Application of Combined Space and Water Heat Pump Systems to Existing Homes for Efficiency and Demand Response

First Midterm Field Study Report

Bonneville Power Administration
Technology Innovation Project 338

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Abbreviations

AC	alternating current
BPA	Bonneville Power Administration
Btu	British thermal unit
CEC	California Energy Commission
CFM	cubic feet per minute
CO_2	carbon dioxide
DHP	ductless heat pump
DHP+	ductless heat pump system that combines ductless heat pump space conditioning and water heating using a conventional refrigerant
DHW	domestic hot water
DOE	U.S. Department of Energy
DR	demand response
EF	energy factor
ER	electric resistance
FAF	forced air furnace
FEF	Field Energy Factor
FM	flow meter
GPD	gallon per day
HDD	heating degree days
HFC	hydrofluorocarbons
HPWH	heat pump water heater
HSPF	Heating Seasonal Performance Factor
IECC	International Energy Conservation Code
kWh	kilowatt hour
NEEA	Northwest Energy Efficiency Alliance
NOAA	National Oceanic and Atmospheric Administration
OAT	outside air temperatures
PG&E	Pacifi Gas & Electric
PNNL	Pacific Northwest National Laboratory
PSI	pound per square inch
RF	radiant floor
RP	radiant panel
RTF	Regional Technical Forum
TIP	Technology Innovation Program
UL	Underwriters Laboratory
WC	wall cassette
WSU	Washington State University

Introduction

This is the first field report of the Washington State University (WSU) Energy Program research into the performance of CO_2 refrigerant heat pumps used for combined space and water heating in existing homes. The research is funded by the Bonneville Power Administration (BPA) through its Technology Innovation Program (TIP) as Project 338. The equipment being tested in this study is manufactured by Sanden International and Mitsubishi Electric.

The three types of heat pumps that are the subject of this research are: Sanden International (Sanden) CO_2 refrigerant split system heat pump water heaters (split system); a larger capacity CO_2 refrigerant system designed specifically for space heating (Eco Runo) manufactured by Sanden; and a conventional refrigerant ductless heat pump with water heater (DHP+) manufactured by Mitsubishi. The Sanden split systems will be installed at two sites in the Pacific Northwest (Olympia, Washington, and Portland, Oregon), plus two sites in northern California (Grass Valley and Nevada City). In addition, two split systems will be tested at the Pacific Northwest National Laboratory (PNNL) Lab Homes Test Facility. If lab tests are successful the Eco Runo systems will be installed at sites in Cowlitz County and Spokane, Washington. The DHP+ systems are to be located in McCall, Idaho; Portland, Oregon; and Kelso, Prosser, Rochester, and Spokane, Washington. All of these locations are characterized in Table 1.

Monitoring was installed prior to system installation, where possible, to establish baseline energy and water use. The second phase at most sites is the installation of the combined system. This report focuses on the baseline data obtained from installation through March 31, 2016, and includes data from four sites.

As of June 30, 2016, all project sites are recruited, and are characterized in this report. All Pacific Northwest sites have baseline monitoring systems installed, and four of those sites had sufficient data collected for analysis during the reporting period, which ended on March 31, 2016.

Baseline data is important to understand the household energy use of domestic hot water and, if possible, space heat prior to the installation of the combined system that will combine the two uses. The four sites have sufficient data to provide this information for both space and water heating.

This report covers the details of the baseline monitoring system and the protocols for data analysis. It includes the monitored outdoor and indoor air temperatures, hot water temperatures, hot water use and the energy used to heat it, and space heating.

This report establishes the framework for the exposition of the data and results of analysis. It maps out the territory covered by the project, and provides a basis for assessing the impact of the systems that are installed in the next phase of the project. It will be presented as a section in the Second Midterm Report with baseline data from these and the other homes in the baseline sample for the period beginning April 1, 2016 through October 31, 2016. By that time, the baseline period will have ended for a number of homes due to installation of the new combined space and water heating system. But their baseline periods will be preserved for comparison to this next phase.

Field Study

This research is designed to assess the performance of heat pumps that provide combined space and water heating in existing homes with a range of thermal efficiencies. This research originally included a controlled field study at the PNNL Lab Homes Test Facility and a field monitoring study of two types of split system heat pump systems at 11 sites. As the project evolved, the Eco Runo was added to the project for two of the 11 sites that have larger design loads than the capacity of the original CO_2 split systems. The Eco Runo will be tested in the lab before deployment in the field.

Monitoring systems were installed at as many of the sites as possible to collect energy use data for space and water heating with the original systems. This baseline monitoring provides a means of comparing the overall impact of the new system and its specific performance difference under comparable conditions. This midterm report provides an early look at baseline data from the first four sites to be monitored.

The midterm analysis also provides an opportunity to critically examine the data, and to develop and apply the analytic tools needed to answer the research questions. The data review allows the field monitoring team to identify monitoring system issues such as solar interference with the outside air temperature (OAT) sensor and flow meters that are not functioning properly. This is valuable to the entire project because research is only as good as the data collected and analysis performed.

One of the unique features of this study is the opportunity to obtain baseline data prior to installing the new technologies in these existing homes. This required developing monitoring techniques that can be installed in a modular fashion so subsequent installation of new tanks and electric loads with the new combined system does not require expensive re-plumbing or re-wiring to preserve the measurement of core temperatures and energy use.

Description

Technologies Researched

Two technologies were originally proposed for this research—the split system CO_2 refrigerant heat pump water heater (HPWH) manufactured by Sanden and the Mitsubishi DHP+ system that combines ductless heat pump space conditioning and water heating using a conventional refrigerant.

Sanden has offered a second CO_2 refrigerant heat pump, called an Eco Runo, that has a higher capacity and is designed specifically for space heat applications. Because it is brand new equipment, it must be lab tested prior to its use in field research. BPA has provided additional funds for this testing, and the use of the Eco Runo in field research depends on the lab test findings.

Site Selection

The sites represent five different climate areas with two in northern California (California Energy Commission (CEC) Building Climate Zones 11 and 16) and three in the Pacific Northwest (International Energy Conservation Code (IECC) Climate Zones 4C, 5, and 6 and Regional Technical Forum (RTF) Heating Zones 1 and 3). The six CO_2 system sites are in the two CEC zones and IECC zones 4C and 5. The DHP+ sites are located in IECC zones 4C, 5, and 6. The site in zone 5 is the hottest, with 228 cooling degree days above a 70°F base. Benton REA, The Energy Trust of Oregon, Cowlitz PUD, and Inland Power and Light assisted in locating sites in their service areas.

