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Combination Ductless Heat Pump & Heat Pump Water Heater Lab and Field Tests

Prepared by:
Energy 350
107 SE Washington St.,
Suite 145
Portland, OR 97214

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
FAX
503-688-5447
EMAIL
info@neea.org

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Executive Summary

This report summarizes the lab and field test findings for Mitsubishi's prototype Ductless Heat Pump (DHP) Plus H_2O product. This product combines a ductless heat pump with a heat pump water heater into a single, integrated product. Mitsubishi has teamed with a water heater partner for the water heater portion of the product. NEEA has partnered with Mitsubishi to test the appliance and to provide feedback regarding performance. NEEA has selected Energy 350 to conduct the testing and reporting.

Energy 350 tested prototypes of the product as it is still in development and is not currently available to the market. Given that product is still in its early stages, this is an ideal time to test and improve the product, prior to final design and full-scale manufacturing.

To date, Energy 350 has conducted a series of lab tests, as well as thirteen months of field testing on three homes in Oregon: one each in Southwest Portland, Gresham, and Bend. Mitsubishi has already implemented a number of product improvements based on test results.

The combined appliance offers several potential benefits, including:

- Elimination of interactive effect of traditional heat pump water heaters. Integrated heat pump water heaters pull heat from their immediate surroundings to heat water. This can have an interactive effect in heating homes. The combined appliance uses outdoor air as the heat source, eliminating the interactive effect.
- Increased applicability. Two of the three homes tested had water heaters located in conditioned spaces that may have proved difficult for installation of an integrated HPWH. Using a combined appliance opens up more homes as candidates for heat pump water heating.
- Heat recovery. During times of simultaneous space cooling and water heating, the water heater can act as the heat sink for heat removed from the space, improving energy performance.
- Cost advantage. While predicting costs is difficult at this early stage of product development, sharing an outdoor unit between two appliances (space conditioning and water heating) may provide a cost advantage compared to stand-alone technologies.
- Potential for increased compressor capacity on water heaters. The compressor on the outdoor unit has significantly higher capacity than compressors on traditional heat pump water heaters. This increased compressor capacity could reduce the use of the backup water heating elements, improving water heater energy performance. However, this effectiveness of the increased compressor capacity is limited by the heat exchange capacity between the refrigerant lines and the tank.
- Increased ambient operating range. Typical heat pump water heaters must switch to electric resistance mode as ambient temperatures approach freezing. However, with the use of ductless heat pump compressor technology, and without the need to remove condensate, this unit can heat water well-below freezing ambient temperatures.

Summary of Findings

The product is performing quite well, particularly considering its early stage of product development. Tests showed very good performance in terms of energy efficiency and cold weather capacity. Table 1 and Table 2 in the body of this report summarize the lab and field test results.

In addition, this report describes a number of planned and recommended product enhancements that could result in performance improvements, particularly in water heating.

1. Introduction

This report summarizes the findings of a lab and field testing study conducted on behalf of the Northwest Energy Efficiency Alliance (NEEA) by Energy 350 for Mitsubishi's prototype Ductless Heat Pump (DHP) Plus H_2O product. This product combines a ductless heat pump with a heat pump water heater into a single, integrated product. Mitsubishi has teamed with a water heater partner for the water heater portion of the product, and NEEA has partnered with Mitsubishi to test the appliance and to provide feedback regarding performance. NEEA contracted with Energy 350 to conduct the testing and reporting.

Energy 350 tested prototypes of the product as it is still in development and is not currently available to the market. Given that the product is still in its early stages, this is an ideal time to test and improve the product, prior to final design and full-scale manufacturing.

1.1. Background

This effort began with a concept for the product proposed by Mitsubishi. With NEEA's commitment to test the product, Mitsubishi worked with its water heater partner to develop prototype versions for testing. With the completion of the first prototype, Mitsubishi began lab testing in its Suwanee, Georgia lab. This early lab testing led to a number of iterative product improvements, in terms of both hardware and control algorithms.

After the initial rounds of product enhancements and lab testing achieved favorable results, Mitsubishi developed several more prototype units for additional testing. It installed three prototype units in Oregon in March 2014 for field testing to collect real-world performance data. Preliminary review of field test data led to some early recommendations for product enhancements. As a result, Mitsubishi developed a modified set of control algorithms and installed them in field test homes through a firmware update in early December 2014.

Field testing continued through April of 2015, providing over a year's worth of field data in addition to the lab data. This report summarizes the lab and field test activities, results and conclusions.

1.2. Overview of Product

The combined appliance consists of:

- One 18,000 Btu indoor unit for space heating and cooling with wall-mount thermostat and remote control for indoor unit
- One 30,000 Btu outdoor unit with compressor, condenser/evaporator to use ambient air as a heat sink or source, reversing valves, two heads (one for space conditioning and one for water heating), and controls
- One 50-gallon water heater with a tank wrap of refrigerant line on the lower portion of the tank, upper and lower temperature sensors, and upper and lower backup heating elements. Additionally, the water heaters used for testing were equipped with a thermistor tree for monitoring.

Two sets of refrigerant lines are run from the outdoor unit; one to the indoor unit and one to the water heater. Communication lines and power lines are run from the outdoor unit to the indoor unit and to the water heater. Due to the high amp draw of the water heater elements, power for the water heater is provided through a separate power supply from the panel.

2. Methodology

2.1. Lab Test Overview

The lab tests took place in Mitsubishi's labs in Suwanee, Georgia. Researchers used two environmental chambers, one for the indoor unit and hot water heater and the other for the outdoor unit. To measure work done at the indoor unit, they connected a powered air handler to the indoor unit. This allowed for the measurement of airflow and enthalpy change across the indoor unit, without the measurement equipment affecting the performance. To accomplish this, air is pulled from the supply of the indoor unit through the air handler and measurement devices at neutral pressure to ambient. This ensures that the measurement equipment does not add pressure drop, which would reduce airflow at the indoor unit.

To test the water heater, researchers maintained inlet water temperature with a chiller. They measured water flow with a Coriolis flow meter; a pump with a balancing valve controlled water flow. Researchers simply opened and closed isolation valves at the inlet and outlet of the water tank to simulate draws. They installed a thermistor tree to measure water temperature at six points throughout the tank. In addition, they measured inlet and outlet water temperatures with thermocouples. **Error! Reference source not found.** The figure below shows the water heater in the test environment.

Figure 1. Water Heater in Lab Test

Researchers installed the outdoor unit in a separate environmental chamber to simulate various outdoor conditions. They controlled and measured environmental temperature and humidity at the inlet to the outdoor air unit.

2.2. Early Testing and Product Evolutions

The first version of the prototype water heater had a double wrap. The intent of the double wrap was to maximize surface area for heat exchange between the compressor and the tank.

Early lab testing revealed that the double wrap resulted in low Energy Factor (EF) results. The upper wrap is able to heat the higher temperature mid-tank section more quickly, resulting in an early termination of a call for heating. When heating is terminated, the lower tank temperature was still relatively cool. As a result, during the overnight portion of the EF test, the tank temperature dropped enough to initiate a call for heating, which created a significant penalty to the EF rating.

