Field Monitoring of Two New Manufactured Homes in the Pacific Northwest

Northwest
Energy
Works, Inc.

Prepared for:

U.S. DOE Building America Program
under PNNL Subcontract # 134996

September, 2011

Prepared by:

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Acronyms

BPA	Bonneville Power Administration
COP	Coefficient Of Performance
DHP	Ductless Heat Pump
DOE	U.S. Department of Energy
HDD	Heating degree day
HPF	Heating Performance Factor (defined within this report)
HPS	The Heat Pump Store
HVAC	Heating, Ventilating and Air Conditioning
NEEA	Northwest Energy Efficiency Alliance
NEEM	Northwest Energy Efficient Manufactured Home Program
NEW	Northwest Energy Works
NREL	National Renewable Energy Laboratory
PNNL	Pacific Northwest National Laboratory
RH	Relative Humidity

Acknowledgements

We want to thank BPA for loaning the monitoring equipment to the project. In addition to the DHP energy savings, this project demonstrated that a DHP could be installed and commissioned on a production line. We appreciate the cooperation and generous assistance from Homebuilders Northwest (HUD code manufacturer), the Heat Pump Store (DHP supplier and trainer), and Ideabox (home designer and retailer) that allowed us to prototype the hybrid DHP electric zonal heating system on a customer-sold home. We especially want to thank Dr. Chandra for his support in developing the project concept and his insights into pulling meaningful observations out of the data.

Executive Summary

In collaboration with Pacific Northwest National Labs (PNNL), Northwest Energy Works (NEW) examined the performance of a hybrid zonal electric heating system utilizing a ductless mini-split heat pump to a purely electric resistance zonal heating system in two new manufactured homes built to aggressive efficiency standards. The scope of this project was to recruit two manufactured home sites, install and commission in the factory one single head ductless heat pump, perform home energy audits at both sites, install meters, collect electric use, temperature and relative humidity data, analyze monitoring data and write a final report of findings.

The project team were: Homebuilders Northwest, PNNL, BPA, The Heat Pump Store, Ideabox, Ecotope, Northwest Energy Works and the Northwest Energy Efficient Manufactured-Home Program (NEEM). NEEM is administered by Northwest Energy Works as a third party that coordinates a manufacturers' consortium to maintain consistent energy efficiency specifications and quality management protocols.

Bonneville Power Administration loaned PNNL/NEW the sub metering equipment. NEW and the sub-metering contractor, Ecotope, installed the monitoring equipment in the two test homes in November 2010. The sub metering equipment measured electricity usage, RH and Temperatures, in these two homes for one heating season (November 2010 through May 2011). Both homes were built in 2010 by the same HUD code builder. Both sites are located in western Oregon, with the DHP home located in the Portland suburb of Milwaukie. The other home is located near the north coast of Oregon, in Cloverdale. The Portland, OR home was built with a factory installed DHP in the main living area and with zonal electric resistance heating in the secondary zones. The Cloverdale, OR home was built with only a zonal electric resistance heating system . Both homes use the same brand of zonal electric resistance heating units. The DHP installed at the Portland site was a 1.25 ton Mitsubishi Mr. Slim, model MUZ-GE15NA

The following items were measured:

- Whole house electricity usage (at house main panel)
- Electric resistance heating usage
- Ductless heat pump energy usage
- Domestic hot water energy usage
- Interior main zone temperature and RH

- Secondary zone (bedroom) temperatures and RH
- Outside temp and heat pump vapor line temp (to confirm heating or cooling operation)

Industry-standard data logging gear was used in the project. Data was stored in the loggers and manually downloaded. A whole house energy audit, including blower door test, was performed so that house heat loss could be characterized. The measurement protocol was aligned with ongoing work being conducted by the Northwest Energy Efficiency Alliance and Bonneville Power Administration.

Results

Monitoring Period: 4150 hrs., beginning 12/2/2010 at 2 PM. A shorter period of 29 days that corresponded with a period of persistent colder weather was chosen for performing heating system efficiency analysis, because the data became rather erratic at milder temperatures.

Portland Site: mean OAT=45.2 deg.F (std. dev.=8.44), mean Delta-T deg.F=20.4 (std. dev.=7.39), heating energy use (excluding misc. internal loads) = 1,784 kWh over the monitoring period.

Cloverdale Site: mean OAT=44.9 deg.F (std. dev.=7.00), mean Delta-T deg.F=23.4 (std. dev.=6.38), heating energy use (excluding misc. internal loads) = 7,104 kWh over the monitoring period.

The two sites were very similar in terms of envelope thermal efficiency and outdoor temperatures during the study period, and all heating system efficiency analysis utilized a correction factor to normalize the data for the differences between the homes' conductive heat loss (U*A) rates, effectively nulling the differences between the two homes.

The Portland (DHP) site whole house "Heating Performance Factor" = 2.3 to 2.6 times as efficient as the Cloverdale house, when outdoor temperatures ranged from the mid-twenties (deg. F) to the mid-forties (deg. F), including miscellaneous internal loads as heating. The apparent COP of the heating system = 3.2 to 3.7 when outdoor temperatures ranged from the mid-twenties (deg. F) to the mid-forties (deg. F), without accounting for miscellaneous internal loads.

The secondary zones of the Portland DHP site required only about 250 kWh of electric resistance heating over the entire monitoring period, compared with over 4,000 kWh for the corresponding zones at the Cloverdale site. The DHP clearly supplied a significant portion of the secondary zone heating, even in the coldest weather seen during the study.

The secondary zones of the Portland DHP site also remained at very close to the same temperature as the main zone of the house, tracking better than the Cloverdale electric resistance site. The participating homeowners reported no significant comfort or performance issues with their heating systems.

The DHP system may show promise as an electric demand management strategy for utilities. The cumulative space and water heating energy use data was sorted into 24 hourly bins to present the extent to which each heat source typically was used and when that use tended to occur during the day. The resulting graphs essentially show the heating season average load profiles for the homes. While the project's study size is too small to draw definite conclusions about actual usage or demand profile implications, the Portland DHP site's highest use-hour for space and water heating is about on par with the Cloverdale home's lowest use-hour, despite very similar home construction, occupancy schedules and overall use of the homes. The times of highest usage for both homes tended to occur during morning peak hours.

1 Introduction

Ductless heat pumps have been used in Asia and Europe since the 1970s and they comprise 80% to 90% of the residential HVAC market there. They have been used in U.S. commercial buildings since the 1980s, but they still comprise less than 3% of the U.S. residential market (Karr 2011). Ductless heat pumps are 25% to 50% more efficient than electric baseboard or wall heaters (NEEA 2010).

"The Pacific Northwest region has embarked on a long-term effort to study the impacts of small split system heat pumps that are designed to provide zone level heating and cooling. These systems are largely manufactured in East Asia and use inverter based compressor and air handler designs. They are designed to deliver conditioned air to a specific zone(s) without ducts. Fourteen initial pilot installations of these systems were carried out in Monmouth OR, Moses Lake, WA and Tacoma, WA in early 2008."(Geraghty, et al, 2009).