Code Issues and Solutions

The systems used in these experiments are not, in most cases, Underwriters Laboratory (UL) listed. Electrical and building permits will be obtained for each of the 11 installations. The situation is complicated because the HPWH is providing space heat as well as hot water. The addition of the second use makes obtaining permits in most jurisdictions more difficult than installing the combined systems simply as water heaters, as was done in TIP 292 and TIP 302. As in those earlier projects, the building official is required to exercise discretion under Section 104 of the International Residential Code, which allows use of alternate materials and systems.

Ken Eklund at WSU works with building officials to assist in obtaining permits. Sites were selected, in part, because they are in jurisdictions that have already allowed research systems without UL listing to be installed. Utilities can often provide assistance with building officials in areas they serve.

Sanden International has obtained UL listing for the CO_2 split system. It is anticipated that the system installed in Portland will be UL listed, but the ones in Olympia and northern California were purchased before listed units were available. UL listing is a long and expensive process, and much of the knowledge and experience obtained in these TIP projects is being incorporated into equipment that will ultimately be UL listed and sold in this country.

The Eco Runo and Mitsubishi DHP+ systems researched in this project will not be UL listed. The DHP+ will probably move from this field test directly to market, and UL listing will be procured for the prototype together with any improvements made as a result of the field study.

System Design and Installation

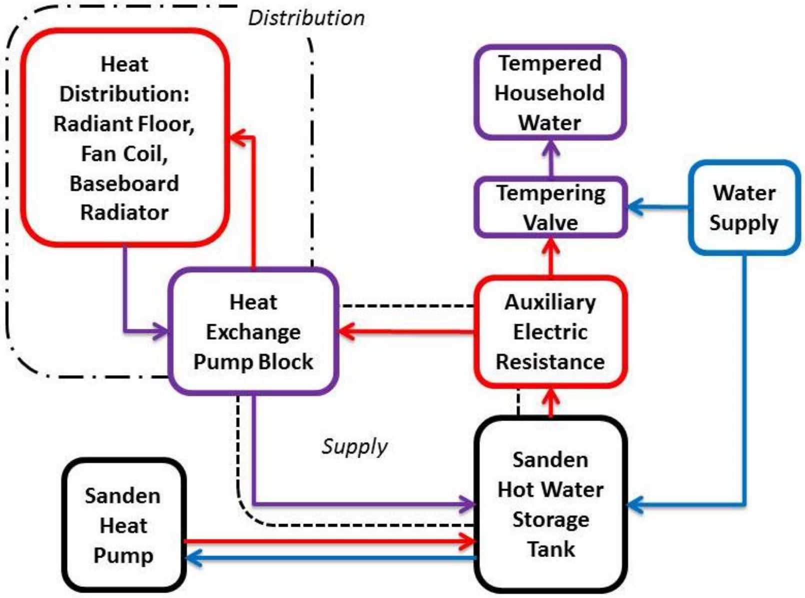
The three different systems each require unique system design, installation, and monitoring. The most developed are the CO_2 split system and the DHP+. The Eco Runo system is now at the concept stage. The system, of course, defines the type of monitoring that will ultimately take place. Baseline monitoring is also a custom project, depending on the existing systems. Each of the system types is briefly described in this section.

The CO_2 split system adds a space heating loop to the HPWH. This heating loop consists of two parts:

- The supply side moves heated water from the tank to a heat exchanger, and
- The distribution loop delivers heat to the heat distribution system.

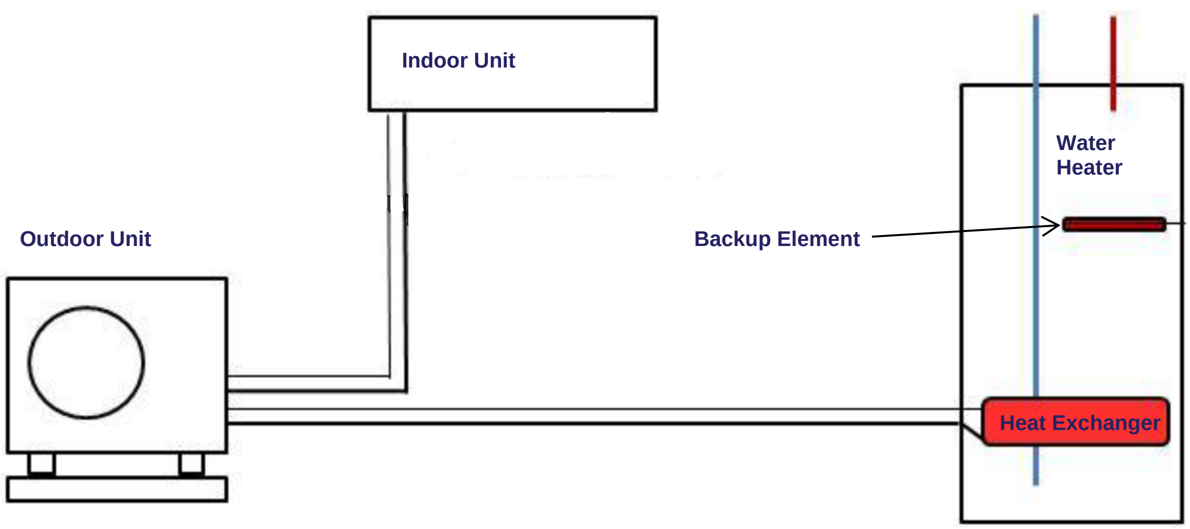
The design includes a backup heater between the tank and the heat exchanger. **Figure 1** shows a basic schematic of the CO_2 split system.

Figure 1. Schematic of the CO_2 Split System



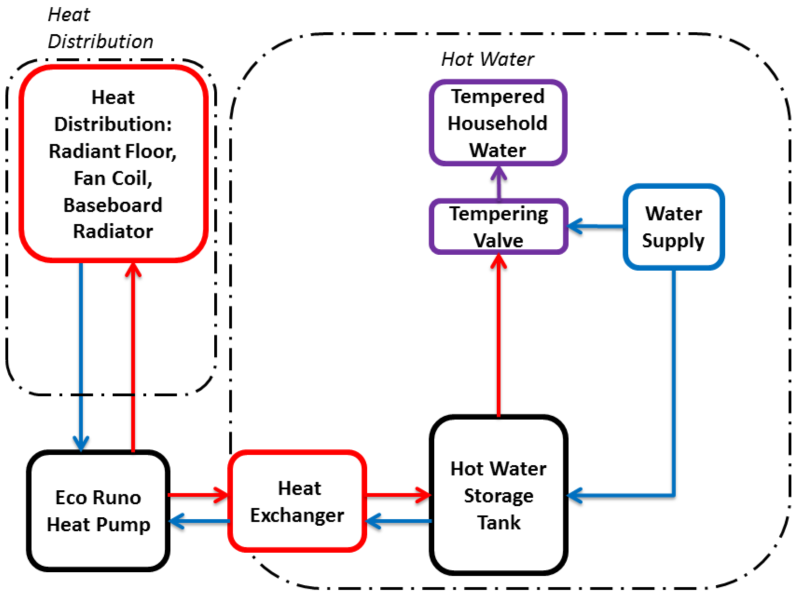
The DHP+ system by Mitsubishi is a large-capacity ductless heat pump (DHP) that heats water and provides cooling and heating to the space. **Figure 2** shows the basic outline of this unit, with refrigerant lines moving from the heat pump in the outdoor unit to distribution in the indoor unit and exchange to water in the tank.