To eliminate this issue, researchers removed the upper tank wrap. This resulted in a higher EF rating, although this limits the capacity for heat transfer from the compressor to the tank. This limited capacity for heat exchange increases the use of the heating elements during high draw periods. This presents an interesting example of a conflict between maximizing real-world efficiency and standardized test ratings; maximizing test results likely reduced real-world performance.

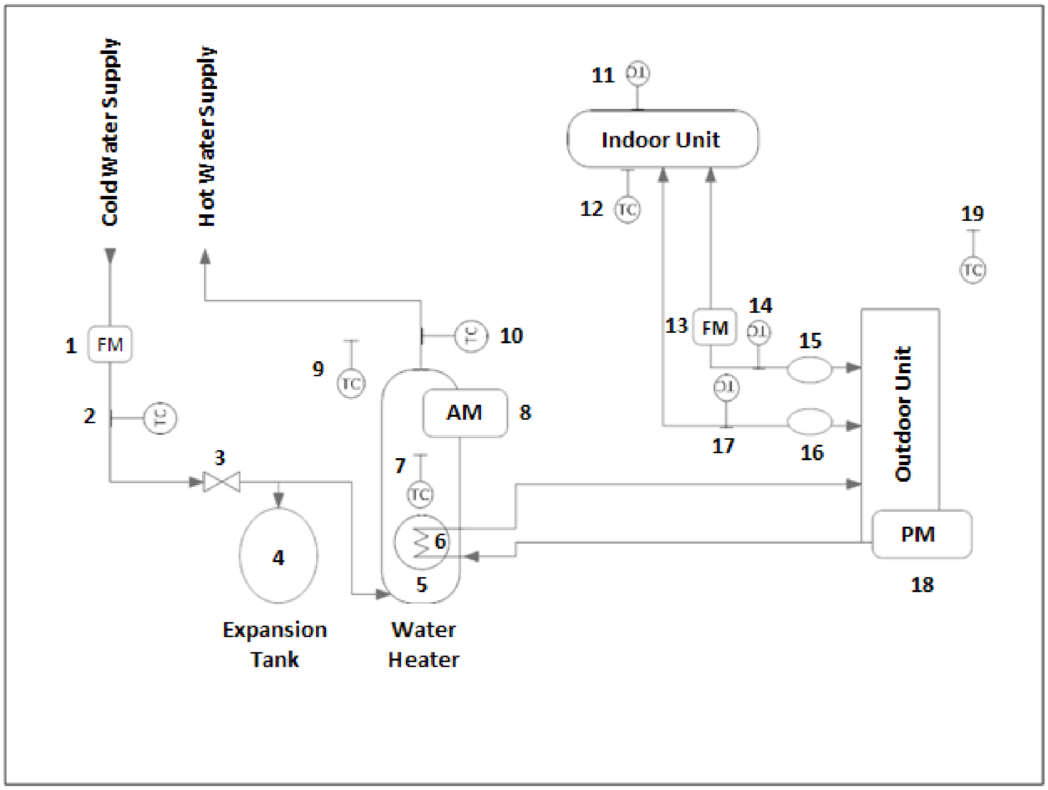
Additionally, early lab testing revealed necessary enhancements to control algorithms such as inverter speed control and capacity split between the indoor unit and water heater. After a series of iterations of product improvements and retesting, Mitsubishi was able to achieve favorable results in terms of capacity, various measures of energy performance, as well as a level of comfort in real-world operability. Lab test results are presented in Section 3.1 of this report.

2.3. Field Test Protocol

After completion of preliminary lab tests, subsequent product improvements, and retesting, the Energy 350 research team prepared for the field tests. Researchers selected three homes in Oregon: two in the Portland area and one in Bend. They strategically selected the Bend home to provide cold weather performance data. The researchers completed field installations in March 2014 and collected data through April 2015, resulting in more than a full year of performance data.

The field installations consisted of the coordinated installation of the combined appliance, overlaid with Energy 350's metering equipment at each of the three selected homes. Researchers collected data in one-minute intervals for thirteen months ending in early April 2015. Figure 2 shows a schematic of the combined appliance and metering configuration.

Figure 2. Monitoring Equipment Schematic



1 Water flow meter
2 Cold water temp. sensor
3 Check valve
4 4.5 gallon expansion tank
5 Electric water heater
6 Tank refrigerant wrap
7 Internal water heater tank thermocouple tree
8 Amp meter
9 Ambient water heater temp. sensor
10 Hot water temperature sensor
11 Return air temperature sensor
12 Supply air temperature sensor
13 Refrigerant mass flow meter
14 Vapor refrigerant temp. sensor
15 Vapor refrigerant pressure sensor
16 Liquid refrigerant pressure sensor
17 Liquid refrigerant temperature sensor
18 Real power meter
19 NOAA weather data

Work done constitutes a key component of performance; it is also one of the more difficult data points to measure and calculate. For this appliance, “work done” consists of heating and cooling the space, as well as heating water.

Work done in water heating is fairly straightforward to calculate. The Energy 350 researchers measured water flow, inlet and outlet temperatures, tank temperature, and ambient temperature surrounding the tank. The tank temperature and ambient temperature surrounding the tank allows researchers to calculate skin losses. The inlet and outlet water temperatures and flow allow researchers to calculate load using a basic $mC_p\Delta T$ calculation. The researchers also installed a check valve and pressure tank to prevent migration of water that might skew their data.

Work done at the indoor unit is more complex to measure and quantify. To maximize accuracy, the researchers chose to measure refrigerant enthalpy change (ΔH) across the indoor unit. They did so by measuring refrigerant flow as well as head and suction pressure and temperature. The refrigerant flow meter measures mass flow of refrigerant. The head and suction refrigerant temperature and pressure allow researchers to calculate specific enthalpy on each side of the indoor unit. This change in specific enthalpy, along with their mass flow rate measurement, allows researchers to accurately calculate work done at the indoor unit.