Residential Ductless Mini-split Heat Pump Retrofit Monitoring presented a first analysis of energy savings achieved by retrofitting ductless heat pumps (DHP) into fourteen zonal electric resistance-heated houses (Geraghty, et al, 2009). That study suggested an average savings of about 4400 kWh/year relative to pre-installation conditions. This two new manufactured home study is a follow-up to the regional Pacific Northwest research. PNNL is funding this study. The project team included Homebuilders Northwest, PNNL, BPA, The Heat Pump Store, Ideabox, Ecotope and Northwest Energy Works.

The regional Northwest Energy Efficient Manufactured Home Program (NEEM) includes all 10 regional manufacturers: one in Washington, five in Oregon, and four in Idaho. The industry, while it has developed an ever-increasing interdependence and a strong relationship with energy efficiency (in this market), has a direct need and a direct incentive to develop more responsive, cutting edge energy-efficiency and sustainable measures that could be used as part of its effort to regain market share. NEEM is consistently striving to develop more efficient manufactured housing.

NEEM is administered by Northwest Energy Works, who is a third party that coordinates a regional HUD code manufacturers' consortium to maintain consistent energy efficiency specifications and construction quality management protocols. The USDOE Building America program provides technical support to the NEEM program and the HUD code industry. BPA and regional utilities provide home buyer incentives for NEEM certified homes. NEEM program operation is industry-funded through certification fees.

Prior to the DHP installation, The Heat Pump Store (HPS), the Oregon Manufactured Home Assoc. and NEW sponsored well-attended informational sessions at the HPS facilities in Monmouth, OR. The owner of Ideabox, a factory-built home designer and retailer, introduced NEW staff to their new homebuyers and encouraged them to participate in this monitoring project. NEW staff attained the cooperation of the homebuyers and their manufactured home builder, who agreed to install a DHP in the factory. NEW and The Heat Pump Store staff sized the DHP and the electric resistance secondary system using Manual J. The Heat Pump Store staff selected the correct DHP unit, supplied the DHP to the factory and performed critical factory installation training. Without the Heat Pump Store's involvement, this project would have not happened as smoothly and effectively as it did. Without help from the owners of Ideabox, who designed and sold the homes, it would have been very difficult for NEW have been able to orchestrate getting a home buyer to select a DHP/zonal electric heat hybrid system and convince the factory to build it. The purchasing, installation, and commissioning process developed for this project could be duplicated in other NW HUD code plants. The Heat Pump Store and NEW are now ready to train other plants to integrate DHP system installation into their homes.

One DHP manufacturer contact interviewed by NEEA noted that manufactured homes are typically single-story, have an open floor plan, and are a perfect fit for ductless multi-zone systems. However, two manufacturer homebuilders cited Housing and Urban Development (HUD) regulations as a barrier to proliferation of DHPs in new manufactured housing. According to the HUD code builder, "HUD requires that a source of heat be installed in new manufactured housing prior to shipment and you cannot install a ductless system and have it travel very well" (pg. 19, NEEA 2010)

This project illustrates that a DHP can be installed at the factory and travel satisfactorily when installed on a bracket attached to the home and adequately tied down for shipping. The entire DHP was installed and commissioned in the factory and traveled to the site as a completed system, only requiring removal of shipping tie downs before activating the DHP. The outdoor unit did not transmit audible sound or vibration inside the home, even when the unit ramped up to satisfy the initial call for cooling in the home. The DHP unit installed in the factory was a Mitsubishi Mr. Slim Model number MS7GE15NA (indoor) and MUZ-GE15NA (outdoor). Figure 1 shows the indoor unit mounting bracket installed in the plant early in the construction process to ensure that all subsequent construction processes will take into account the later addition of the DHP equipment to the home, and figure 2 shows the successful function check of the DHP at the factory.

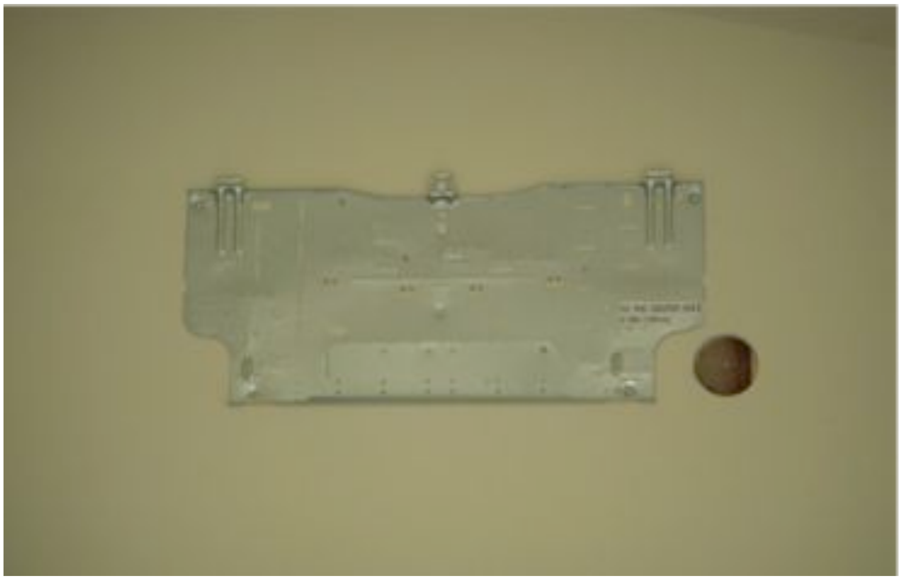


Figure 1. Factory DHP install

Figure 2. Function test of successful factory install

1.1 Project Outline, Goals and Objectives

A. **Protocol.** In collaboration with Dr. Chandra of PNNL, NEW developed a test plan to monitor and evaluate a single DHP home and an all zonal electrically heated home. The protocols include a data collection form, a list of monitoring equipment needed for the project and a detailed implementation field data collection form (appendix A). The data collection form also contains homeowner participation acknowledgement and utility billing data release authorizations, homeowner survey, step-by-step house characterization and audit, and metering equipment setup information.

B. **Identify builder.** With the help of the Ideabox owners, NEW recruited a HUD code builder in Salem, OR who agreed to allow the project team to work with them to design and install a hybrid DHP zonal electric heating system in a new factory built, Energy Star HUD code home. The builder already had some experience installing zonal electric resistance heating systems in a few of their homes. Typically HUD code home are equipped with electric forced air furnaces connected to ductwork located in the floor cavity. HPS trained the factory staff on how locate the indoor and outdoor DHP units on an outside wall during wall framing, so that factory workers could install blocking and run electrical service to the DHP. The step-by-step training of factory personnel and installation of the DHP took a total of five hours (HPS was the trainer). HPS evacuated and charge the DHP system. Ultimately the HUD code builder will have to figure out how to get the DHP system charged. Following the installation, the DHP was energized and allowed to operate for an hour for function testing and to familiarize the HUD code builder's staff on DHP unit operation and how to educate their homebuyers.