Figure 2. Schematic of the DHP+ Water Heating System



The Eco Runo system is designed specifically for space heating. The concept, which has not been tested, is to turn it into a combined system by using a heat exchanger for hot water, as shown in Figure 3. The lab test may reveal issues that need to be solved before the system can be placed in a field location. Installations will be staged first in a warmer site and, if it performs well in cold weather, at a second site located on Climate Zone 2. The manufacturer is prepared to address issues if necessary.

Figure 3. Schematic of Eco Runo System



Challenges in Monitoring

The project was designed to use Onset U30 loggers and sensors owned and provided by the Northwest Energy Efficiency Alliance (NEEA), which were installed at the first two sites. Onset then informed Ecotope, the monitoring equipment steward, that it no longer manufactured U30 loggers because ATT is phasing out the 1 and 2 gigabit infrastructure that supports them. In fall 2015, Onset informed Ecotope that it would charge $450 instead of the budgeted $290 for the data plan, and that the option was available for one year. Onset offered its new system, the RX3000, for $810 with a free one-year monitoring plan. At the time this report was prepared, two sites have U30 loggers and the project has purchased nine RX3000 loggers.

Issues with the new RX3000 loggers include poor reception in rural areas, one failed logger, and lack of an active local port that facilitates setup and data download when needed. Rural areas without either solid cellular or internet connection are particularly challenging.

At the time of this report, baseline monitoring is installed at four Sanden sites and five Mitsubishi sites. The two sites where the systems still need to be installed are located in northern California; installation is contingent on an agreement being in place with Pacific Gas and Electric (PG&E).The lead monitoring installer for the Sanden sites is David Hales of WSU. He is assisted by Luke Howard, also of WSU. Bob Davis of Ecotope is the lead installer for the Mitsubishi sites.

Field Study Details

Site Summaries

The specific sites are typical of the regional heating zones they represent, as shown in **Table 1**. Most of the sites in Heating Zone 1 are warmer than the median value for that zone, but represent the most populated areas in the region. Spokane is warmer and McCall is much colder than the zone median.

Table 1. Heating Zones of Ten Test Sites

Site Location	Heating Zone	Median HDD65 [1]	Site HDD65 [2]	System Type
Grass Valley , CA	CEC CZ11		3,521	CO_2 Split System
Kalama, WA	RTF HZ1	5,182	4,975	Eco Runo
Kelso, WA	RTF HZ1	5,182	4,975	DHP+
Milwaukie, OR*	RTF HZ1	5,182	4,109	DHP+
McCall, ID*	RTF HZ3	8,363	8,976	DHP+
Nevada City, CA	CEC CZ16		4,565	CO_2 Split System
Olympia, WA	RTF HZ1	5,182	5,567	CO_2 Split System
Portland, OR*	RTF HZ1	5,182	4,109	CO_2 Split System
Prosser, WA	RTF HZ1	5,182	5,511	DHP+
Rochester, WA*	RTF HZ1	5,182	5,567	DHP+
Spokane, WA	RTF HZ1	6,824	6,143	Eco Runo

Tables 2 and 3 provide specific information about each site. Baseline data from only the four sites asterisked in Table 1 are presented in this midterm report.

Table 2. CO_2 Test Site Characteristics

Site Location	Grass Valley	Kalama	Nevada City	Olympia	Portland	Spokane
HDD	3,521	4,975	4,565	5,567	4,109	6,143
Design T	19	19	14	22	23	2
Heating System	NG Water Heater	ER Heaters	CO_2 Split**	CO_2 Split**	ER Zonal	ER Heaters
Dist. system*	FAF	FAF	FAF	RP	WC	RF
DHW T°F	120	125	122	120	130	145
# Occ.	2	4	2	2	4	2

*RF=radiant floor, RP=radiant panel, FAF=forced air furnace, and WC=wall cassette
**The Nevada City and Olympia homes do not have data on any heating system except the Sanden CO^2 split system.

[1] Source: Northwest Power and Conservation Council, 6th Power Plan Assumptions
[2] Source: Western Regional Climate Center. All heating degree days (HDD) are calculated with 65°F base.

Table 3. DHP+ Test Site Characteristics

Site Location	Kelso	Milwaukie	Prosser	McCall	Rochester
HDD	3,521	4,109	5,511	8,976	5,567
Design T	19	23	14	-16	22
Heating System*	DHP & ER	ER Zonal	ER + Wood	ER Zonal + Propane	ER Zonal
DHW T°F	120	125	122	140	120
# Occ.	2	2	5	2	2

*The distribution system in these homes is primarily radiant and convective transfer from electric resistance (ER) heaters.

Monitoring Setup

The baseline monitoring is designed to capture the space and domestic hot water energy use prior to installation of the combined space conditioning and water heating system. In some cases, the monitoring was able to capture space heating; in others, installation occurred too late. In all cases, water heating energy and hot water use were recorded. The factors needed to monitor this baseline activity are:

Water flow:

- Through hot water tank measured at the cold water inlet (cubic feet per minute, CFM) (FM=flow meter)

Temperatures:

- Cold water supply (CWT)
- Hot water to household (HWT)
- Outside air temperature (OAT)
- Inside air temperature near the hot water tank (WHT)
- Inside air temperature in conditioned space (IAT)

Power measurements:

