 11 also serves to illustrate not only the potential for control issues, but what can happen once the issue arises. Different from the design and operation of a DHP, the eFAF system cycles frequently to maintain zone temperatures (with larger quantities of warm air), while the DHP is designed to remain on for much longer periods of time offering lower quantities of warm air. As is evident from the figure, without some method to prevent (or mitigate) coincident system operation, while not compromising life-health-safety requirements, the DHP will not achieve its full efficiency potential.

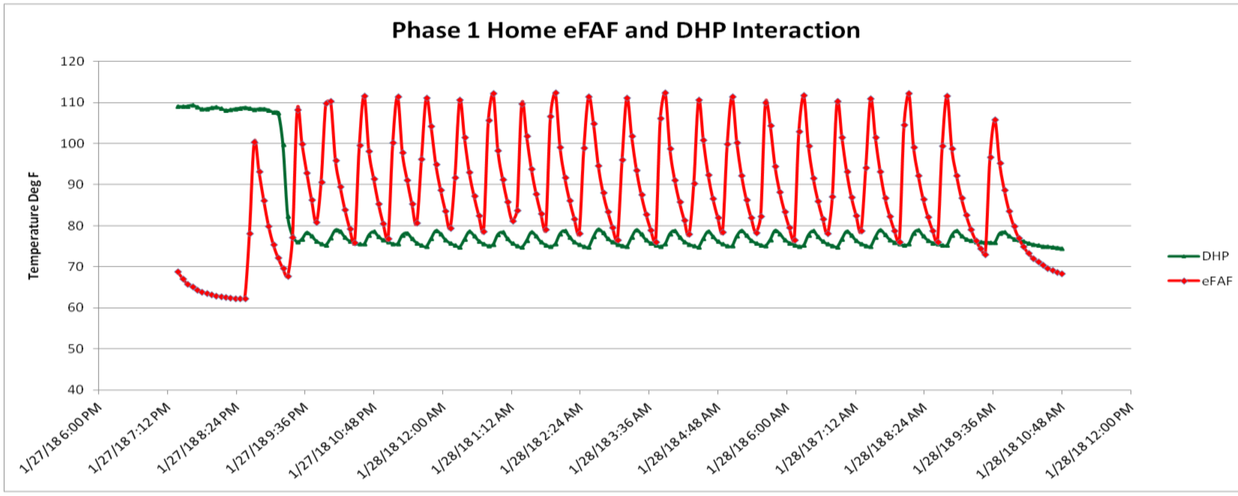


Figure 11. eFAF and DHP Interaction During Coincident Use Event – Note the displacement of the DHP (cycles off

C. Evaluation Findings: Energy Impacts

Billing Analyses

2018 billing history studies of Phase 1: Table 3 summarizes the billing analyses performed by TPU.

Season	Bill Month	Approach 1: Constant Monthly Savings	Approach 2: Weather Normalized Savings		
		kWh Savings	% Savings	Normalized Consumption	kWh Savings
Winter	1	408	21%	2,187	459
Winter	2	408	21%	2,125	446
Winter	3	408	21%	1,987	417
Shoulder	4	408	21%	1,468	30/
Shoulder	5	408	21%	1,223	257
Summer	6	-	0%	826	-
Summer	7	-	0%	783	-
Summer	8	-	0%	739	-
Summer	9	-	0%	754	-
Shoulder	10	408	21%	958	201
Shoulder	11	408	21%	1,284	270
Winter	12	408	21%	2,136	448
Annual Total		**3,264**		**16,470**	**2,807**

Table 3. Phase 1 Annualized Savings Estimates

Table 4 provides data for each Participant. Hobo logger data (recorded for the Process Evaluation) are compared with the independent billing evaluation for each home. This information was helpful in the program design and evaluations recommended for Phase 2.

Hobo Logger Data						Home Billing Evaluation		
Frequent Use eFAF		Frequent Use DHP	Main Space Temp			H Reichmuth		Site Specific
First Period	Second Period	Second Period	Min	Max	Avg	Annual kWh pre DHP	Daily kWh post savings	Energy Reduction
		X	64.04	78.70	71.94	12,730	18	Positive
		X	57.55	70.21	64.40	9,050	20	Positive
X		X	57.55	71.37	66.75	19,190	0	Push
		X	58.85	73.01	65.97	18,720	0	Push
		X	65.62	77.56	74.19	15,800	20	Positive
		?	66.01	80.55	71.37	10,150	-2	Push
		X	66.39	81.70	71.04	19,040	10	Positive
		X	59.54	75.60	69.03	16,880	20	Positive
						15,170	35	Positive
X		X	46.67	74.39	59.57	11,150	12	Push
X	X		60.14	73.44	67.48	19,920	-20	Negative
X	X	X	66.05	76.30	70.71			Negative
X	X	x	64.85	78.48	70.34	26,519	3	Push
		x	64.47	74.60	69.89	23,390	12	Positive
		x	62.02	74.48	66.44	10,090	15	Positive
	X		65.66	76.60	70.14	29,780	-30	Negative
		x	60.78	73.74	66.65	27,190	-10	Push
								Negative
		X	61.90	80.46	73.34	19,850	0	Positive
						14,403	15	Push
		x	54.52	69.56	63.59	15,640	30	Positive
						4,050	2	Push
		x	54.74	68.06	62.62	11,880	18	Positive
						15,270	40	Positive
						25,950	30	Positive
								Push
						11,540	25	Positive
		x	66.95	76.78	73.21			Positive
						22,690	40	Positive
						11,280	20	Positive
	X	x	56.43	80.15	67.05	21,490	40	Positive
X	X	x	68.75	83.12	73.79	29,610	30	Push
						8,959	12	Push
		x	59.75	75.86	68.36	18,920	30	Positive
X	X	x	60.22	82.32	73.27	14,640	0	Push
		x	55.26	69.87	63.22	22,360	15	Positive
		x	56.00	75.04	68.44			Positive
		x	54.70	71.02	63.76	18,577	23	Positive
	X		63.69	78.44	71.62	27,830	3	Negative
		x	65.92	84.60	72.13	20,230	15	Positive
	X	x	54.13	69.69	62.48	22,520	26	Positive
X	X	x				19,720	18	Push
		x	66.05	74.69	70.68	17,880	35	Positive
	?	x	62.50	77.08	71.56	18,390	15	Positive
						12,710	20	Positive