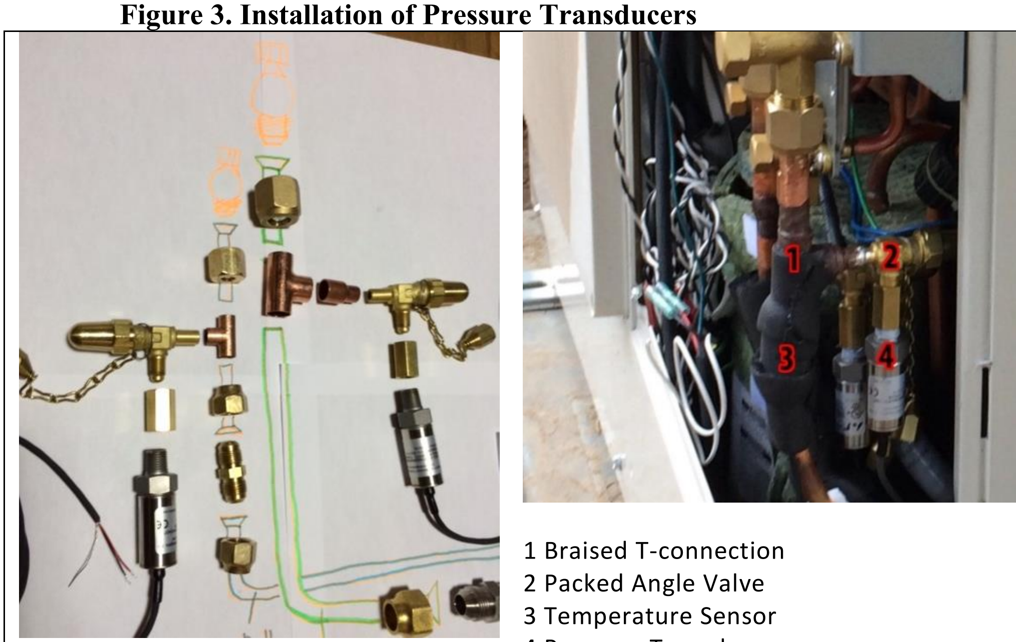
To complete the energy balance, researchers must also measure energy used by the system. To do this, they measured real power at the outdoor unit. Since the indoor unit is powered through the outdoor unit, they can capture energy use of both pieces of equipment through a single measurement. Lastly, they measured amps of the backup elements in the water heater. Using measured amps, and the voltage measurement from the outdoor unit, they calculated real power use of the backup heating elements in the water heater.

Additional metering points included supply and return air temperatures at the indoor unit and water temperatures at various heights in the tank. In addition to quantitative analysis, these points helped the researchers to better understand the details of how the system operates.

These data points are all read real-time, stored in one-minute intervals, and uploaded to a web-based data collection platform every half-hour. The researchers installed all metering equipment at the time of the appliance installation with care to not allow the metering to affect the equipment performance. They performed installation consistent with factory specifications, and properly sized all line sizes for the factory refrigerant charge and lines pumped down prior to releasing the factory charge.

Figure 3 and Figure 4 show the refrigerant pressure and temperature measurement equipment and the refrigerant flow equipment.

Figure 3. Installation of Pressure Transducers



1 Braised T-connection
2 Packed Angle Valve
3 Temperature Sensor
4 Pressure Transducer

Figure 4. Refrigerant Flow Meter

To measure refrigerant flow, the research team specified a Coriolis mass flow meter. Coriolis flow meters measure mass flow directly, rather than measuring volumetric flow and then calculating mass flow. They do this by measuring the deflection of the line from the Coriolis effect as fluid is passed through the curvature of the meter. By measuring refrigerant mass flow, along with liquid and vapor pressure and temperature, researchers can accurately calculate the work done by the system.

This particular meter has the following sets of characteristics, making it an ideal measurement tool for this application:

- Highly accurate – Accuracy varies slightly with conditions, but is in the range of +/- 0.5%
- Can measure flow in both directions. Since this is a heat pump with a reversing valve, flow direction will reverse as it switches between heating and cooling modes
- Negligible pressure drop – Measurement will not affect the outcome
- Highly pressure-resistant to high-pressure refrigerant

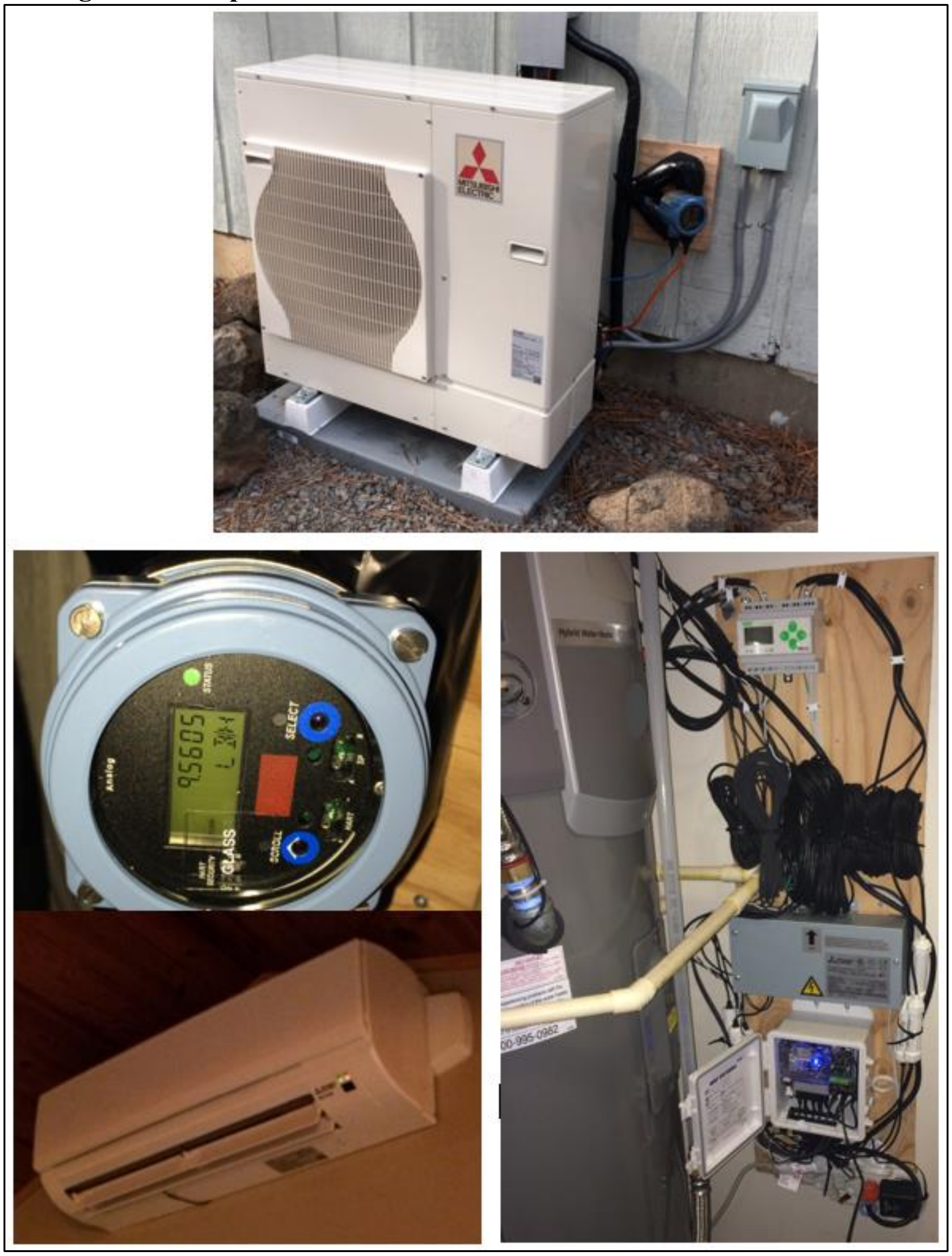
While the meter is capable of measuring either liquid or vapor flow, the researchers specified this meter to measure vapor and installed it in the refrigerant vapor line. To measure liquid introduces the bias of having entrained air within the liquid. However, the vapor line is always achieving a superheated state, avoiding mixed phase conditions. In cooling mode, researchers control the electronic expansion valve to maintain superheat, avoiding a mixed phase condition. When in heating mode, the meter is at the discharge of the compressor, before the heat rejection occurs at the indoor unit; thus it is superheated.