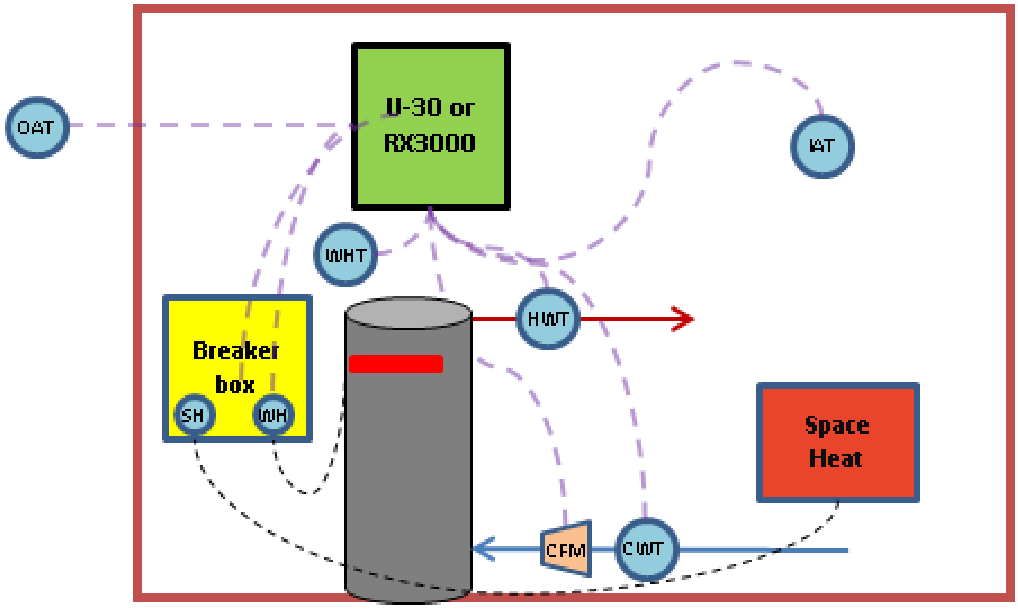
- Time and amperage of space heat electricity use (SH)
- Time and amperage of water heat electricity use (WH)

The baseline field monitoring setup is illustrated in **Figure 4**. The main monitoring collection device is an Onset U30 or RX000 with cellular or internet connection so data can be downloaded daily and settings on the logger can be controlled remotely. This quality assurance ensures that issues are identified and corrected as soon as possible. The following monitoring equipment is used:

- U30 GSM or RX3000 (includes 10-port option and data plan)
- WattNode (WNB-3Y-208-P option 3)
- 50 amp split core alternating current (AC) transformers
- Pulse adapters S-UCC_M006
- 12-bit temperature sensors with 6-meter cable
- 12-bit temperature sensors with 17-meter cable
- Water flow meter sensor (T-Minol-130)
- Pulse adapter for flow meter S-UCD-M006
- 10K ohm type 2 thermistors with temperature documentation
- Thermal wells for the thermistors

In some instances, on-site HOBOlink® monitoring is also required to capture all data streams. These data are downloaded manually at several-month increments.

Figure 4. Baseline Field Monitoring Setup



Field monitoring requires experience in monitoring design equipment and installation. OAT sensors must be positioned where solar gains do not strike the sensor at any time of year to eliminate false readings. Polarities on sensor connections can be difficult and confusing to set up properly, and are occasionally crossed by experienced installers, but are critical to proper data collection. The ability to check all connections and signals before leaving the test site aids research and avoids lost data and costs associated with repeat trips to a site. The lack of a local port on the RX3000 inhibits this checking and is considered a design flaw by WSU and Ecotope.

The monitoring equipment was designed to be installed in a modular fashion to facilitate subsequent installation of the combined space and water heating system with additional sensors. The goal is to avoid expensive re-plumbing and re-wiring when the hot water tank is replaced, the original heating system transformed to a backup system, and a heat pump is added. The strategy is explained in the Field Study Metering Plan provided as Attachment A.

Description of Analyses

The midterm analyses are designed to focus on the field monitoring while it is occurring in order to provide quality assurance, develop analysis procedures, and organize reporting for the project. The period covered by this analysis is from the time monitoring began at each site through March 31, 2016. This timeframe includes data from 4 of the 11 sites, providing a look at hot water and heating use prior to the installation of the new systems.

Baseline Monitoring and Data Analysis

Baseline monitoring for water heating is exactly the same as baseline monitoring for the combined systems on the end use side of the equation, and the analysis is also the same. It requires measuring the water flow through the system, as well as the cold and hot water temperatures. The difference is that in baseline monitoring, the source of the energy used to heat the water is measured and the efficiency can be calculated. Parsing the energy component for a specific end use (space heating or water heating) is not possible in combined systems because there is a single energy measurement for space and water heating.

As with hot water, the baseline space heat energy can be directly monitored in the baseline study and will continue to be monitored after installation of the combined system. In the baseline period, the measured space heat is in most cases the sole source of heat in the conditioned space, but becomes backup heat supply when the combined system is installed.

Analysis Protocols

Measured flow and temperature values are used to calculate the following variables.

Domestic Hot Water Use

Calculating domestic hot water (DHW) use requires the following data:

- Average temperatures by flow event or by day for cold water supply, hot water, and tempered water for the DHW supply
- Thermal energy required to heat the cold supply water for each flow event
- Volume of total water for each flow event

To calculate accurate temperatures for cold supply water and heated water for DHW, at least three minutes of consecutive flow was required. Temperatures were then calculated by dropping the initial reading and averaging over the remaining readings for a given flow event (or draw). Daily averages were used as the representative temperatures for short-duration draws that were less than three consecutive minutes. When only short draws occurred during a given day, the daily average water temperatures from adjacent days were used.

Only water volume flowing into the HPWH tank was metered via data loggers.

Average water temperatures were used to calculate the thermal energy needed to heat the cold water for each draw. The energy is calculated via the familiar calorimetric equation shown below, where p is the density and C_p is the heat capacity of water.

Equation 1: Energy = Volume x p x C_p x (Temperature 1 - Temperature 2)

Once new technologies are installed, specifically the Sanden split system and Eco Runo, the temperature of hot water stored in the tank is greater than what would be safe for household use. Water used at the tap is tempered by additional cold water that needs to be taken into account to calculate the volume of total water for each flow event. These protocols will be outlined in the next midterm report

Space Heat

Most of the space heating at the field sites is ER, which converts to heat with an efficiency of one, not counting distribution losses. With the radiant heaters used in the zonal systems at most of the sites, the distribution is passive and the measured electricity use can be directly converted to space heat. If a fan is used to move the heat, that energy use must be added to provide a complete picture of heating energy.

At the McCall site, the master bedroom and bath are heated with ER floor elements, and will be retrofitted with the DHP+. The living room, kitchen, and guest bedroom are heated by a propane furnace. In the baseline data, this heat is included in the whole house space heating energy. The final analysis will be a choice between either whole house or master bedroom suite analysis.