Table 4. Phase 1 matrix (comparing process and billing evaluations)

Appendix D provides an illustration of the billing methodology employed by Howard Reichmuth. Both the TPU billing study of all participants (and the separate impact evaluation conducted by Howard Reichmuth for each separate participant) averaged close to 2,800 kWh for Phase 1. In Phase 1, there was sufficient billing data (and process data) to prepare these exhibits. This data was useful in determining:

- Different systems and controls to employ in Phase 2
- Additional measurements and data to record in Phase 2 to assist the utility and the customer in how to further energy improvements and equipment operation.

In its review of Phase 1 and Phase 2 billing analysis, TPU (final draft as of this writing) points to significant reduction in eFAF energy use resulting from both the installation and better control of DHPs as installed in Franklin Pierce Estates manufactured homes. These savings have been reported as:

- Phase 1 – DHPs with traditional controls of both systems: 3,954 kWh/year
- Phase 2 – DHPs with added controls, larger DHP, and space heaters: 3,502 kWh/year.
- While the TPU analysis reported no statistical significance in the reduced energy use in Phase 2 over Phase 1, the reported combined program annual energy savings is 3,503 kWh/year.

The higher energy savings found by TPU in Phase 2 was evaluated from two winter heating season of post billing data.

Our independent evaluation of Phase 2 participants also demonstrates energy savings above 3,000 kWh, but this evaluation is preliminary as there are limited billing data for 10 of the 29 Phase 2 participants.

Based on TPU's recent billing evaluation (whereby Phase 1 energy savings increased from 2,800 kWh to 3,800 kWh), it will be interesting to see how a 2nd year of billing data for Phase 2 participants will impact the energy savings found in Phase 2.

A preliminary evaluation of Phase 2 billing data has been performed by Howard Reichmuth based on billing data from TPU of only 17 Phase 2 participants. Without billing data for all participants, an evaluation of each home performance in Phase 2 is not possible at this time. The performance of the new heating systems in each home is important to each participant. UCONS will review performance (and missing data) with each Phase 2 participant at a time appropriate (following the current pandemic).

Based on the limited billing history data received, our independent evaluator was able to report the following findings:

1) Phase 2 Energy Savings were above 3200 kWh for a single winter heating season (an increase of nearly 400 kWh above Phase 1 measured savings
2) The highest savings found in Phase 2 were closely associated with the participants who had the highest energy bills (prior to their participation in Phase 2).

Engineering Assessment of Savings

For this Pilot, historical data and engineering estimates of savings were employed (along with use of statistical models and pre- and post-billing history studies) to evaluate energy savings. Phase 1 billing evaluations benefitted from a larger population and a complete pre and post billing history for the 53 participants. For Phase 2, a review of the equipment used (and hours of operation) were evaluated to compare with the reasonableness of the billing evaluations reported to date:

- Review of eFAF winter heating loads regionally: There are numerous regional reports which demonstrate annual electrical loads (for manufactured homes with electric water heating and eFAF heating systems) are between 17,000 and 18,000 kWh.[1] The baseline usage (excluding winter heating) has been found to be 10,000 to 12,000 kWh. The goal of installing the more efficient DHP was to reduce the winter heating load (of homes with an eFAF) by at least 50%. Energy savings above 3,000 kWh appear reasonable on this basis.
- How do changes made in Phase 2 impact an engineering evaluation of savings? It was anticipated the curtailment of the eFAF system in Phase 2 would save more energy than the increase in energy used by the 400 and 700-watt bedroom zonal heaters. There is insufficient billing data at this time to confirm if this occurred. Suggested Next Steps are identified in this report. A review of the following equipment used during the Pilot was considered:
  - A range of hours of the 400 and 700-watt zonal heaters was modeled (Appendix D). This illustration shows usage of 683 kWh for the small bedroom heaters. Frankly, most of these heaters did not have any controls so it is reasonable that some participant loads could increase by as much as 1,000 kWh annually.
  - What is the expected energy savings from the eFAF (shown to be removed from service in all but 2 of the 29 participants in Phase 2)? That is more difficult. A review of Phase 1 shows the eFAF used nearly 800 hours (on average) for each of the 53 participants. The eFAF systems employed in Phase 1 were mostly 15 to 20 kW systems. Without power meters installed on all systems, there is insufficient data to demonstrate that the savings in use of the eFAF could be offset by the small bedroom heaters.

TPU and UCONS have discussed the possibility that the following factors may contribute to a reduction of savings in Phase 2:

- Multiple bedroom space heaters (while low wattage) if run continuously may have reduced overall energy savings. Most of the bedroom heaters employed in Phase 2 were the 700-watt oil heaters (that did not use separate controls employed for the 400-watt wall heaters). This has been identified for evaluation in a future study.
- Installation of larger DHP in Phase 2 (1.25 and 1.5 tons), may have been more in accordance with manufacturer installation specifications, but may also have reduced overall energy savings.