C. **Homeowner Recruitment.** Working through the manufacturer and designer/retailer, NEW contacted the homeowners of two homes of similar size and design that met desired criteria (climate zone, home size and floor plan, heating system characteristics). The homeowners agreed to participate in the monitoring project. Homeowners were paid a $100 incentive to participate.

D. **Leverage Other Efforts.** The project team was able to build upon existing work being performed by BPA and NEEA by using a DHP monitoring protocol that would provide data compatibility with the other monitoring projects in the Northwest. As part of their proposal to PNNL, NEW and Ecotope customized the existing protocols in their selection of metering equipment for this project. NEW then gave the equipment list to BPA for purchase of monitoring equipment. BPA loaned the equipment to the project.

E. **Fieldwork.** NEW scheduled a date with homeowners for installation of the monitoring equipment. NEW also performed house characterization audits. Ecotope conducted return visits to both sites to confirm that data is being collected properly.

F. **Closeout Monitoring.** NEW and Ecotope scheduled and conducted final visit to remove equipment and perform a homeowner exit survey

G. **Data Analysis.** NEW Organized and cross-checked data to ensure dataset validity and performed primary analysis to develop curve for each home's kWh per square foot per average daily delta-T. NEW also compared the main zone temperature and temperature swings of each home's secondary zones.

2 Methodology for Monitoring a DHP

This DHP monitoring project was originally intended to monitor two similar homes, both equipped with a DHP to serve the main zone and electric resistance wall heaters in the secondary zones. NEW proposed to PNNL a modification of the original research plan to instead monitor one DHP home with zonal electric resistance backup heat and one similar-sized home, located in a similar climate, built in the same factory but having zonal electric resistance heat only - no DHP. Given the extremely small sample size for this project (two homes), the research team believed that obtaining the daily heating kWh versus daily average delta-T indoors to outdoors multiplied by the conductive heat loss rate for each home might allow the project to see the contribution of the DHP in terms of an overall reduction of heating energy required. The decision was made to change the research plan to included one home with a DHP and one without a DHP. This project also seeks to examine uniformity of temperature between zones in the homes. Monitoring one home without a DHP allowed the research team to explore the extent to which the DHP is able to condition secondary zones of the homes and how that influences electric resistance heating usage in those zones.

2.1 Equipment Selection

In order to align this DHP testing with the much larger NW regional DHP testing projects being conducted by BPA and NEEA, NEW hired Ecotope as a subcontractor to help install the monitoring equipment. Ecotope has the NW regional contract to sub-meter DHP homes for Bonneville Power and the Northwest Energy Efficiency Alliance. Thanks to the loan of monitoring equipment from BPA NEW was able to use the same sub-metering equipment and protocols that are being used in the NW DHP project so the analysis can be compared to the larger regional database.

Table 1. Detailed list of metering equipment.

Quantity Used	Manufacturer/Device
4	Dent Instruments Elite PRO 4 channel datalogger, line powered, extended memory (512 kB)
2	Onset Computer Corporation U23-004 outdoor rated temp sensor module (gets outdoor temperature and also ductless heat pump vapor line temperature to determine operating status (heating or cooling))
6	Onset Computer Corporation wireless temp sensor (U12-011) (Temperature and relative humidity in main zone plus 2 bedrooms)
8	Magnelab 100 amp current transformer (CT) (SCT-0750-100)
8	Magnelab 50 amp CTs (SCT-0750-050)

3 Monitoring Parameters

3.1 Items monitored

A. Whole house electricity use, 1 hr. intervals

B. DHP electricity use, 1 hr. intervals (Portland site)

C. Electric resistance heat use, by zone, 1 hr. intervals

  i. Master bedroom

  ii. Guest bedroom

        iii. Master bath fan/light/heater, also with max amp draw and time
        iv. Guest bath fan/light/heater, also with max amp draw and time
        v. Living room (Cloverdale site)

D. Hot water electricity use, 1 hr. intervals, plus max. amps and time of maximum amp draw. This was to help create better correlation between hot water draws and potential relative humidity changes in the various zones. The water heating systems at both sites are tankless electric units, so the current draw corresponds to the time and intensity of hot water use.

E. Outdoor load connected to house exterior outlet, 1 hr. intervals (RV at Portland site)

F. DHP vapor line temp (to determine heating or cooling operation), 15 min. intervals, ave. temp. (Portland site)

G. Outdoor temperature & relative humidity, 15 min. intervals, ave. values

H. Indoor zone temperatures & RH, 15 min. intervals, ave. values

    i. Master bedroom
    ii. Guest bedroom
    iii. Main living area

4 Homeowner recruitment

NEW worked closely with home manufacturers and retailers to identify likely candidates to participate in the project. Working closely with the home designer and retailer, Ideabox, NEW recruited two homeowners, reviewed their home designs and interviewed the homeowners to confirm their homes' suitability for the project. Both sites had the homes installed during 2010 and are occupied full time by two retired adults. The Portland site has a DHP installed with zonal electric resistance heating in secondary zones, and the Cloverdale site has zonal electric resistance heating throughout, without a DHP. The homeowners agreed to allow monitoring in their homes, and were offered a small incentive for their participation.

Figure 3. Portland site view

The Portland site, shown in figure 3, is a 1,002-sq.ft. home with a photo studio in an outbuilding on the same revenue meter. Care was taken to separate the studio from the rest of the home electrical circuits. The Cloverdale site, shown in figure 4, is a 805 sq. ft., house that also has an outbuilding that includes home office space. At the Cloverdale site, the out building also was separated and not metered. The homeowners at both sites reported that they did not utilize any heating setback in the homes during periods when they were absent from the homes and spending time in the outbuildings.

Figure 4. Cloverdale site

5 Equipment Deployment

The project team made use of local electricians to perform work inside the wiring panels. The data logging computers were mounted inside the panels to minimize the extent to which the equipment intruded into the home, and it also reduced the odds of anything happening to disrupt the equipment. Figure 5 shows a service panel with the data logging computers installed.

Figure 5. Data loggers inside main panel

The project team thoroughly surveyed each test home to be certain that virtually all loads connected to the home interior were being captured either directly or as part of the house main service-metering channel. The team looked for circuits connected to exterior loads, so as to either re-locate the load to a circuit not running through the house panel or to dedicate a metering channel to that load. The project team found that the Portland site had an RV with a space heater plugged into an exterior outlet on the house, so the team added a new monitoring channel for that load during the follow up visit to the site to confirm proper operation of the data loggers. The RV load then could be subtracted from the house main load for all assessments of interior loads. The Cloverdale site had no apparent exterior loads at the time the home was instrumented, but the homeowner placed a space heater, powered from an outlet on the house, into a garden greenhouse during the last two months of the study. The periods prior to installation of the RV monitoring channel and after the addition of the greenhouse heater were discarded for the purposes of determining overall heating system efficiency.

The field protocol included a complete energy audit of both homes. Table 2 presents the audit results. The Cloverdale home has about 4 percent higher U*A conductive heat loss than the Portland home, something the data analysis takes into account. Blower door tests were conducted, but the results were not used in this analysis.