Efficiencies

The kWh per gallon is calculated at the daily level as the total energy used to heat water for a given day divided by the gallons of cold water entering the hot water storage tank for the same day. For baseline analyses, there is no tempering valve because hot water used in the house is replenished by an equivalent volume of cold water entering the storage tank.

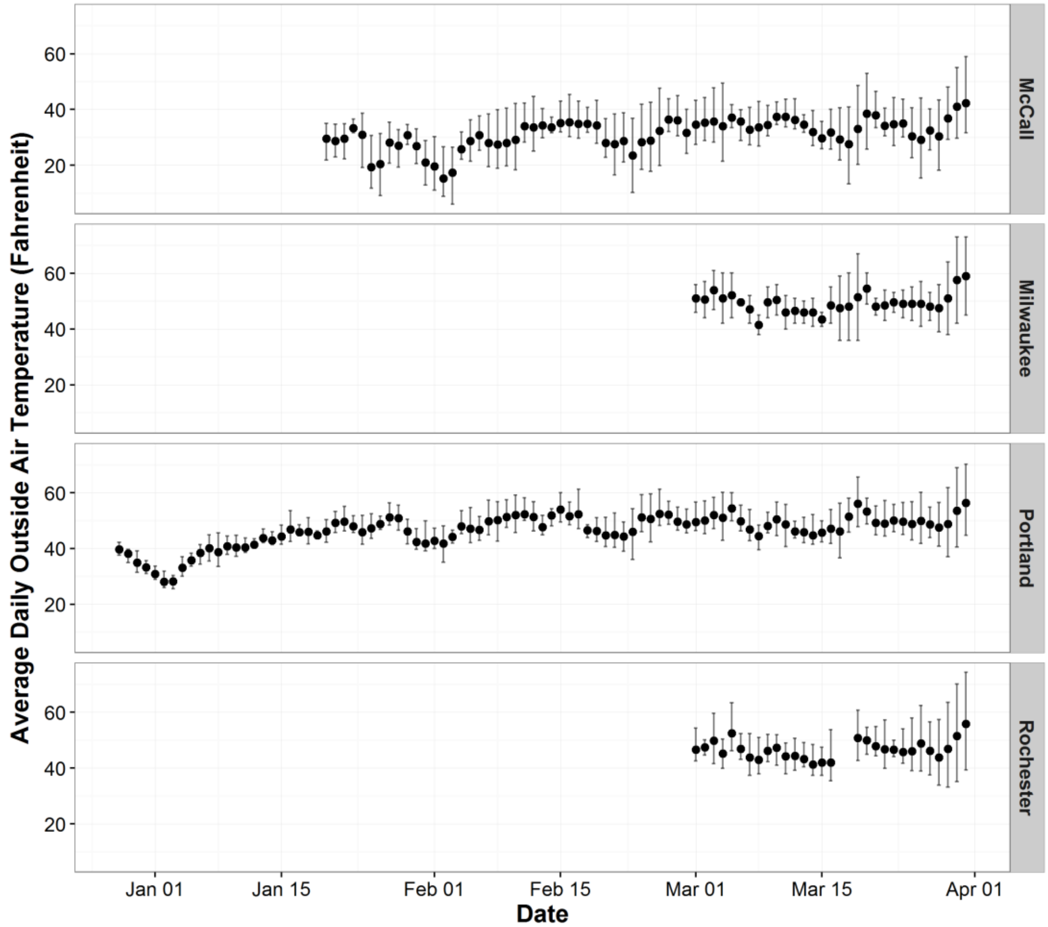
Results

Data summaries and calculations for baseline data collected at four sites from installation through March 31, 2016 are presented here.

Outside Air Temperature

Figure 5 shows the daily average temperature at the four sites through March 31, 2016. Each day has a bar – the dot is the average temperature for that day, and the bar extends to the daily extreme temperatures. Proxy weather from a National Oceanic and Atmospheric Administration (NOAA) weather station is used to summarize the Milwaukee site because reliable on-site weather measurements were not possible.

Figure 5. Daily Average Outside Air Temperature through March 31, 2016



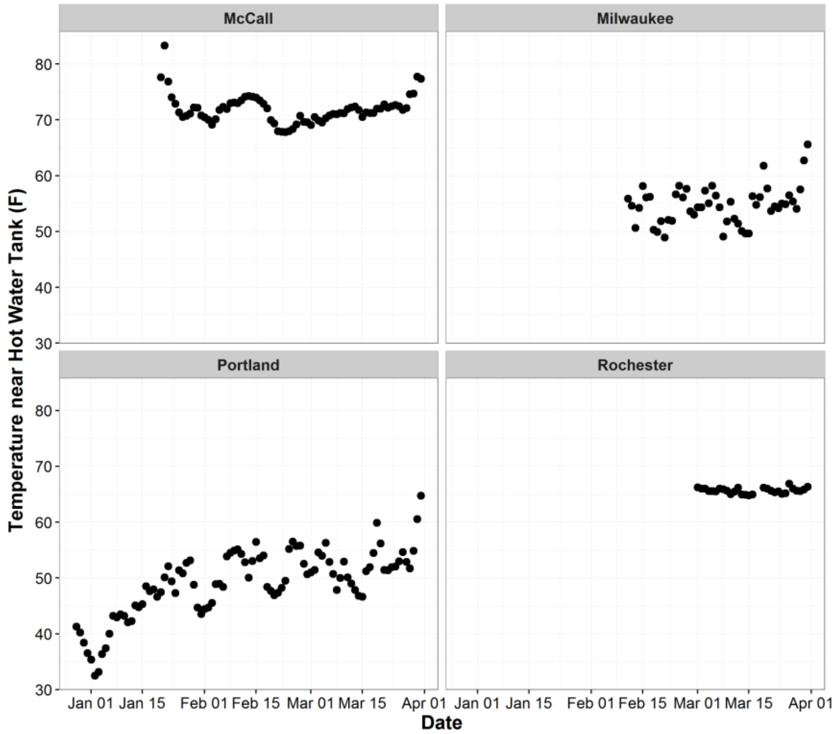
Mechanical Room Temperature

The space surrounding the tank impacts the heat loss rate from the tank and piping. **Figure 6** shows the indoor air temperature of the space where the tank resides. Tank room temperatures varied by site during the heating season. McCall's temperatures tended to be fairly stable (around 70°F), while Portland's temperatures dipped below 40°F, but were more generally between 55°F and 65°F. Much less of the heating season period was captured for Milwaukee and Rochester, but individual site differences are apparent there, with Rochester staying relatively stable (around 65°F) and Milwaukee (similar to Portland) showing day-to-day variability and an overall cooler temperature (less than 65°F).