---

[1] *Independent M&V Report, Puget Sound Energy, Manufactured Home Duct Sealing (MHDS) Program*, Howard Reichmuth, December 5, 2013 at Figure 6.; *Northwest Residential Electric Bills: A report on residential electricity use, annual bills, income, and poverty by utility type and service area characteristics*, Northwest Power and Conservation Council, July 2016

- Selection of a 2^{nd} year of billing savings (and evaluation methods employing different weather adjustments and control groups) may have impacted energy savings

In review, both Phase 1 and Phase 2 evaluations of savings have demonstrated substantial energy savings (above 3,000 kWh annually) when installing a single-head DHP in a manufactured home. Additional studies are suggested in the next section of this report to further refine the results of the Phase 1 and Phase 2 demonstrations.

IV. Customer Impacts and Next Steps to Maximize DHP Performance

A. Operational and Safety Impacts

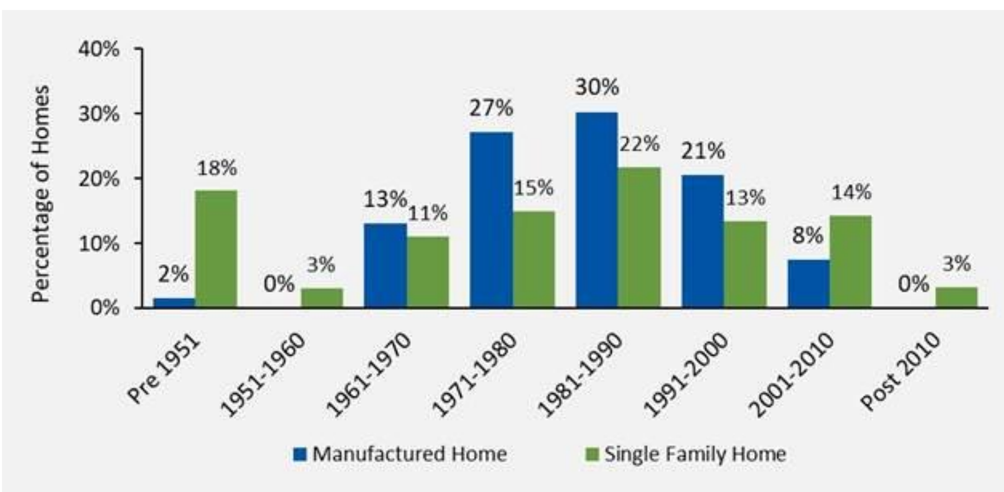
Phase 2 had two primary objectives, to:

1. Reduce the high continued use of eFAFs found in Phase 1 and
2. Evaluate options for increasing energy savings.

During the summer and fall of 2018, TPU and UCONS reviewed options to address the lessons learned from Phase 1. We reviewed the requirements from other regions (that regulatory practices required removal from service of an older HVAC system when installing a new system). This was implemented in order to achieve "assured savings" (by not having multiple HVAC systems operating concurrently). UCONS successfully implemented a Pilot program in Sacramento focused on summer cooling loads, not on winter heating loads. However, both TPU and UCONS recognized the need to address winter heating loads of the Northwest differently. There are comfort and safety concerns that homeowners (whose primary heating was by eFAF and then an installed single-head DHP), would have cold bedrooms in their homes when removing a whole house heating system from service.

Section II demonstrates curtailing the eFAF could be successfully achieved, and also provide customer comfort in areas away from that serviced by the single-head DHP. Only 2 of the 29 participants requested no controls placed on their eFAF (which limited operation of the older electric furnaces). These were homes with 7 or more occupants. Reducing the continued use of the eFAF was critical to this customer class, as the average age regionally of eFAF systems in manufactured homes is often when the home was manufactured.[2]

Figure 12. Age of Manufactured and Single-Family Homes – RBSA II Data



[2] *Residential Building Stock Assessment*, NEEA https://neea.org/data/residential-building-stock-assessment

In the nearly 40,000 Washington manufactured homes served by UCONS since 1994, a duct sealing job was not allowed to be provided in over 3,000 of these homes as the eFAF was found to be disconnected or removed from service. This customer class typically does not have the funds to replace or repair an expensive heating system.

If this customer class does not have the financial ability to repair or replace their failed eFAF, why leave an old system in place?

- What will this customer do when the old eFAF does fail?
- Historically, what has this customer used for heating after their eFAF failed?

When the eFAF furnace fails, some are replaced with newer equipment. In most situations we found the homeowner employed 1,300 to 1,500 watt portable electric space heaters. This is often a prudent solution. The customer is only heating spaces where they require heating. Unfortunately, manufactured homes older than 30 years (which comprise over 70% of the homes), have limited electrical service. Most of these homes already have overloaded circuits in each room. Portable heaters of this size often overload the capacity of the typical manufactured home. In addition, we noted several customers who employed kerosene heaters, wood stoves and even (unvented) charcoal heaters. These were clearly unsafe conditions.

In sum, Phase 2 demonstrated it is not necessary to leave an eFAF in service when installing a new single-head DHP and addressed the situation whereby a customer (having procured a new DHP) is not relying on a heating system with a short service life. Phase 2 did leave the eFAF as a “backup heating system” when the DHP was unable to meet customer demand. Phase 2 also showed that where the DHP cannot heat the entire home to the satisfaction of the resident, the deficiency can be met by low wattage space heaters which do not present a problem for the limited electrical panel capacities found in most manufactured homes.