Figure 6. Installing sensors on the Portland site DHP

Table 2. Home Thermal Characteristics

Item	Portland Site	Cloverdale Site
Ceiling	R-38 full width batts in cathedral straight truss roof	R-38 full width batts in cathedral straight truss roof
Walls	R-21 batts in 2 x 6 intermediate framing	R-21 batts in 2 x 6 intermediate framing
Floor	R-33 batts/blankets	R-33 batts/blankets
Windows	U-0.28 vinyl double pane low-e with Argon fill	U-0.28 vinyl double pane low-e with Argon fill
Conditioned Floor Area	1,002 sq. ft.	805 sq. ft.
Home U * A, Btu/hr-deg. F	274.8	286.1
Site Delta-T Multiplier **(To account for differences in U*A)**	1.0	1.041
Blower Door, CFM at 25 Pa	520	345
Blower Door, CFM at 50 Pa	816	510
Home ACH at 50 Pa	5.4 (Bath window found open after test)	3.66

6 Data Analysis and Documentation

6.1 Assuring Quality Data

As already stated in section 5, above, the first two weeks of data collected at the Portland site lacked a channel for tracking the RV plugged into a house circuit. There was also one current transformer with a poor connection at this site, which caused unreliable readings, that was repaired when the RV channel was added. The initial two-week period was discarded from both sites to maintain comparable monitoring periods. As also stated above, the greenhouse space heater was not separately logged, so the data from March 20 through May 24 also was discarded for the purpose of assessing heating system efficiency.

The channels logging the bathroom heater/light/fan units showed different current draw rates depending upon the mode of operation, but there appear to have been numerous false triggers where the heater switch may have been momentarily thrown as the user sought to activate the fan and/or light. Since the kWh used by the bath lighting and fan is very small, we chose to log all energy use on these channels as heating.

Temperature and RH Sensors were located in each bedroom and the main living area. See figure 7 for an example of how the loggers were deployed. Average temperature and RH were recorded on 15-minute intervals, which allowed us to see events like showering. RH quickly returned to normal. There were no likely condensation events and no big swings in humidity. Therefore we didn't analyze the RH data. We collapsed the temperature data into 1-hour intervals to match the power data files.


Figure 7. Portland site living area temp and RH logger. Closeup in inset.

During periods when the daytime temperatures rose above the heating balance point for the Portland site, the DHP may have gone into brief periods of cooling. Unfortunately, the 15-minute average temperature data for the DHP vapor line did not provide adequate resolution for the project team to confidently identify cooling events. As a result, DHP heating performance during mild weather could not be assessed reliably.

The same problem occurred when it came to looking for defrost cycles. Periods of minimal DHP operation during prime defrost conditions appear to yield an average vapor line temperature close to ambient outdoor temperature, which could well be the same result as when a defrost cycle is followed by a call for heating. The project might have had better success seeing the DHP operating states by instead capturing maximum and minimum temperatures for each time interval.

Fortunately, the discarded data at the beginning and toward the end of the monitoring period also corresponded to periods of rather mild weather, so its loss was not too great. Western Oregon experienced its longest period of sustained colder weather (during the monitoring period) beginning around December 14, 2010 and lasting through January 11, 2011. At the advice of Dr. Chandra, the team focused its data analysis efforts to ascertain heating system efficiency on this time period. Figures 8 & 9 show that daily average delta-T inside to outside at both sites remained above 20 deg. F for the entire period. Figures 8 & 9 also show the relative contributions from the various heating system components, miscellaneous interior loads and the total daily energy use inside the homes.