The tank room temperatures are more stable in McCall and Rochester because the tanks are located in conditioned space. At the Portland site the tank is outside in an open car port, and at the Milwaukie site the tank is in an unconditioned garage.

This temperature data may not be collected during the next phase of monitoring due to the limited number of sensors. The temperature of the space being heated is more critical to the performance analysis than the tank room temperature. During the baseline study, interior air temperature is either logged at one-minute intervals by the main logger or at 15-minute intervals by independent loggers at some of the sites.

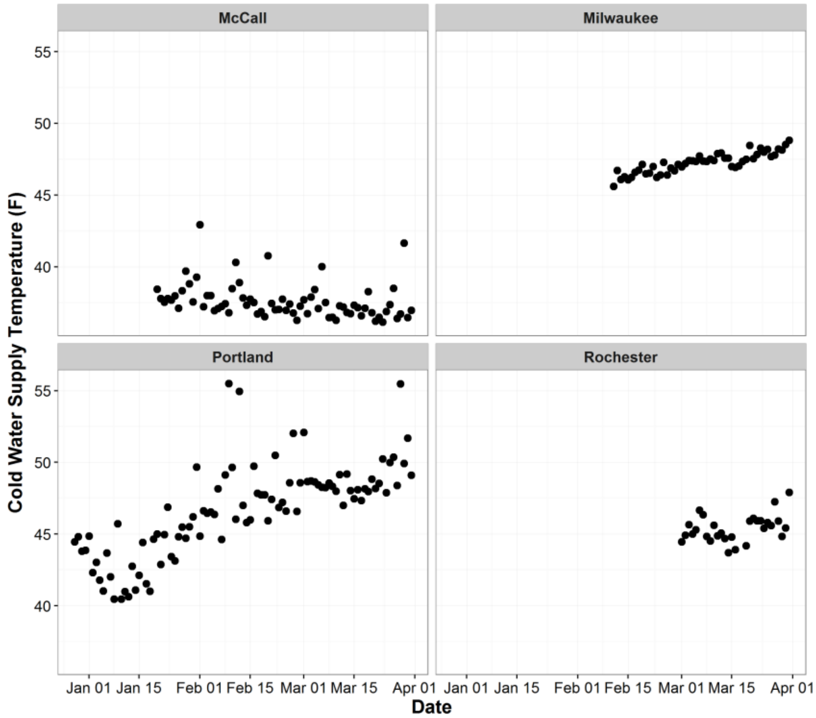
Figure 6. Temperature of Space Surrounding the Tank



Cold Water Supply Temperatures (from Flow Event Averages)

The plot in **Figure 7** shows the average cold water supply temperatures at each of the sites. Note how cold the incoming water is at the McCall site compared to the other sites.

Figure 7. Average Cold Water Supply Temperature

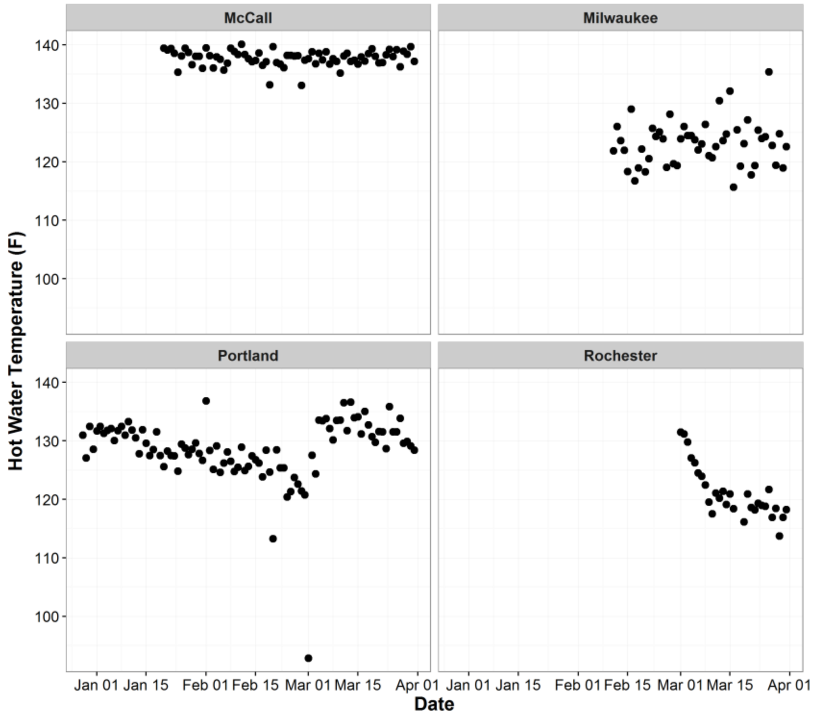


The measured water temperature can be impacted by the sensor cooling off or heating up. A cold water sensor heated by conduction or hot water sensor cooled by heat loss masks the true temperature of the flowing water. This effect is reduced in analysis by requiring a minimum of three consecutive readings for calculating average temperatures. Outliers caused by these factors may still be apparent in the temperatures used in the calculations, although the errors are lower than those that result from instantaneous temperatures.

Hot Water Supply Temperatures

Figure 8 shows the daily average hot water supply temperature. Note the broad range in temperatures. This is reflected in the energy use at each site. Portland's lowest hot water temperatures coincide with a failed gas valve that was discovered and repaired at the beginning of March. McCall has an overall fairly high set point. It appears Rochester decreased the set point as monitoring began in early March; however, that should be verified with the homeowner in case there is another explanation.

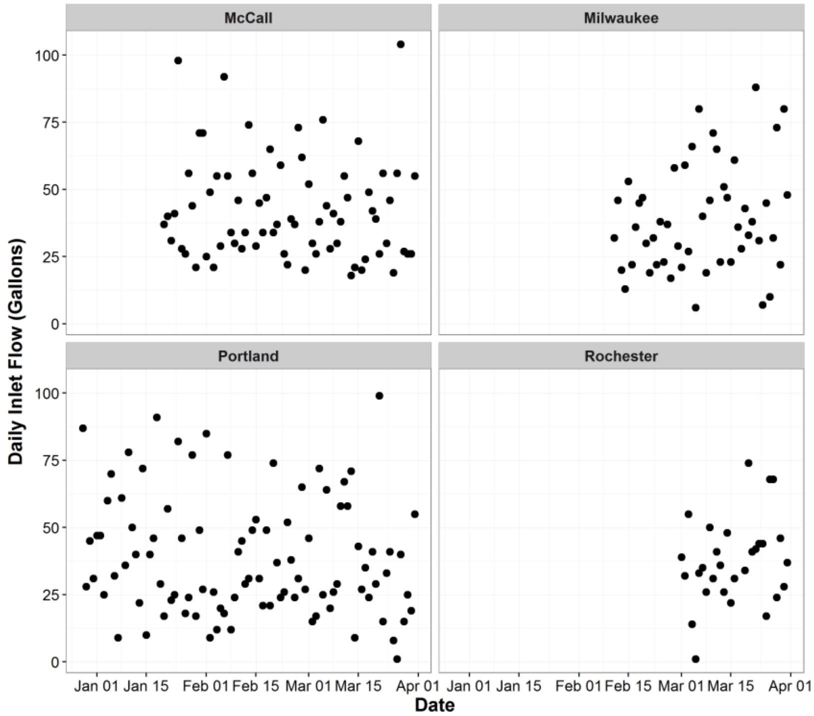
Figure 8. Average Daily Hot Water Supply Temperature