Customer surveys of all Phase 2 participants demonstrated high satisfaction and comfort, even during the coldest winter months.

B. Participant Surveys

As part of this study, UCONS administered participant surveys at the conclusion of Phase 2, to the Phase 2 occupants. 20 of 29 participants responded to some or all of the questions. The survey responses are provided as Appendix C.

In general, the survey responses reflect a high degree of satisfaction with most aspects of the DHP, including the new eFAF thermostats and controls.

Regarding your experience this past winter (after your home was upgraded through Tacoma Public Utilities’s program)

1. How cold was your home during this past winter, after your home was upgraded?

☐ Way Too Cold ☐ A little Too ☐ Comfortable ☐ A little Too ☐ Way Too

Cold | Warm | Warm

2. How well did your ductless heat pump heat your living room?

☐ Very Well ☐ Pretty Well ☐ Not too well ☐ Very Poorly

3. Over this past winter, what temperature did you usually set your DUCTLESS HEAT PUMP to when you were at home? (Please enter a number. You best estimate is fine.)

☐ degrees

4. Over this past winter, did you use any plug-in electric heaters to help heat your home? (Please check ALL ANSWERS THAT APPLY.)

☐ Yes, in the living room ☐ Yes, in the bedroom(s) ☐ Yes, in the bathroom

☐ Yes, in another room besides the living room, bedroom(s) or bathroom

☐ No

5. Over this past winter, did you use wood heat (wood stove, pellet stove, etc.) to help heat your home?

☐ Yes ☐ No

Regarding your experience this summer

6. How hot has your home been LAST SUMMER?

☐ Way Too Hot ☐ A little Too Hot ☐ Comfortable ☐ A little Too Cold ☐ Way Too Cold

7. How often have you been using your DUCTLESS HEAT PUMP to cool your house THIS SUMMER?

☐ Never ☐ Rarely ☐ Sometimes ☐ Often

8. Over LAST SUMMER, what temperature have you usually set your DUCTLESS HEAT PUMP to when you were at home? (Please enter a number. You best estimate is fine.)

☐ degrees

9. Have you used any OTHER AIR CONDITIONING UNITS (window units or portable units) to cool your house THIS SUMMER, in addition to or instead of your ductless heat pump?

☐ Yes ☐ No

Regarding your satisfaction with the upgrades

10. How satisfied are you with how much you saved on your energy bills since your home was upgraded?

Very Satisfied	Pretty Satisfied	Pretty Dissatisfied	Very Dissatisfied
☐	☐	☐	☐

11. How satisfied are you with your DUCTLESS HEAT PUMP overall?

Very Satisfied	Pretty Satisfied	Pretty Dissatisfied	Very Dissatisfied
☐	☐	☐	☐

    Why did you give this rating?

12. Do you have any other comments you'd like to share with us about your new equipment or your experience with our program?

C. Next Steps

Discussions with the "Maximize mini split performance" task force members ("mini split" being another term for DHP) have identified the following questions to address in subsequent evaluations of occupied manufactured homes:

- Which zonal heaters (and controls) may provide the greatest comfort and savings?
- Other than number of occupants, what other limitations may impact success of a single-head DHP in a manufactured home?
- What are the limitations impacting a single-head DHP in a manufactured home?
- Do demographics of home age or size impact savings?
- Do low versus high pre-billing characteristics affect savings?
- Would better controls (e.g., auto-off or setback schedules) on any supplemental heaters result in improved savings?
- How does a second year of billing data impact savings?

This demonstration program provided the opportunity to evaluate optional control strategies in the Northwest when employing DHP systems in a home in which the original eFAF furnace was left operational. As the findings highlighted, the new controls employed in Phase 2 successfully precluded the operation of the older eFAF systems in all but 2 homes. This information can be helpful to improve guidance to utilities and regulators for future applications of DHPs in manufactured homes.

Appendix A Ductless Heat Pump and Thermostat Specifications

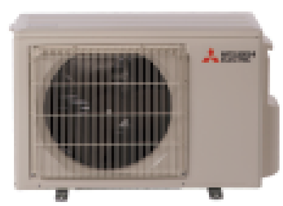
1. Ductless Heat Pump

M-SERIES

SUBMITTAL DATA: MSZ-GL15NA & MUZ-GL15NA
15,000 BTU/H WALL-MOUNTED HEAT PUMP SYSTEM

MITSUBISHI ELECTRIC

Job Name:	
System Reference:	Date:

Indoor Unit: MSZ-GL15NA	Outdoor Unit: MUZ-GL15NA-U1 MUZ-GL15NA-U2	Wireless Remote Controller
		

GENERAL FEATURES

- Slim wall-mounted indoor units provide zone comfort control
- The outdoor unit powers the indoor unit, and should a power outage occur, the system is automatically restarted when power returns
- INVERTER-driven compressor and LEV provide high efficiency and comfort while using only the energy needed to maintain maximum performance
- Multiple fan speed options: Quiet, Low, Medium, High, Super-high, Auto
- Multiple control options available:
  - Hand-held Remote Controller (provided with unit)
  - kumo cloud® smart device app for remote access
  - Third-party interface options
  - Wired or wireless controllers
- Quiet operation
- Smart Set: recalls a preferred preset temperature setting at the touch of a button
- Blue Fin anti-corrosion treatment applied to the outdoor unit heat exchanger for increased coil protection and longer life

Specifications are subject to change without notice.