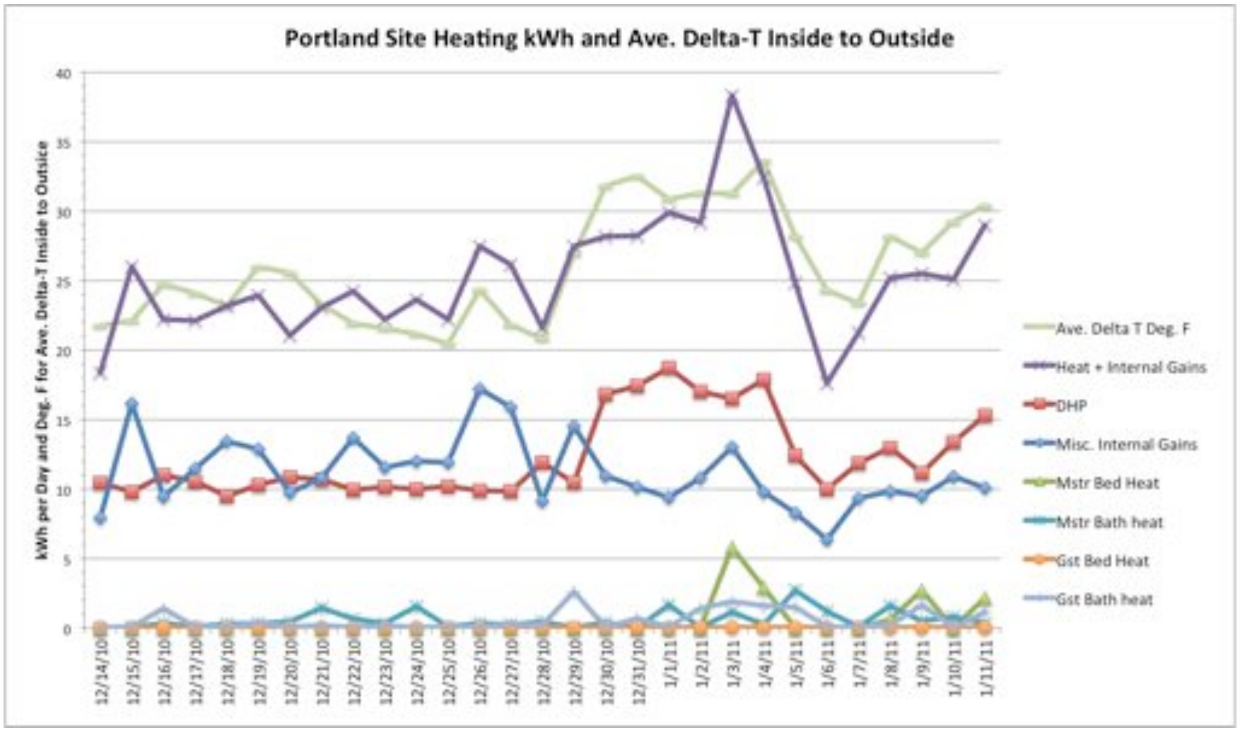


Figure 8. Portland site, all internal loads (kWh) and ave. delta-T to outside

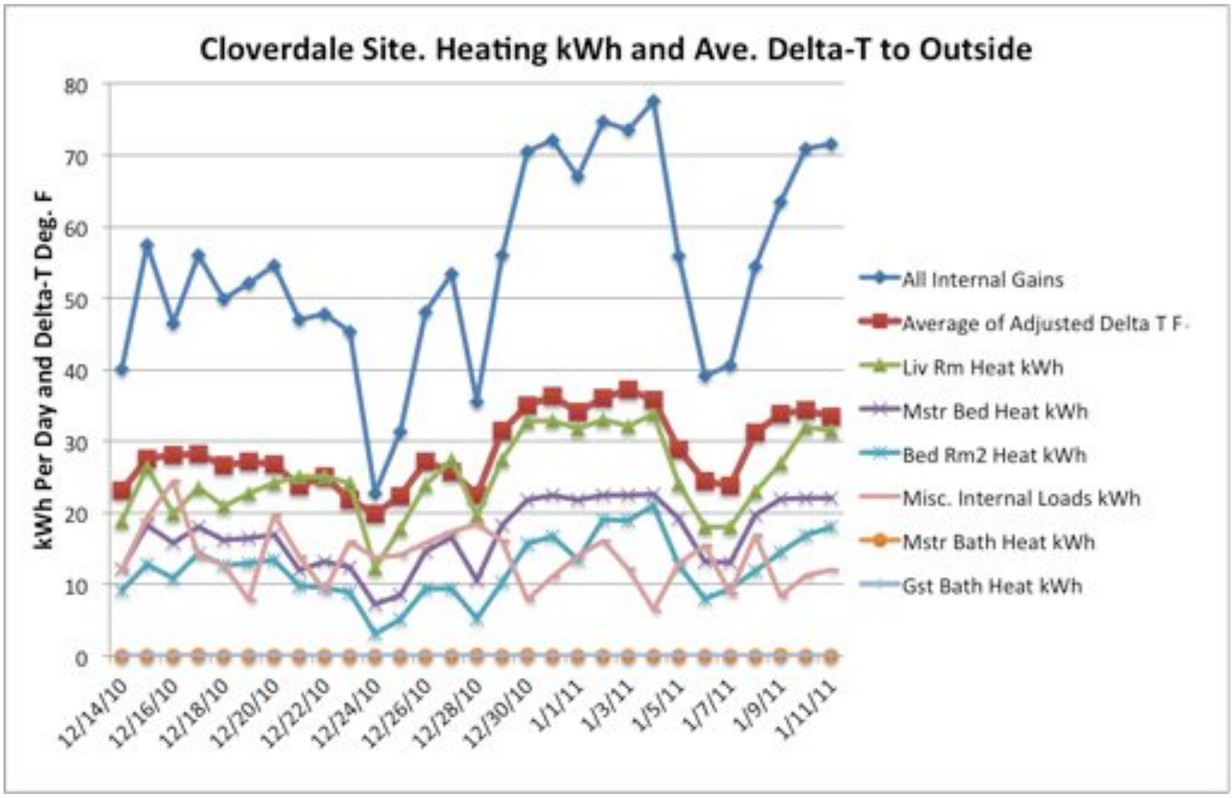


Figure 9. Cloverdale site, all internal loads (kWh) and ave. delta-T to outside

6.2 Normalizing the Data

Table 2 shows the U*A values for both sites, with the U*A for the Cloverdale site being approximately 4 percent higher than the Portland site. This means that for every degree of temperature difference between the inside (heating balance point) temperature and the outside temperature, the Cloverdale site would be expected to use about 4 percent more energy to maintain that temperature difference. Since the project is seeking to determine the daily heating kWh vs. delta-T inside to outside deg. F, we can normalize for the site U*A differences by multiplying the Cloverdale delta-T values by an adjustment factor as follows:

Adjustment factor = Cloverdale U*A / Portland U*A = 1.041

Figures 9, 11 & 14, which depict energy use for the Cloverdale site, incorporate this adjustment factor.

6.3 Appropriate Measures of Home Heating Efficiency

During the heating season, miscellaneous loads in a house, like lighting, cooking and appliances contribute heat to the home, which offsets energy that otherwise would be used by the heating system to condition the space. The size of these loads can vary considerably from one home to the next. In a larger study, such miscellaneous loads might be disregarded and not considered as part of the heating system (as it takes some effort to account for all house loads and all fuels that might be contributing heat to the house), allowing the variances to average out over the population. This project's very small study size does not permit such averaging, and one home with a large miscellaneous interior loads easily could skew the findings. For this analysis, domestic hot water is not considered an internal load.

6.3.1 "Heating Performance Factor"

The project team created a measure of efficiency, the "Heating Performance Factor (HPF)," which is much like the COP commonly used to state heat pump efficiency, except that the HPF is measuring the overall efficiency of one home relative to another "baseline" home. To calculate the HPF, the daily kWh usage measured by all of the heating circuits was added to the daily kWh usage by all other indoor circuits and plotted against the average delta-T between inside and outside. Figures 10 & 11 show this plot for the cold period of the study. Then, we used linear regression to obtain an equation that can be used to describe the relationship between daily total heating energy (called internal loads in Figures 10, 11 and 12) and delta-T. When we divide the heating energy predicted by the equation for the Cloverdale (baseline) site by that predicted for the Portland (DHP) site over a range of delta-T values, we get a curve that represents the Portland site's HPF, as can be seen in Figure 12.

For the range of delta-T values seen during the cold period we analyzed, the Portland site HPF ranged from heating over 2.3 times as efficiently as the Cloverdale site at a delta-T of 20 degrees (mid- to upper-forties outdoors) to being over 2.6 times as efficient as the delta-T increased to 40 degrees (mid- to upper twenties outdoors).

The apparent increase in heating efficiency at the Portland site as outdoor temperature decreases is opposite from what one would expect of heat pump performance. To a large degree it is the decreasing portion of heating load that is being met by the miscellaneous interior loads as delta-T increases that allows the DHP to carry an increasing portion of the heating load, showing increasing efficiencies as that happens. Had the sites experienced weather sufficiently cold that the DHP capacity was significantly reduced, we would expect the Portland site HPF to again begin dropping toward 1.0 as the electric resistance heating would be required to supply a greater share of the heating load. Monitoring in a colder region would be needed to test this hypothesis.