Household Water and Water Heater Energy Use

Without a tempering valve, the volume of hot water supplied to the occupants is exactly the same as the volume of cold supply water provided to the water heater. The graphs in **Figure 9** show average daily hot water use. For the winter/spring the sites included in this report have average daily use of 43, 39, 38, and 37 gallons per day (GPD) at McCall, Milwaukee, Portland, and Rochester, respectively.

Figure 9. Daily Hot Water Use



Water Heating Performance

Figure 10 shows the electrical energy used per day to heat water at each of the sites. The Portland site uses no electricity because it has a natural gas water heater. Note how constant the energy use is over time. This is particularly apparent at the McCall site. The Milwaukie site record of energy used for water heating was reduced due to an instrumentation issue. Although the sensor was checked onsite, it did not report data prior to March 12, 2016. This was discovered on March 8,2016 and the monitoring technician visited shortly therafter and corrected the issue.

Figure 10. Daily Energy for Water Heat

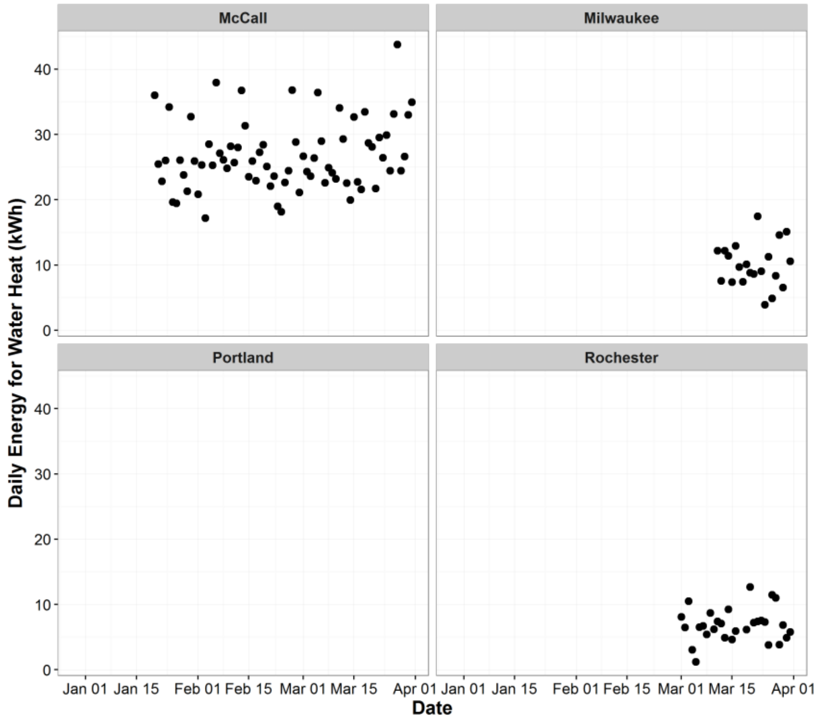
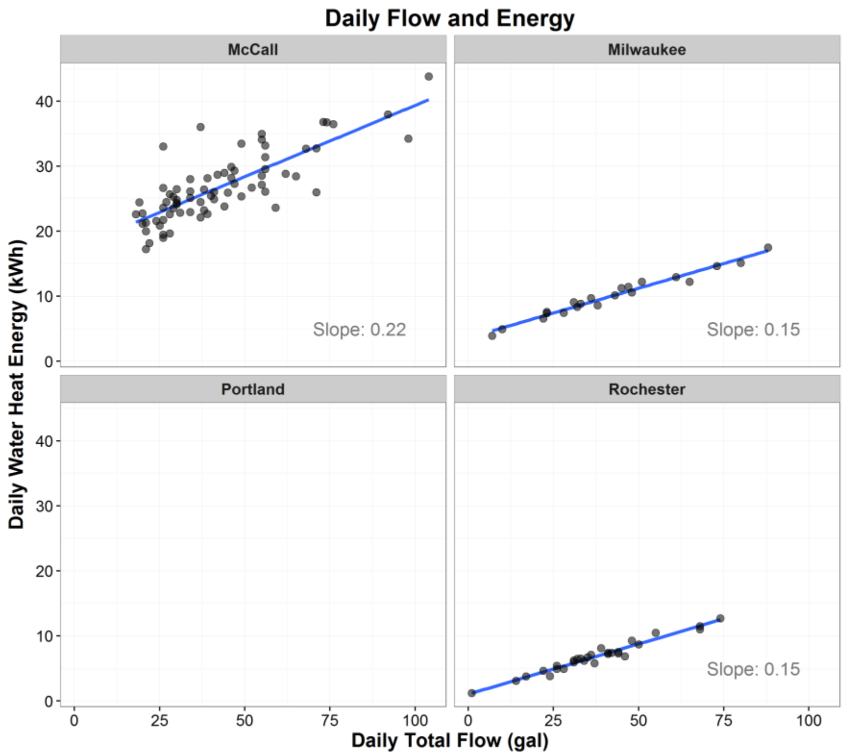


Figure 11 shows hot water volume and the energy used to heat it. The hot water used per day is on the X axis and the electrical energy (in kWh) used on that day to heat it is on the Y axis. A linear fit shows the relationship between kWh and gallons of hot water used. The slopes of the lines in **Figure 11** are actually kWh per gallon of water heated and include standby losses. There is no baseline data for the Portland site because it has a natural gas water heater for which daily data is not available. The slope of 0.22 for the McCall site is considered average for ER water heaters, but this is the only house with a system controlled by an occupancy sensor that circulates hot water for instant use when the kitchen is occupied. This site also had the coldest supply water and the highest hot water temperatures which also contribute to energy use.