SPECIFICATIONS: MSZ-GL15NA & MUZ-GL15NA

Cooling[1]	Maximum Capacity	Btu/h	18,200
	Rated Capacity	Btu/h	14,000
	Minimum Capacity	Btu/h	3,100
	Maximum Power Input	W	2,000
	Rated Power Input	W	1,080
	Moisture Removal	Pints/h	2.7
	Sensible Heat Factor		0.78
	Power Factor	%	97 / 97
Heating at 47°F[2]	Maximum Capacity	Btu/h	20,900
	Rated Capacity	Btu/h	18,000
	Minimum Capacity	Btu/h	4,800
	Maximum Power Input	W	2,010
	Rated Power Input	W	1,600
	Power Factor	%	98 / 98
Heating at 17°F[3]	Maximum Capacity	Btu/h	16,400
	Rated Capacity	Btu/h	12,200
	Maximum Power Input	W	1,850
	Rated Power Input	W	1,190
Heating at 5°F[4]	Maximum Capacity	Btu/h	13,680
	Maximum Power Input	W	1,570
Heating at -4°F[5]	Maximum Capacity	Btu/h	11,160
Heating at -13°F[6]	Maximum Capacity	Btu/h	-
Efficiency	SEER		21.6
	EER[1]		13.0
	HSPF (IV)		11.7
	COP at 47°F[2]		3.30
	COP at 17°F in Maximum Capacity[3]		2.60
	COP at 5°F in Maximum Capacity[4]		2.55
	ENERGY STAR® Certified (ENERGY STAR products are third-party certified by an EPA-recognized Certification Body.)		YES
Electrical	Voltage, Phase, Frequency		208/230V, 1 phase, 60Hz
	Guaranteed Voltage Range	V AC	187 - 253
	Voltage: Indoor - Outdoor, S1-S2	V AC	208 / 230
	Voltage: Indoor - Outdoor, S2-S3	V DC	24
	Voltage: Indoor - Remote Controller		Wireless Type
	Recommended Fuse/Breaker Size	A	15
	Recommended Wire Size (Indoor - Outdoor)	AWG	14
Indoor Unit	MCA	A	1
	MOCP	A	15
	Blower Motor Full Load Amperage	A	0.76
	Blower Motor Output	W	30

Specifications are subject to change without notice.

SPECIFICATIONS: MSZ-GL15NA & MUZ-GL15NA

	Airflow Rate at Cooling, Dry	CFM	533-420-335-272-205
	Airflow Rate at Cooling, Wet	CFM	498-385-300-237-170
	Airflow Rate at Heating, Dry	CFM	463-367-304-247-205
	Sound Pressure Level (Cooling)	dB(A)	49-44-38-32-26
	Sound Pressure Level (Heating)	dB(A)	46-40-35-30-26
	Drain Pipe Size	In. (mm)	5/8 (15.88)
	Heat Exchanger Type		Plate fin coil
	External Finish Color		Munsell 1.0Y 9.2/0.2
	Unit Dimensions	W: In. (mm)	31-7/16 (798)
		D: In. (mm)	9-1/8 (232)
		H: In. (mm)	11-5/8 (295)
	Package Dimensions	W: In. (mm)	33-1/2 (850)
		D: In. (mm)	12 (300)
		H: In. (mm)	14 (350)
	Unit Weight	Lbs. (kg)	22 (10)
	Package Weight	Lbs. (kg)	26 (11.5)
Indoor Unit Operating Temperature Range	Cooling Intake Air Temp (Maximum / Minimum)*	°F	90 DB, 73 WB / 67 DB, 57 WB
	Heating Intake Air Temp (Maximum / Minimum)	°F	80 DB / 70 DB
Outdoor Unit	MCA	A	10
	MOCP	A	15
	Fan Motor Full Load Amperage	A	0.5
	Fan Motor Output	W	55
	Airflow Rate	CFM	1,243 / 1,229
	Refrigerant Control		LEV
	Defrost Method		Reverse cycle
	Heat Exchanger Type		Plate fin coil
	Sound Pressure Level, Cooling[1]	dB(A)	49
	Sound Pressure Level, Heating[2]	dB(A)	51
	Compressor Type		DC INVERTER-driven
	Compressor Model		SNB130FQBMT
	Compressor Rated Load Amps	A	7.4
	Compressor Locked Rotor Amps	A	9.3
	Compressor Oil Type // Charge	oz.	FV50S // 11.8
	External Finish Color		Munsell 3Y 7.8/1/1
	Base Pan Heater		Optional
	Unit Dimensions	W: In. (mm)	31-1/4 (800)
		D: In. (mm)	11-1/8 (285)
		H: In. (mm)	21-5/10 (550)
	Package Dimensions	W: In. (mm)	37 (940)
		D: In. (mm)	14-15/16 (380)
		H: In. (mm)	24-13/16 (630)

Specifications are subject to change without notice.

SPECIFICATIONS: MSZ-GL15NA & MUZ-GL15NA

	Unit Weight	Lbs. (kg)	81 (37)
	Package Weight	Lbs. (kg)	90 (40)
Outdoor Unit Operating Temperature Range	Cooling Air Temp (Maximum / Minimum)*	°F	115 / 14
	Cooling Thermal Lock-out / Re-start Temperatures**	°F	-1 / 3
	Heating Air Temp (Maximum / Minimum)	°F	75 / -4
	Heating Thermal Lock-out / Re-start Temperatures**	°F	-9 / -4
Refrigerant	Type		R410A
	Charge	Lbs, oz	2, 9
Piping	Gas Pipe Size O.D. (Flared)	In. (mm)	1/2 (12.7)
	Liquid Pipe Size O.D. (Flared)	In. (mm)	1/4 (6.35)
	Maximum Piping Length	Ft. (m)	65 (20)
	Maximum Height Difference	Ft. (m)	40 (12)
	Maximum Number of Bends		10