Figure 5 on the following page shows a number of components during the installation process.

Figure 5. The Installation Process

Figure 6 shows the completed installation of the combined appliance with the field monitoring equipment.

Figure 6. Completed Installation



3. Findings

3.1. Lab Test Results

Due to the iterative nature of rounds of lab testing and iterative product improvements, lab testing occurred over the course of months. Over time, lab space became limited and lab testing had to be cut short to allow for the testing of other products. This prevented the Energy 350 research team from conducting some of the tests it had planned, such as the first hour rating, as well as some of the simultaneous water heating and space conditioning tests. However, the researchers were able to conduct a number of key tests on water heater performance and on space heating and cooling efficiency and capacity. These tests showed very good performance in terms of energy efficiency and cold weather capacity. Lab test results are summarized in Table 1.

Table 1. Summary of Lab Results

Northern Climate Energy Factor	DOE Energy Factor	SEER	HSPF	Indoor Unit Capacity @ 5^0F Ambient (Btu)	Indoor Capacity While Water Heating (Btu)
2.20	2.33	17.17	10.05	16,750	12,457

Notes: SEER = seasonal energy efficiency ratio; HSPF = heating seasonal performance factor

3.2. Field Test Results

The researchers installed the three field tests in early March 2014. To date, they have thirteen months of operational data for all three test homes, including both heating and cooling design days. Based on preliminary feedback from early monitoring results, Mitsubishi updated the control algorithm to improve performance. It did so without any hardware upgrades; it simply downloaded a firmware update onto each control board. Mitsubishi updated firmware in early December 2014 for all three sites.

Table 2 summarizes key energy performance data by site.

Table 2. Energy Performance Summary by Site Pre-Firmware Update

Site	Cooling SEER	Heating COP	Heating HSPF	Water Heating COP	% Water Heating Done by Elements	Overall COP
SW Portland	20.9	3.1	10.4	1.6	22%	2.58
Gresham	23.2	3.5	11.8	1.2	43%	1.95
Bend	19.8	3.4	11.7	2.6	9%	2.87
Average	**21.3**	**3.3**	**113**	**1.8**	**24%**	**2.47**

Notes: The SEER rating has strictly-defined testing procedures that can only be created in a lab environment. However, Energy 350 has calculated an actual operating SEER under real-world operating conditions. COP = coefficient of performance.

3.2.1. Use of Backup Heating Elements for Water Heating

The electric element portion of the water heater is less than half as efficient as the heat pump, and as such, its use should be minimized. The mode of the water heater has a significant effect on water heater efficiency. The Gresham home substantially used the water heater backup element, which in large part stemmed from the occupants' high water use (84.6 gallons per day) and their use of high demand mode in the water tank. Figure 7 through Figure 9 show the portion of water heating done by the electric elements vs. various heat pump modes for the three houses.