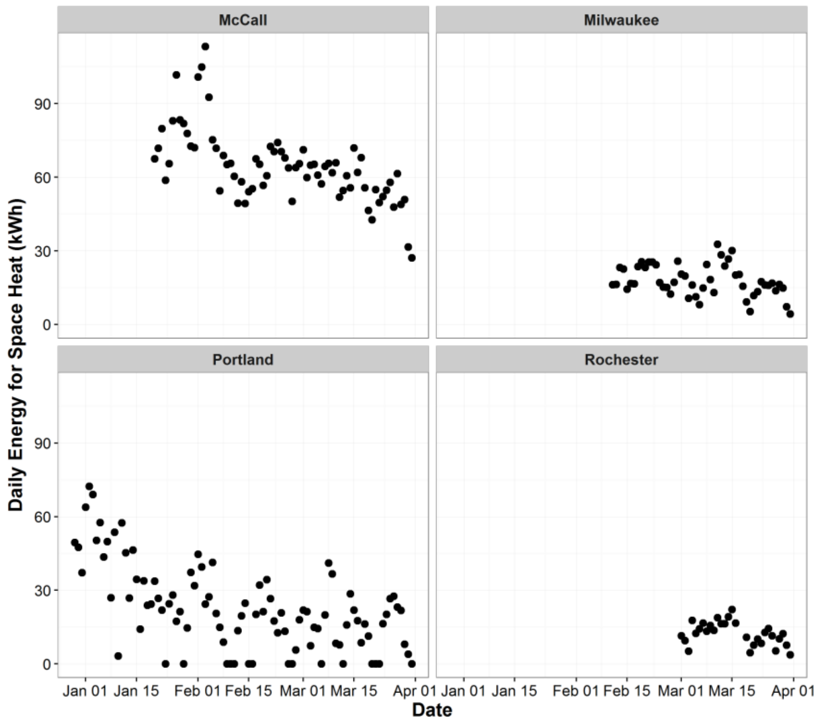
Figure 11. Water Flow through the Hot Water System and the Energy Used to Heat It



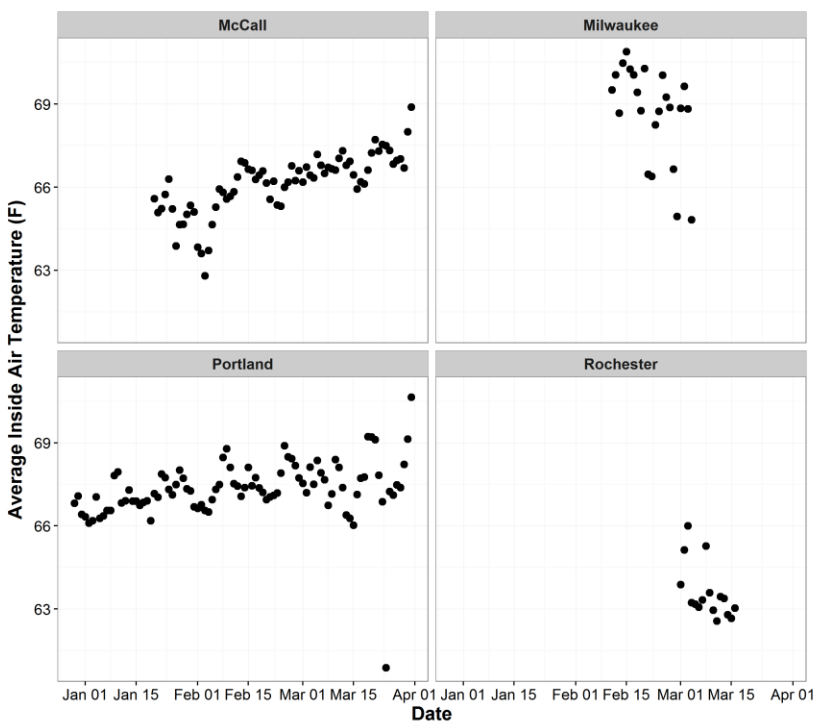
Space Heat

The space heat shown in **Figure 12** is provided by the baseline heating systems as presented in Table 2 and Table 3. At the Portland site, the ER heater was integrated into a heat recovery ventilator (HRV) and the energy used by the heater and the HRV is summed here. The ER heater at the McCall site was located in the floor of the master bedroom and bath; this home also has a propane furnace for the main part of the house, making it the highest energy user for space heat.

Figure 12. Daily Energy Use for Space Heat



Space heat is driven by inside and outside air temperatures. Figure 13 shows the average daily interior air temperature. The average household temp (for the purposes of the midterm) is the average of all the indoor temp sensors in the living Room and Bedrooms (if we have them).



Conclusions

People who volunteer to participate in emerging technology experiments may not be representative of average energy users—particularly in use of hot water. Of the small sample in this report, only one of the sites with electric water heat has energy use near the 0.20 kWh per gallon average for electric water heat.

The highest space heat use is unsurprisingly at the coldest site in McCall, Idaho, and the lowest is at the site with a DHP in Kelso, Washington. The Portland and Milwaukie sites are similar during the months when both were monitored. This appears to be a good sample for space heat impact assessment of the combined space and water heating technologies.

Regarding the overall project, the overarching cause of delay has been the delay in obtaining the combined space and water heating systems. Lack of equipment prevented PNNL from conducting the tests at the Lab Homes during late winter 2016. The test sites in McCall, Portland, and Milwaukie have all provided sufficient baseline data, but systems needed for testing are not yet available. Timely installation would have provided combined system performance data on the McCall and Portland sites for this report. This conclusion is not aimed at the manufacturers who have been making good faith efforts to deliver equipment for testing but have been delayed by prototype development and production issues.

Recommendations

The issues of obtaining good baseline data and what may be inevitable delay in testing equipment delivery indicate that the two-year time period may not be feasible for this type of project. A three-year project timeline is recommended for this type of research.

Monitoring these systems is complex, and monitoring accuracy, especially of flow measurement, is critical. The best approach is to have each system commissioned on site using ultrasonic flow meters, which is possible, but expensive. The alternative is to commission each system with a micro-weir handheld device, but this is only possible for flows that exit the system, such as domestic hot water. It is recommended that this be done on every system.The new logger by Onset—the RX3000—does not have an active local port to allow setup on site without access to the Onset website, or to download logger data if it has accumulated a large amount while being offline. This makes setup more difficult, and this project has suffered from setup errors that could have been avoided by local review onsite. It is recommended that Onset activate the local port for use with HOBOware® or that WSU actively look for an alternative logging system that provides a local setup and download option.

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Appendix A: Field Metering Plan

TIP 338 Combination Water/Space Heat in Existing Homes Field Study Metering Plan, rev. June 15, 2016.