Notes

AHRI Rated Conditions (Rated data is determined at a fixed compressor speed)	[1]Cooling (Indoor // Outdoor)	°F	80 DB, 67 WB // 95 DB, 75 WB
	[2]Heating at 47°F (Indoor // Outdoor)	°F	70 DB, 60 WB // 47 DB, 43 WB
	[3]Heating at 17°F (Indoor // Outdoor)	°F	70 DB, 60 WB // 17 DB, 15 WB
Conditions	[4]Heating at 5°F (Indoor // Outdoor)	°F	70 DB, 60 WB // 5 DB, 4 WB
	[5]Heating at -4°F (Indoor // Outdoor)	°F	70 DB, 60 WB // -4 DB, -5 WB

*Applications should be restricted to comfort cooling only; equipment cooling applications are not recommended for low ambient temperature conditions.
**System cuts out in heating mode to avoid thermistor error and automatically restarts at these temperatures.

Specifications are subject to change without notice.

2. Honeywell T4 Thermostat – Use to Control Existing eFAF

T6 PRO SMART

Geofencing, 7-day, 5-2, 5-1-1, 1-week or non-programmable

- Connect from anywhere with smartphone or tablet and the Honeywell Home app
- Smart alerts remind to change filter and warn of extreme indoor temperature
- Auto-change from heat to cool
- Fan settings for Auto, On, or Circ
- Touchscreen Display: 6.89 sq. in.

T6 PRO

7-day, 5-2, 5-1-1 or non-programmable

- Filter change reminders
- Auto-change from heat to cool
- Simple push-button functionality
- Screen Size: 5.44 sq. in.

T4 PRO

7-day, 5-2, 5-1-1 or non-programmable

- Filter change reminders
- Auto-change from heat to cool
- Simple push-button functionality
- Screen Size: 3.93 sq. in.

T1 PRO

Non-programmable

- Simple push-button functionality
- Screen Size: 2.37 sq. in.

For more information
800-468-1502
forwardthinking.honeywell.com

Home and Building Technologies
715 Peachtree Street NE
Atlanta, GA 30308
www.honeywell.com

Honeywell

Appendix B. Metering Equipment Specifications

Data Loggers

Consider Onset Computer “Hobo” data logger series.

1. **Temperature only. Hobo UX 100-001**

- **Range:** -20° to 70°C (-4° to 158°F)
- **Accuracy:** ±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F)
- **Memory: 84,650 readings – 58 days at 1 minute intervals**
- **Size**: 3.66 x 5.94 x 1.52 cm (1.44 x 2.34 x 0.6 in.)

Appendix C. Participant Survey Questionnaire (Participant Responses)

1. How cold was your home during this past winter, after your home was upgraded?

- 17 of 20 respondents (85%) reported “comfortable”
- 2 of 20 respondents (10%) reported “a little too cold”
- 1 of 20 respondents (5%) reported “a little too warm”

2. How well did your ductless heat pump heat your living room?

- *16 of 20 respondents (80%) reported “very well”*
- *4 of 20 respondents (20%) reported “pretty well”*

3. Over this past winter, what temperature did you usually set your DUCTLESS HEAT PUMP to when you were at home?

- Sample low: 66 F
- Sample mean: 70 F
- Sample high: 75 F

4. Over this past winter, did you use any plug-in electric heaters to help heat your home?

- 16 of 20 respondents (80%) reported “yes, in bedrooms”
- 4 of 20 respondents (20%) reported “Did not use space heaters”

5. Over this past winter, did you use wood heat (wood stove, pellet stove, etc.) to help heat your home?

- 20 of 20 respondents (100%) reported “No wood or pellet stoves”

10. How satisfied are you with how much you saved on your energy bills since your home was upgraded?

- 8 of 20 respondents (40%) reported “Very satisfied”
- 6 of 20 respondents (30%) reported “Pretty satisfied”
- 6 of 20 respondents (30%) reported “Unsure because bills were averaged and paid on comfort pay system”

11. How satisfied are you with your DUCTLESS HEAT PUMP overall?

- 11 of 20 respondents (55%) reported “Very satisfied”
- 8 of 20 respondents (40%) reported “Pretty satisfied”
- 1 of 20 respondents (5%) reported “Pretty dissatisfied”

11 A. Why did you give this rating?

- “I am pleased how it heats and cools”

- “Could not be happier”
- “Overall it was fine”
- “9 out of 10”
- “A+”
- “Furnace never came on”
- “Old furnace was noisy and not constant temperature; heat pump was quiet and great”
- “Love my DHP”
- “Furnace not on in over a year”
- “Because I am satisfied with the DHP and the contractor was very helpful”
- “Very happy”
- “Easy to use and very comfortable “
- “Saves money and heats most of my house”
- “Because I like the service this system provides”
- “Because it has helped a great deal to save energy and money”

Appendix D. Independent Energy Savings Methodology

The energy savings estimated for these study participants are whole building energy savings using all energy sources serving the building, electric and gas usually. In the case of this particular study, the subject buildings are all-electric, since the buildings with other fuel sources such as wood or propane have been excluded. The methodology employed follows the International Performance and Measurement and Verification Protocol, IPMVP. This protocol is reasonably broad and includes specifications for estimating savings from small individual measures such as LEDs, to larger items such as air conditioners. The methodology applied here is discussed in the sections dealing with estimating whole building energy savings, in particular Option C.