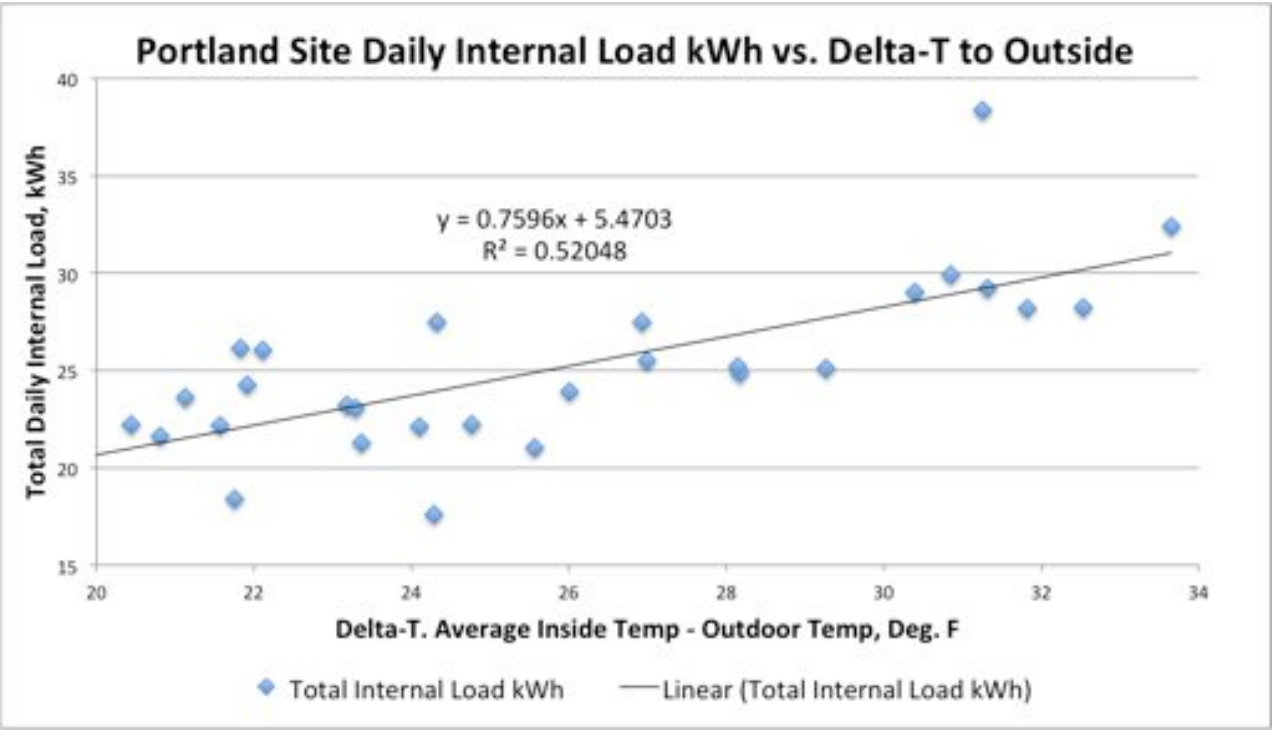


Figure 10. Portland site, daily kWh (heating plus interior loads) vs. delta-T to outside

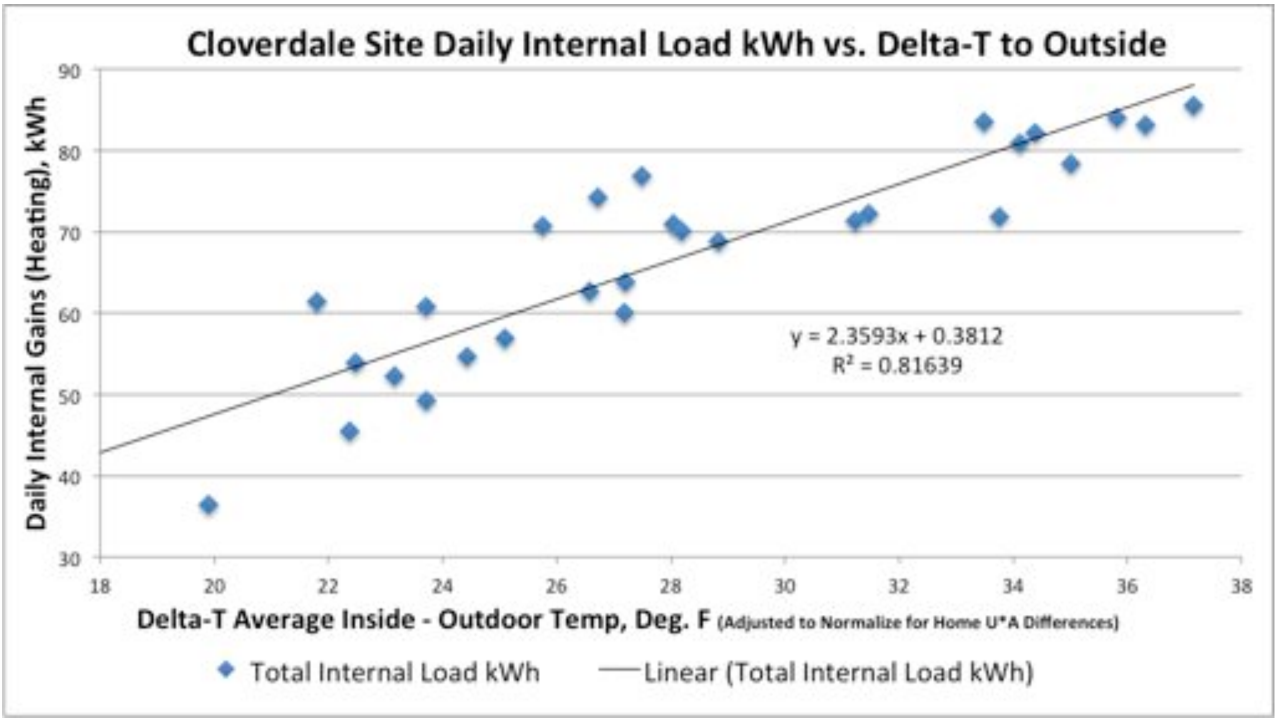


Figure 11. Cloverdale Site, daily kWh (heating plus interior loads) vs. delta-T to outside