Figure 7. Southwest Portland Home Water Heater Modes

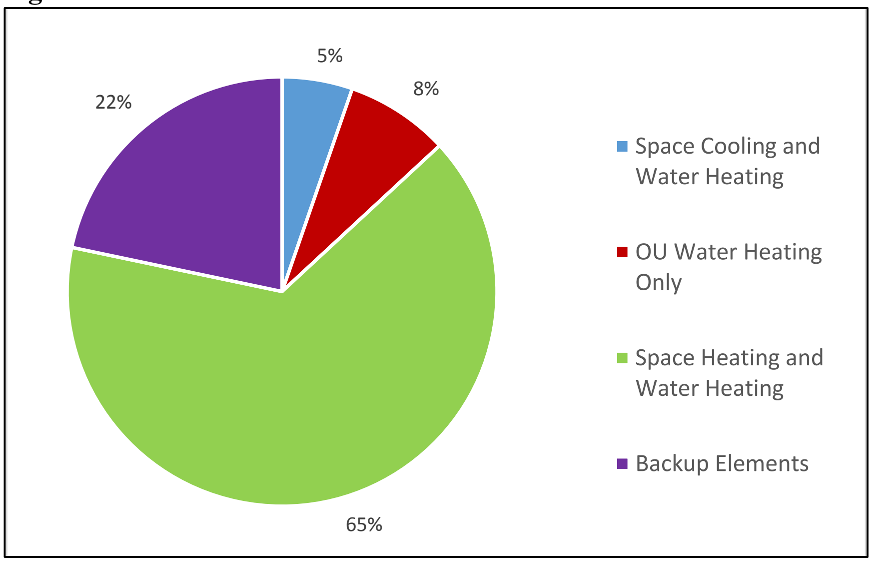


Figure 8. Gresham Home Water Heater Modes

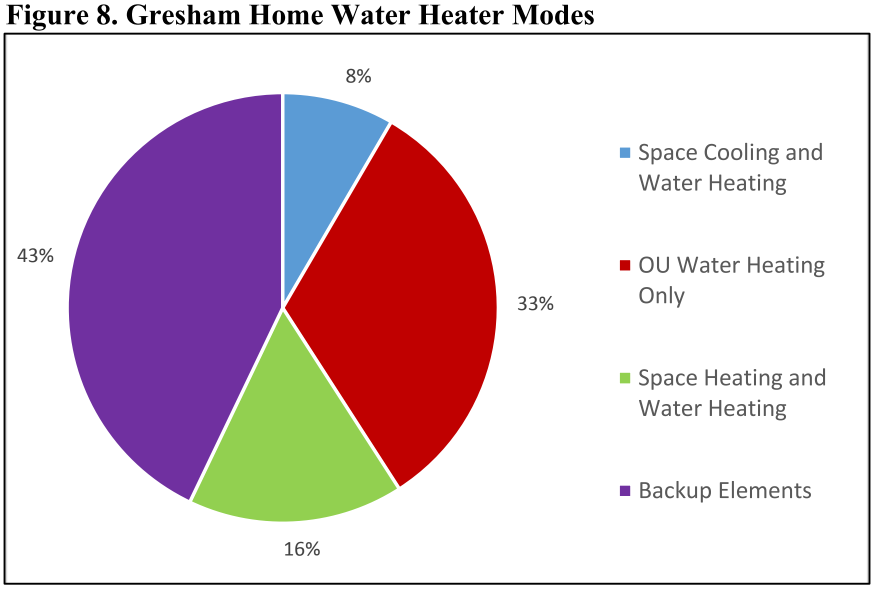


Figure 9. Bend Home Water Heater Modes

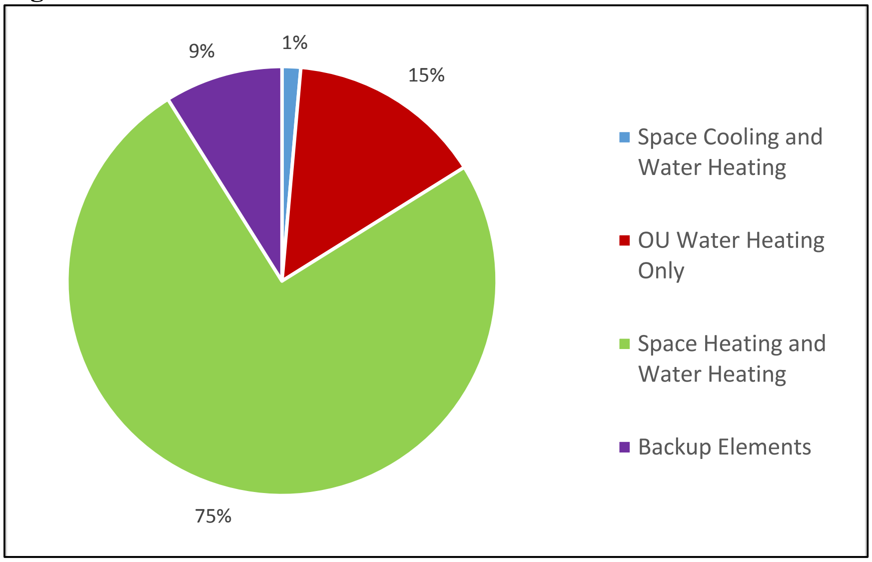


Table 3 summarizes the water usage of each site. The high water use in the Southwest Portland and Gresham homes contribute to the frequent use of the backup elements. Figure 10 through Figure 12 show the amount of work done by the outdoor unit and the water heater for each house.

Table 3. Hot Water Usage by Site

Site	Hot Water Drawn (Gal)	Duration (Days)	Average Gal/Day
SW Portland	34,848	405	86.0
Gresham	34,182	404	84.6
Bend	5,107	403	12.7
Average	**24,712**	**404**	**61.2**

Figure 10. Southwest Portland Water Heater Modes

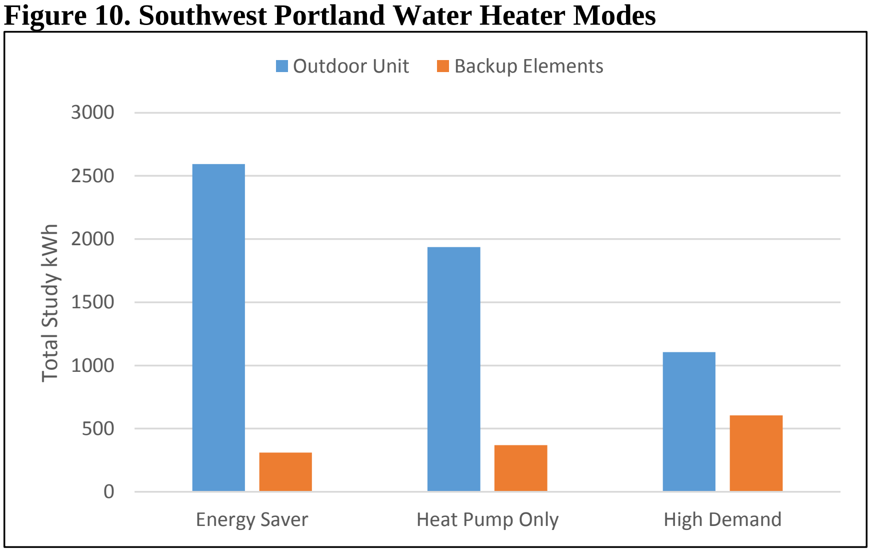


Figure 11. Gresham Water Heater Modes

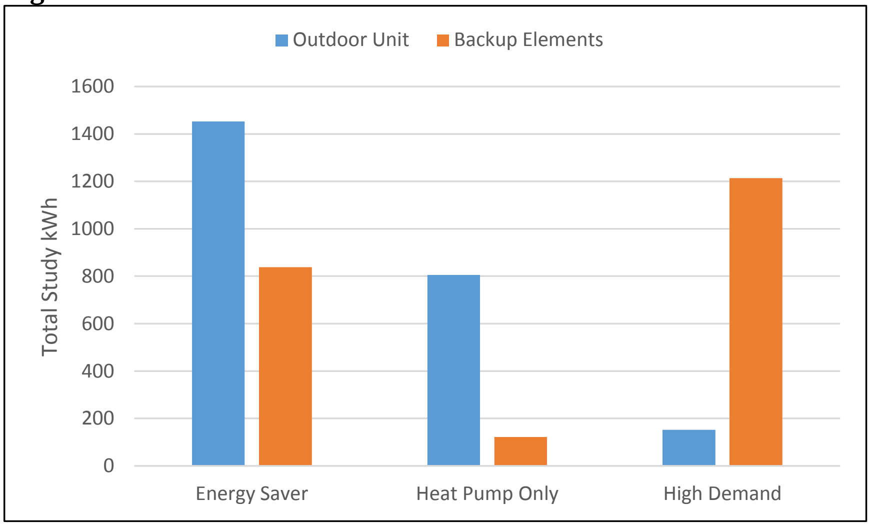
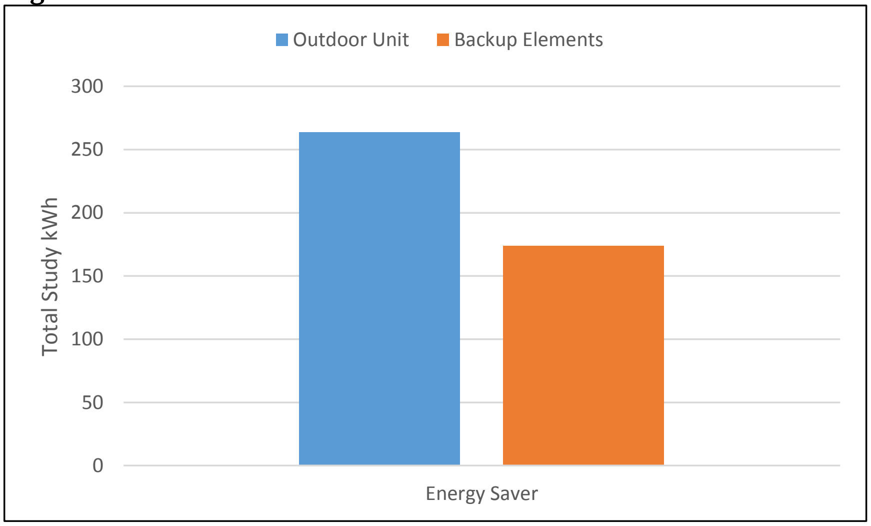


Figure 12. Bend Water Heater Modes



3.2.2. Whole Home Energy Use

The Energy 350 researchers tracked home energy use prior to and during their tests, and in most cases, observed a significant reduction in home energy use. They normalized the baseline and study energy use for weather to allow for an apples-to-apples comparison between two different time periods with varying weather. The following figures show utility data normalized to heating and cooling degree days with a reference temperature of 60°F for heating and 70°F for cooling at each site both prior to and during the study. The Southwest Portland home did not have air conditioning prior to the test, so it shows an increase in summertime energy use. The Gresham home previously had window unit air conditioners, so it shows a reduction in energy use even during the summer months due to the increased seasonal energy efficiency ratio (SEER) of the ductless cooling, combined with reduced water heating energy.