In brief, the Option C protocol will associate with each monthly kWh meter read .with a temperature representing the average daily temperature [*footnote 1*: i*n practice it has been found that local airport NOAA temperatures are reasonably available and sufficiently accurate. The temperature measurements need not be made on the building]* during the meter read interval typically 30 days or so. Thus each of the twelve meter reads for a year will have an average temperature associated with it. The key step in the analytical process is to organize these 12 or so kWh/temperature pairs into a graphic plot referred to in the IPMVP and ASHRAE literature as an ***ENERGY SIGNATURE***.

This plot is essentially a plot of building power, kWh/day or Watts/ft2 vs average outside air temperature. For most residential and commercial buildings the plot will appear as in Figure 1.

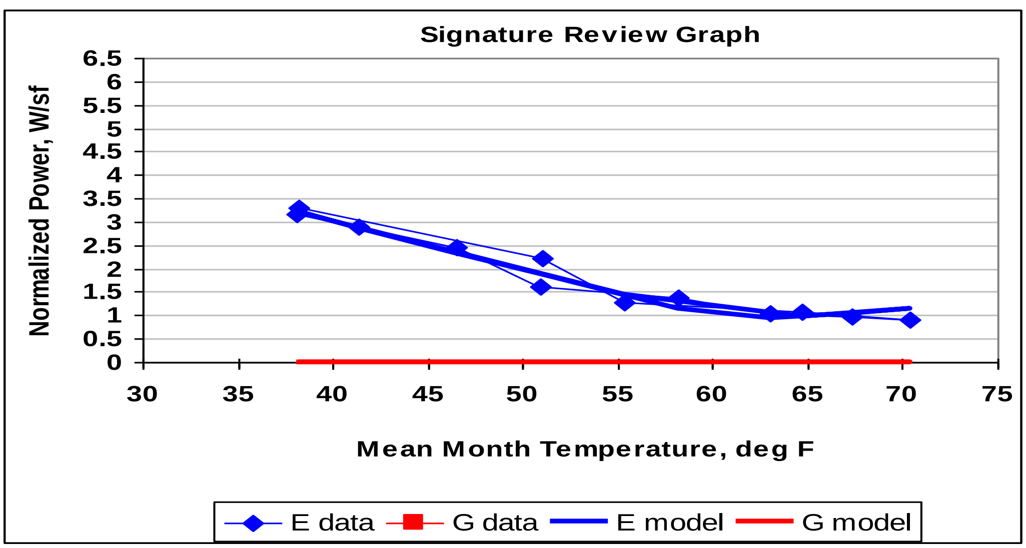


Figure 1 Example Energy Signature, R square =90%

Note that this figure shows a fairly orderly pattern for the plotted points. This is because the fundamental physics of all thermostatically conditioned buildings follow the physical law that the average building power of a thermostatically controlled building is a function of the building interior temperature minus the outside air temperature. While it is true that the building and the outside air temperatures may vary widely on an hourly basis, with various lag times, on a monthly basis, the algebra of the matter will be much simpler, and these hourly variations will average out and the monthly data will present as in Figure 1. This orderly data is such that a variety of mathematical functions may be closely fitted to it by regression, as illustrated by the line in Figure 1.[*footnote 2 often this function is a quadratic or cubic function with average temperature as the independent variable. The ASHRAE methods often use a piecewise fit involving several functions for different temperature ranges. In this particular work, a simple building model has been fitted to the data. In practice, several different mathematical models can be fitted almost equally well to the data. For the purpose of estimating savings it doesn't make much difference which type of function is fitted to the data.]* The mathematical model, which essentially models whole building power as a function of outdoor temperature, is referred to here and in the literature as a ***COUNTER-FACTUAL MODEL.*** The purpose of such a model is to predict the energy the subject building would have used, had the retrofit not occurred.

Such models commonly fit the pre-retrofit data so well that they can be relied on as the base case to which post retrofit performance is compared to produce an estimate of the "avoided energy savings." This type of estimate continues to be employed in the building science community [*footnote 3: the IPMVP was derived through a multi-year committee process of building professionals as was the ASHRAE guideline 14. It is notable that neither of these processes calls for, or even mentions, a comparison group. This is because in the formal statistical process a comparison group is necessary where there is no adequate counterfactual model as in a medical trial or a manufacturing process. For the case of whole building energy savings analysis there is a well demonstrated counter-factual model. Also in the case of whole building analysis, it is very difficult to assemble a small reasonably comparable comparison group. Though admittedly, in the case of utility econometric analysis of elastic response to a rate change for example, an entire customer class may be used as the comparison group. But in cases such as this the comparison group brings in other external effects beyond the effects of the energy savings measures alone. It is important to distinguish between the utility purposes here and the engineering purposes; the utility wants to include all effects, the engineering purpose is to identify the effects of a particular package of measures*] as a reasonable measure of physical energy savings, with the caveat that the post retrofit behavior and operations at the site is exactly the same as it was pre-retrofit, which is very often the case in the real world.

It is well known that savings at a particular site estimated in this way may include the energy effects of behavioral changes, which are basically un-measurable, such as family changes, equipment purchases etc. In most samples these behavioral changes at specific sites balance out with as many increases as decreases so that the average avoided energy use from the whole sample is not seriously changed. This is why the M&V community was willing to define a consensus savings protocol that did not require the use of a control group, since a good control group is usually hard to define and find and quite reasonably would double the cost of an M&V project.

Figure 2 is an example of the use of this process to estimate the savings from a fairly strong heating savings measure..