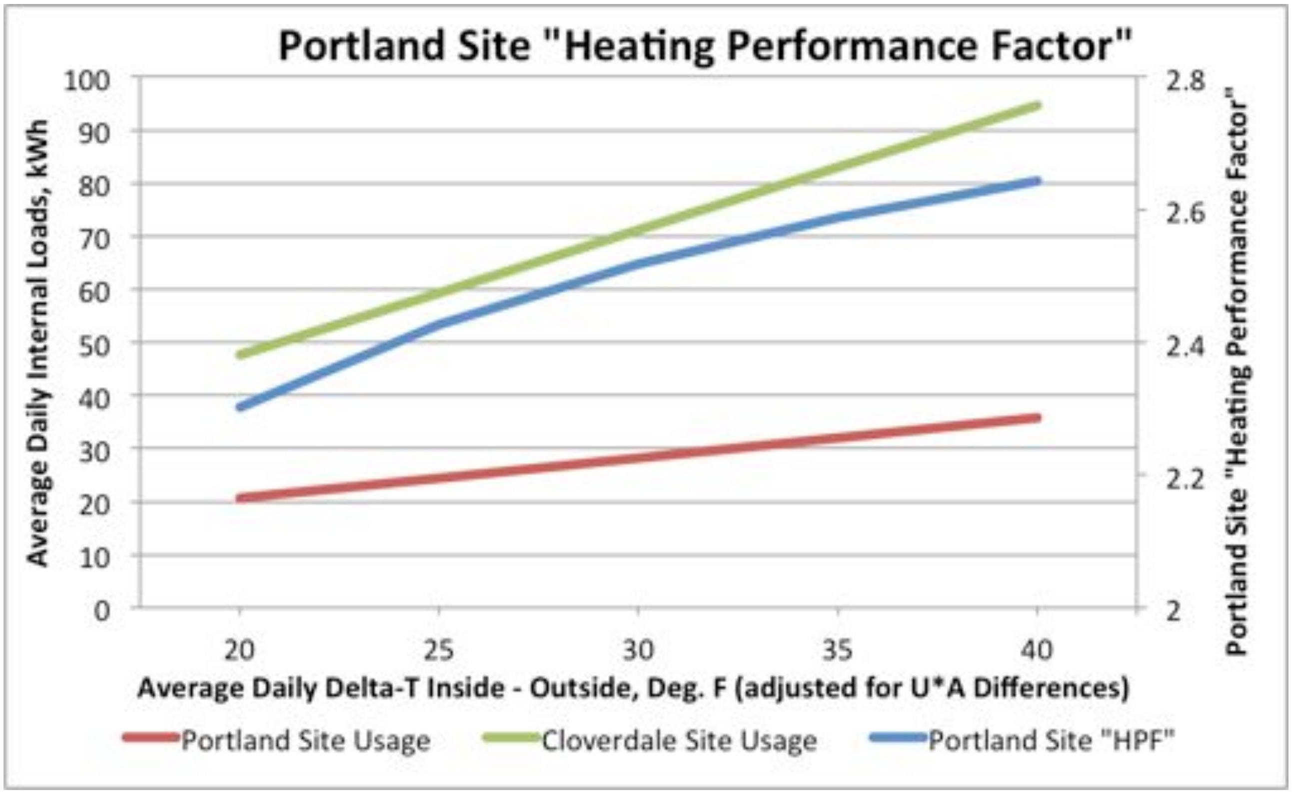


Figure 12. Portland site "heating performance factor"

6.3.2 "Apparent COP"

This report also presents the "apparent COP" of the Portland DHP site's heating system relative to the Cloverdale site's electric resistance heating system. If we consider the Cloverdale site as our reference, with its zonal electric resistance heating system (located entirely in conditioned space) having a theoretical COP of 1, then the heating system energy used by the Cloverdale site divided by the heating system energy used by the Portland (DHP) site yields an apparent COP for the Portland site's hybrid DHP/electric resistance heating system. This measure does not take into account the contribution from the non-heating system loads inside the homes.

To calculate the Portland site's "apparent COP" we again measured each site's daily kWh usage by all of the heating circuits and plotted it against the daily average delta-T between inside and outside. Figures 13 & 14 show this plot for the cold period of the study. Then, we used linear regression to obtain an equation that can be used to describe the relationship between daily heating usage and delta-T. When we divide the heating energy predicted by the equation for the Cloverdale (baseline) site by that predicted for the Portland (DHP) site over a range of delta-T values, we get a curve that represents the Portland site's "apparent COP", as can be seen in Figure 15.