Figure 13. Southwest Portland Pre and Post Electricity Use

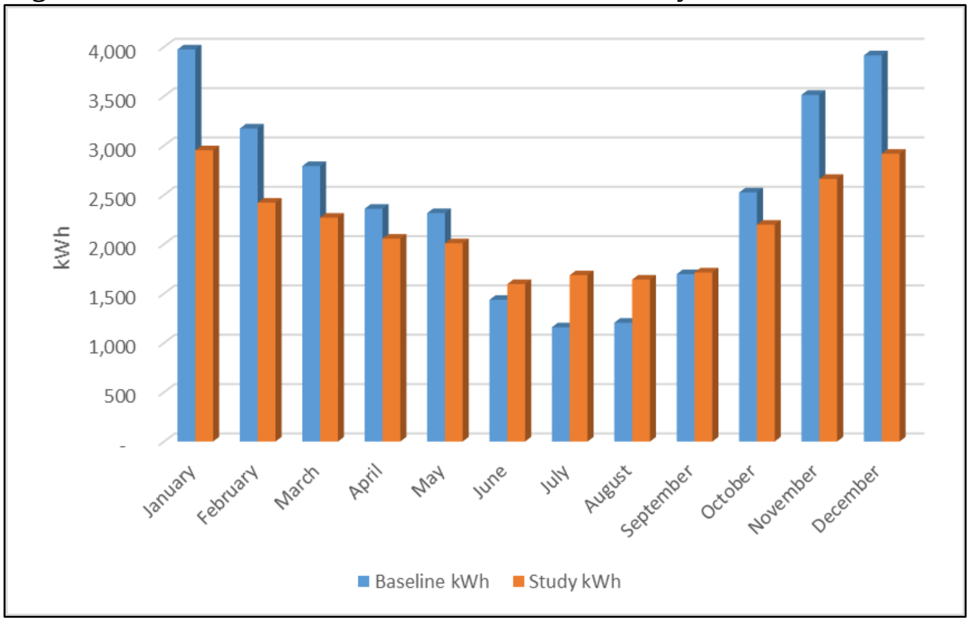


Figure 14. Gresham Pre and Post Electricity Use

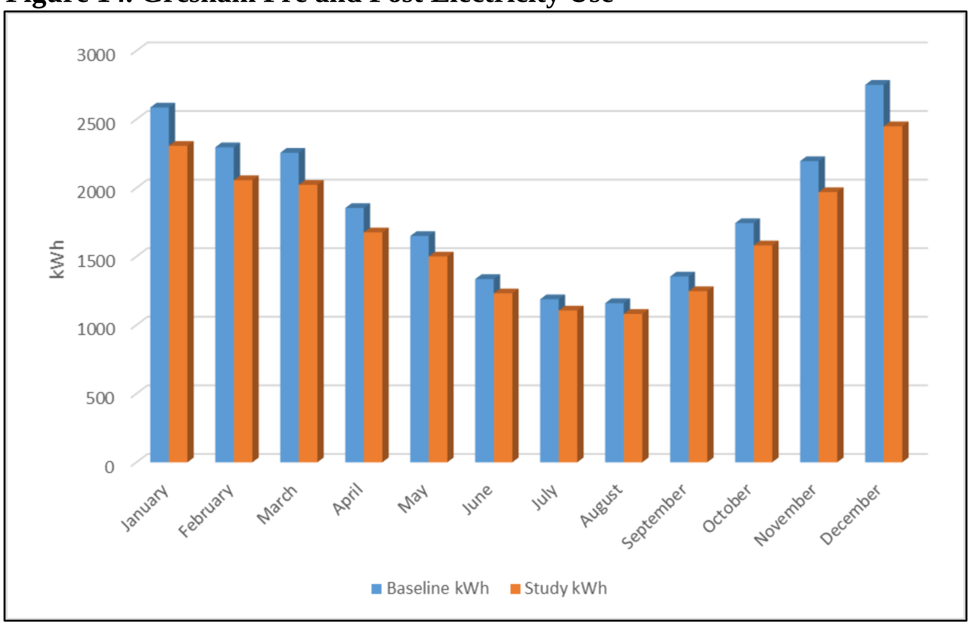
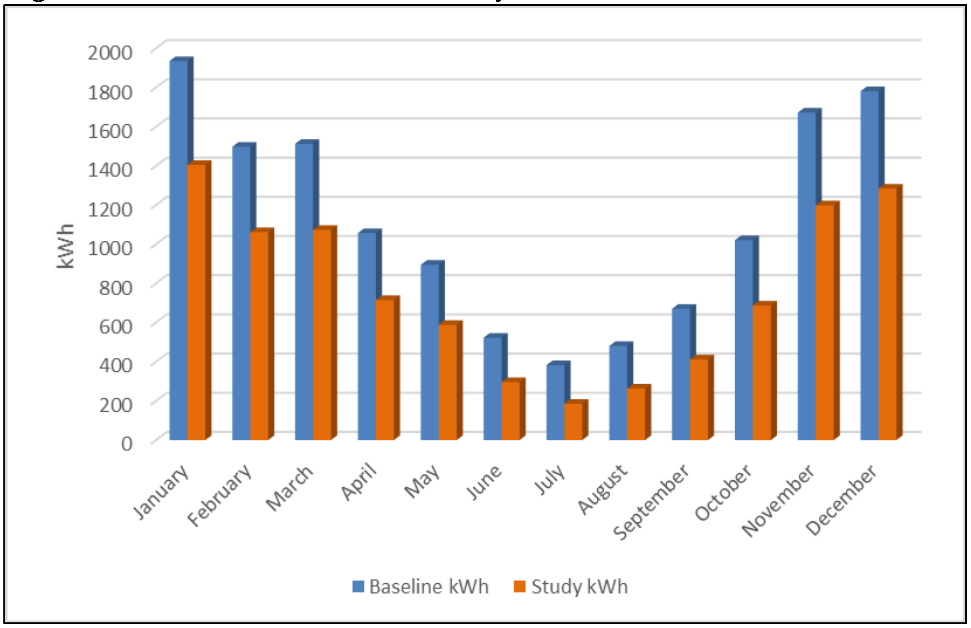


Figure 15 shows the weather normalized whole home energy use of the Bend home. The Bend home did not have air conditioning prior to the test, but uses cooling mode very infrequently, resulting in year-round energy savings.