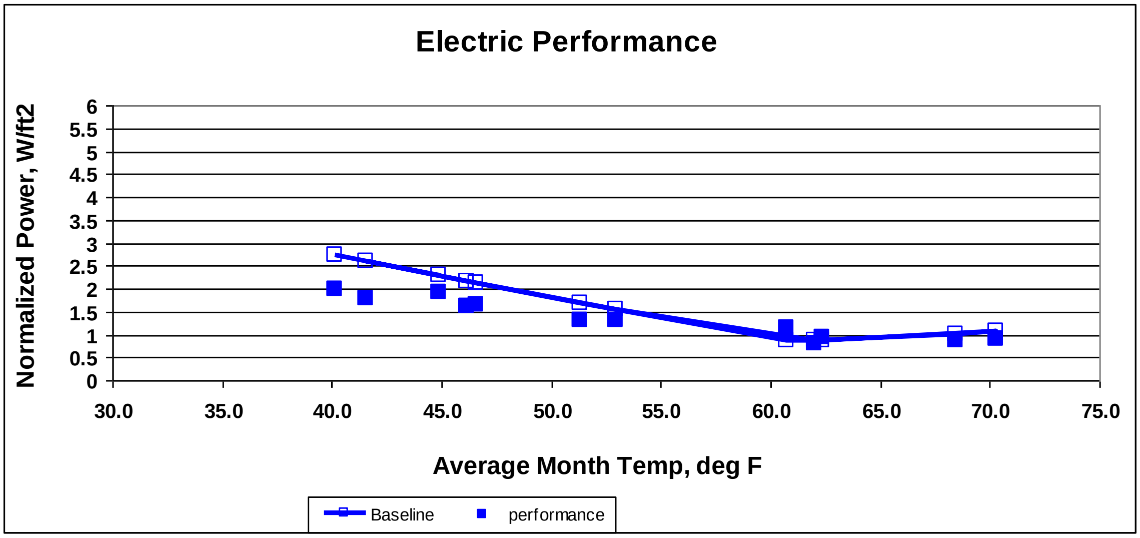


Figure 2 Post retrofit monthly data compared to pre retrofit data, Savings 3,161 kWh/yr.

Note in Figure 2 that the observed savings are particular to the temperatures observed in the post-retrofit year, thus the savings are referred to as the avoided energy use, and not the weather normalized energy savings. It is quite possible to continue this process to produce the weather normalized savings but that would involve a regression process on the post retrofit data which would increase the uncertainty in the results, complicate the process, and make it harder to see the results directly in terms of the monthly meter reads.

Figure 3 below shows the savings for the same building for the second post retrofit year, i.e. one year later than that shown in Figure 2.

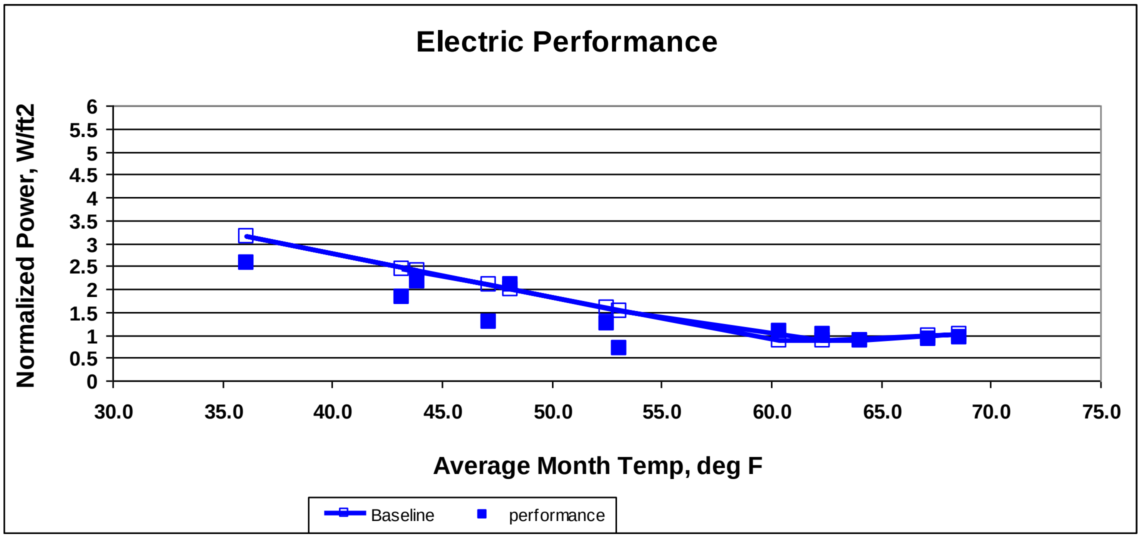


Figure 3 Second Post Retrofit year Savings 2,798 kWh/yr.

Notable in this Figure are two or three points, above 43 deg, 47 deg and 53 deg, for which there appear to be almost no savings. These points are the reason why the savings for this second post retrofit year are lower than the first post retrofit year in Figure 2. But more importantly, these points may indicate instances where the subject measure was not functioning properly and provide an entry point for examining other site material, including interviews, to identify problems with the retrofit, which is one of the prime purposes of the M&V exercise. (these points could also be a behavioral aberration, but as most building managers can attest, out of pattern points usually bear investigation).What is important here to take away, is that the savings for a particular site can be observed at the monthly level..

In summary the energy savings methodology used here is essentially the common engineering approach as described in the IPMVP and ASHRAE guideline 14. It relies on the use of local outside air temperature data, closely aligned to the meter read intervals. In this work, the estimated energy savings are the monthly avoided energy use in the post retrofit year, as opposed to the normalized energy use, in an attempt to reduce uncertainties and to better support site specific performance analysis.