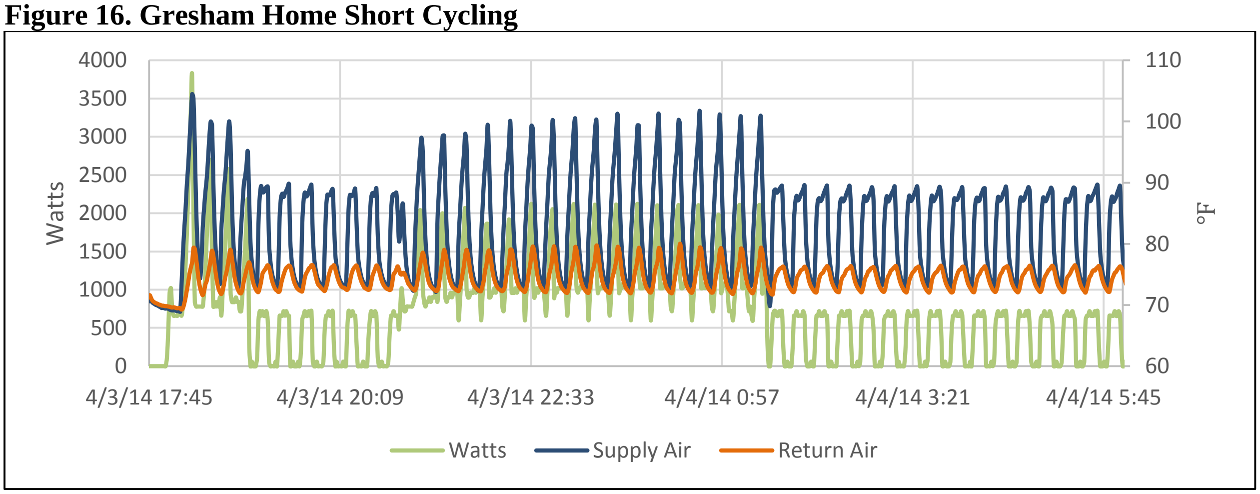
Figure 15. Bend Pre and Post Electricity Use



3.2.3. Short Cycling Issue at the Gresham Home

Early in the test period, the Gresham home experienced significant cycling. Figure 16 illustrates an example of the observed short cycling.

Figure 16. Gresham Home Short Cycling



Below are further observations regarding the short cycling issue.

- Primary Cause of Short Cycling – The primary cause of the short cycling occurred at the point of measurement of space temperature. Researchers measured space temperature at the return airstream of the indoor unit. Inevitably, a meaningful portion of the supply air immediately short-circuits back to the return air. This causes the return air sensor to very quickly meet the space temperature setpoint and the unit cycles off. However, due to the short-circuiting of supply air back to the return air, return air temperature is not a good representation of space temperature. Given that the return air achieves setpoint before space air, shortly after cycling off, the return air temperature sensor approaches an accurate measurement of space air temperature. Upon measurement of an accurate space air temperature, the unit cycles back on and the cycle repeats itself.
- Short Cycling Solution – The researchers solved the short cycling issue in the Gresham test home where it was occurring, by switching the unit control to a wall thermostat. The wall thermostat is less directly affected by conditioned supply air and is able to more accurately read space temperature.
- Short Cycling Broader Implications – Many DHPs have only a remote, rather than a wall, thermostat. These units measure space temperature at the return of the indoor unit, and will be prone to short cycle. Additionally, where wall thermostats are installed, the option still exists to measure space temperature at the return of the indoor unit. These units will also be prone to short cycle. Two methods are available to mitigate the potential for short cycling. Ideally, both strategies would be used together.
    - Measure space temperature at the wall thermostat. The use of properly-located wall thermostats will result in a more accurate reading of space temperature. This will lead to a more accurate control of the indoor unit, and reduce the likelihood of short cycling.
    - Adjust control algorithms to minimize short cycling. Control parameters such as start-up inverter speed, length of time held at that speed, min/max inverter speed, and start/stop temperature deviations from setpoint will all affect the cycle time of the indoor unit. For example, a lower start-up inverter speed and minimum speed would reduce the capacity of the indoor unit and result in longer runtime before temperature is achieved and the unit cycles off. Similarly, an increased allowable temperature deviation from setpoint would allow the indoor unit to sit idle longer before cycling on, then run longer before cycling off. Of course, large temperature swings will have an impact on occupant comfort, so efficiency will have to be balanced with comfort/operability.

3.2.4. Water Heating Performance

The product’s space heating and cooling is highly efficient. However, with the prototypes tested, the water heater efficiency was not as high as expected. Mitsubishi is currently working with its water heater partner to develop a next-generation water heater. Below are some factors that contributed to these lower water heating coefficients of performance (COPs). The research team expects that the next generation of the product can address these factors and increase COPs.

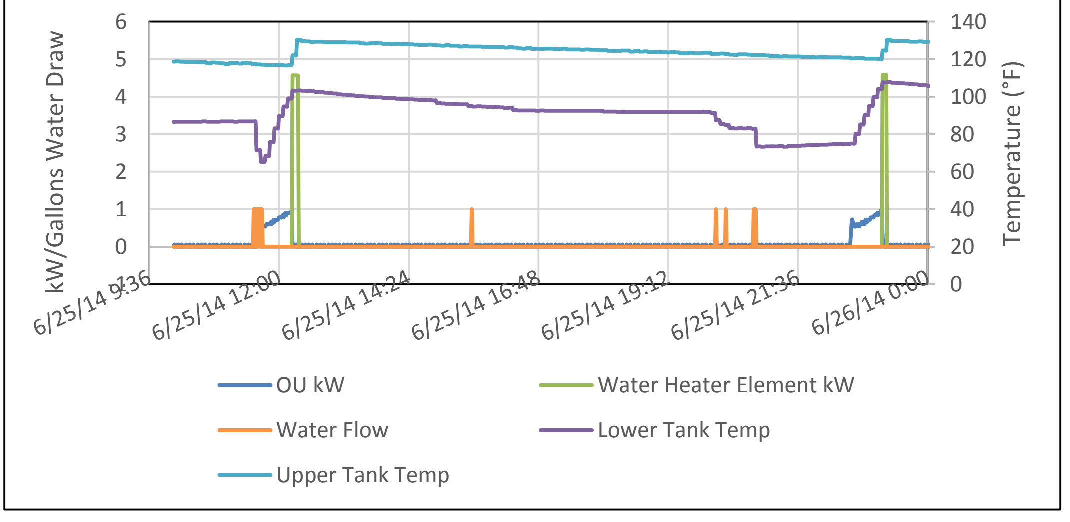
- High water usage in two of three test homes – Two of the three test homes had high water usage, making the 50-gallon tank undersized for these homes. This resulted in high use of the electric elements, lowering the COP. This issue is not a reflection of the product, but rather an observation of a sizing mismatch that affected performance. As this product is further developed, a range of sizes will likely be available, thus eliminating this issue. Table 4 summarizes the water usage for each home.

Table 4. Water Usage by Home

Site	Hot Water Drawn (Gal)	Duration (Days)	Average Gal/Day
SW Portland	34,551	405	85.3
Gresham	34,999	404	86.6
Bend	5,104	403	12.7
Average	**24,885**	**404**	**61.6**

- Limited heat exchange between the outdoor unit and tank – The tank uses a refrigerant wrap at the bottom portion of the tank. However, the surface area is limited, limiting the heat exchange capacity between the outdoor unit and the tank. The less capacity that the compressor can provide, the more work is shifted to the backup elements, reducing COP. Given the large capacity of the outdoor unit, increased heat exchange between the outdoor unit and the tank would allow better utilization of compressor water heating, which would reduce backup element usage and increase COP.
- Inability to achieve high water temperatures with compressor heat – In water heating mode, the condensing temperature target of the outdoor unit is 140°F. Since heat transfer relies on a temperature delta between the refrigerant and water, this limits the capability for compressor heating as water temperatures exceed 130°F. As the rate of change of water temperature slows, the compressor is shut off and the backup elements take over. As Figure 17 illustrates, the unit starts with a water draw, followed by compressor heating, then finally by backup element heating. Ideally, the backup elements would only be used in times of high demand, not at the end of a heating cycle following a draw.

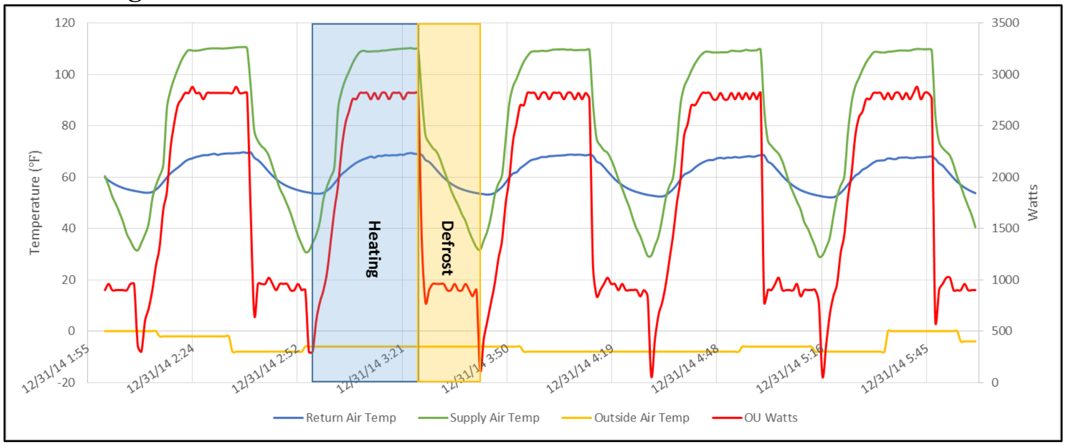
Figure 17. Inability to Achieve Tank Temperature with Compressor



3.2.5. Cold Weather Performance

The Bend test home experienced weather as cold as -8°F during the test period. Throughout the cold weather, the heat pump continued to heat the home without backup heat. This is a very cold temperature to operate a heat pump and an impressive demonstration of performance. As would be expected, the defrost cycles were quite frequent. However, when in heating mode in sub-zero ambient, the heat pump was able to deliver 110°F supply air temperature. Figure 18 shows its cold weather performance.

Figure 18. Cold Weather Performance – Bend Test Home



4. Recommendations for Enhanced Performance

The lab and field testing has already resulted in several rounds of product enhancements to the prototype product. Even given the product enhancements already in place, the Energy 350 research team believes that additional opportunities exist for further performance improvements.

4.1. Minimize Likelihood of Short Cycling at the Indoor Unit

Mitsubishi can take a number of steps to minimize the likelihood of short cycling. Energy 350 believes a key contributor to short cycling is the measurement of space temperature at the return air stream of the indoor unit. Energy 350 thus recommends that Mitsubishi consider the following actions to minimize short cycling. The research team understands that each of these has operational impacts and that Mitsubishi may not wish to implement all of them.

- All units should use a wall thermostat and the default factory setting should be to control the indoor unit based on the thermostat measured temperature.
- The inverter start-up speed may be reduced.
- The length of time that the inverter is held at start-up speed may be reduced.
- The cut-in and cut-out temperature deviations from setpoint may be increased.
- The minimum inverter speed may be reduced.

4.2. Increase Heat Transfer between Compressor and Water Heater

At 30,000 Btus, the compressor has over 300% more capacity than similarly-sized traditional heat pump water heaters. This can lead to faster recovery times and reduced dependence on backup electric water heating. However, the effective capacity is limited by the heat transfer between the compressor and the tank. Energy 350 recommends that future product iterations seek to maximize heat transfer between the compressor and the tank. This would likely be accomplished by a tank and refrigerant wrap design that maximizes the contact surface area between the tank and refrigerant wrap. The larger the capacity for heat transfer from the compressor to the tank, the less reliant the tank will be on the backup heating elements, which will improve COP.

4.3. Enable Compressor to Achieve Higher Water Temperatures

As shown in Figure 17, the compressor often failed to achieve the desired water tank temperature. The current control algorithms monitor the rate of change of water temperature. When the rate of change of tank temperature gets too slow, the controls shut off the compressor and turn on the backup elements. This causes the backup elements to run not just in times of high demand, but at the end of the heating cycle, long after the water draw has ended. Of course, this increased reliance on the electric elements reduces COP. Energy 350 recommends that Mitsubishi consider one or more of the following enhancements to allow higher tank temperatures to be achieved without the need for the heating elements.

- Increase the target condensing temperature when water heating. The current water heating condensing temperature is 140°F. This results in a low ΔT between refrigerant temperature and water temperature, which often triggers the need for the electric elements as water temperature approaches refrigerant temperature. An increased refrigerant condensing temperature when water heating would increase the heat transfer and allow the compressor to achieve desired tank temperatures without the need for the backup elements.

- Implement a dynamic refrigerant condensing temperature control that increases target condensing temperature as the rate of change of water temperature slows.
- Decrease the allowable rate of change of water temperature before the elements come on.
- Have a Sequence of Operation (SOO) that varies based on rate of change of water temperature. Below is an example of a possible SOO.

    - <u>Stage 1 water heating</u> – Would initiate as it does currently
    - <u>Stage 2 water heating</u> – When water temperature rate of change gets to some minimum value, increase target condensing temperature
    - <u>Stage 3 water heating</u> – If water temperature rate of change falls below some value lower than the Stage 2 value, shut off compressor and use heating element

5. Conclusions

Conducting this testing in the early stages of product development has provided data that allow for a nearly real-time evolution of the product. As Mitsubishi is planning the manufacture and market rollout of this product, it is continuing to implement design changes, likely both in terms of hardware and control algorithms. As a result, the results of testing conducted to date have influenced the product evolution, but will not reflect performance of the next generation of the product.

The activities conducted to date have shown significant product improvements and many positive test results, as well as room for further improvement, particularly in water heating. The unit has demonstrated very positive performance in space heating efficiency, space cooling efficiency, and performance in cold ambient conditions. Energy 350 researchers believe that further enhancements to water heating efficiency are possible and have also identified a path toward enhancing that performance.

This product has shown the potential for positive benefits in terms of cost, performance and market penetration. Given the performance results to date and quick evolution of the product, Energy 350 feels that this technology has a reasonable likelihood of achieving the following outcomes as it matures:

- Competitive or improved energy efficiency compared to standalone ductless heat pumps and heat pump water heaters
- Competitive or reduced first cost compared to standalone ductless heat pumps and heat pump water heaters
- Increased market potential for heat pump water heater deployment. This product can replace heat pumps within conditioned spaces without the interactive cooling effect of traditional heat pump water heaters