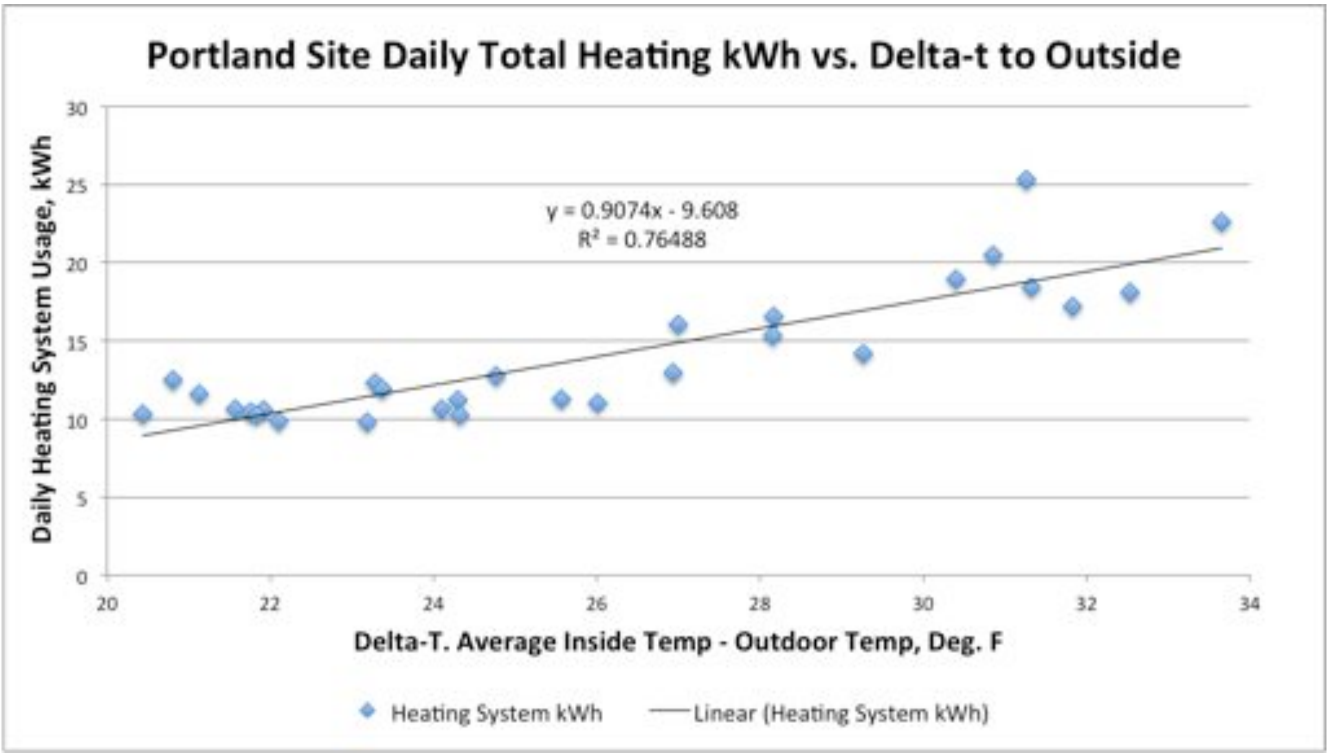


Figure 13. Portland site heating kWh vs. delta-T to outside

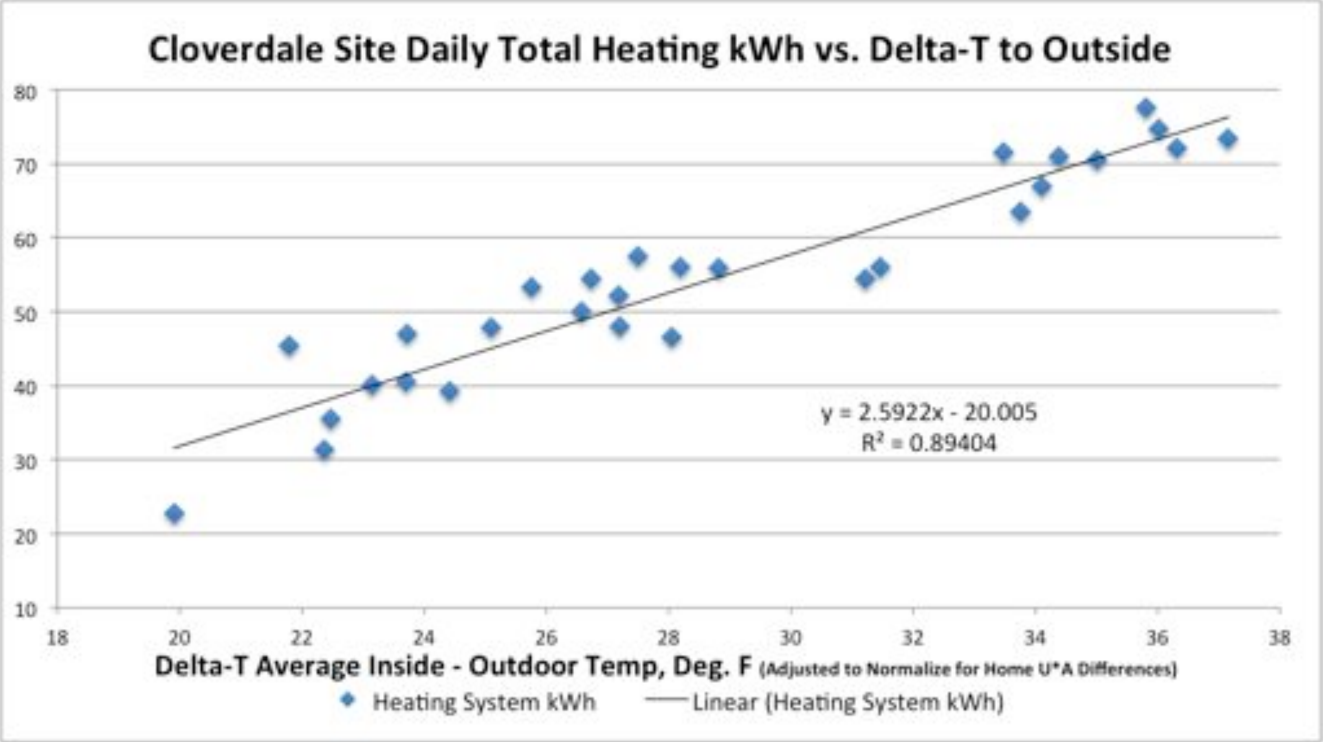


Figure 14. Cloverdale site heating kWh vs. delta-T to outside

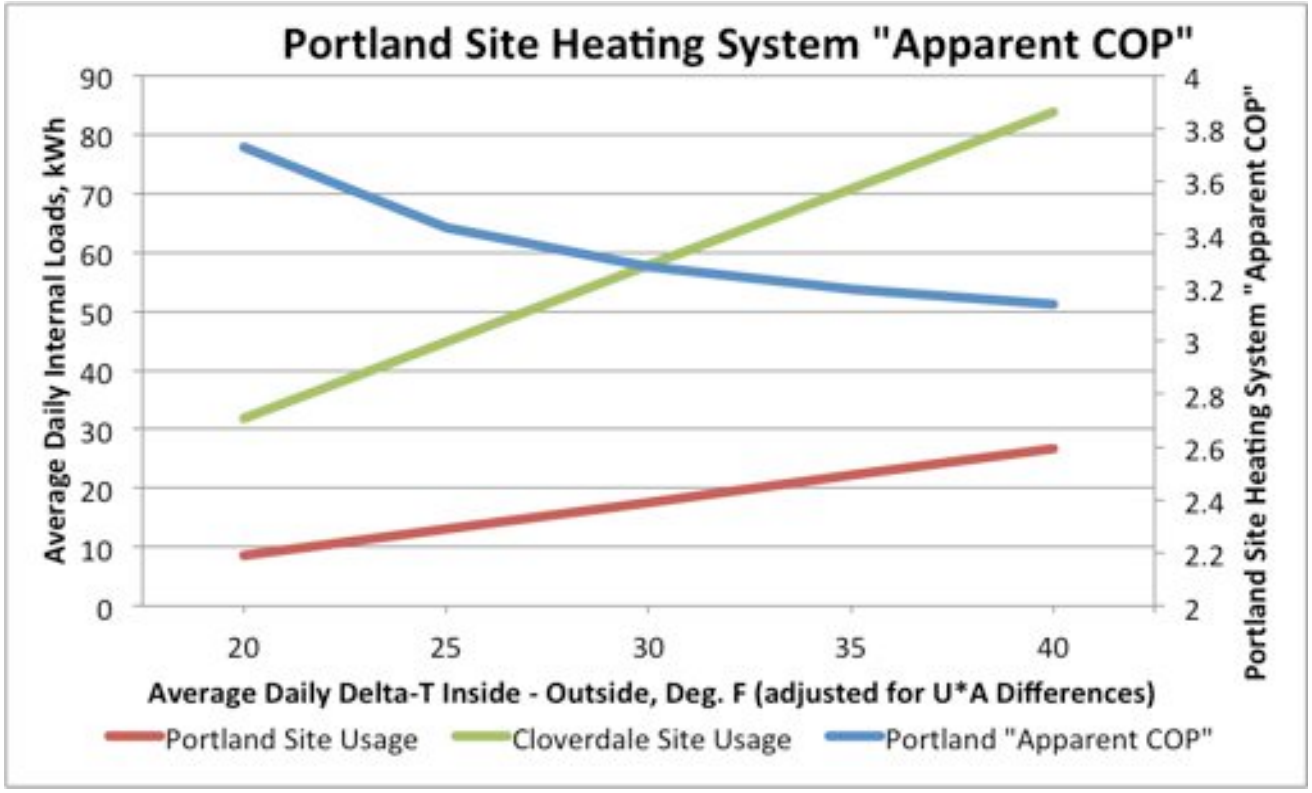


Figure 15. Portland site "apparent COP"

6.4 Secondary Zone Heating

The project team was unable to locate much information about how much a DHP could be counted upon to supply conditioning to secondary zones in a home. The heat pump monitoring projects underway in the northwest were not looking closely at exactly how closely the temperatures in other rooms in the homes were tracking the temperatures in the DHP zone. From the data available at the time this project's research plan was being drawn up, one could not tell if part of the energy savings being realized with DHP installations was due to homeowner behavior changes (not turning on bedroom electric resistance heating) or whether the DHP was able to supply conditioning beyond the zone where it was located.

When the project team presented the hybrid DHP/electric resistance heating system to the home manufacturers, their first questions were about how well the DHP could be expected to condition the secondary zones, or whether multiple indoor heads would be required. Once the project team found a manufacturer willing to try out the proposed hybrid heating system, NEW and the HPS developed heater sizing requirements based on ACCA Manual J. Heaters were called out for each zone of the house and sized to provide adequate heat for the zone at design conditions (17 deg. F for these homes). The DHP rated capacity at design conditions was 13,600 Btu/hr, and the main living area of the Portland house was estimated to require just under 7,900 Btu/hr, leaving about 5,700 Btu of surplus DHP capacity. The Portland house's total design load was estimated to be just under 14,600 Btu/hr, so if the DHP proved able to condition the secondary zones of the house, it should have adequate capacity to do so under most conditions.

Figures 16 and 17 show the hourly average temperatures in each of the monitored zones and the outdoor temperature. One can see from the plots that the bedroom temperatures at the Portland DHP site remain closer to the main zone temperature than do the bedrooms at the Cloverdale site.

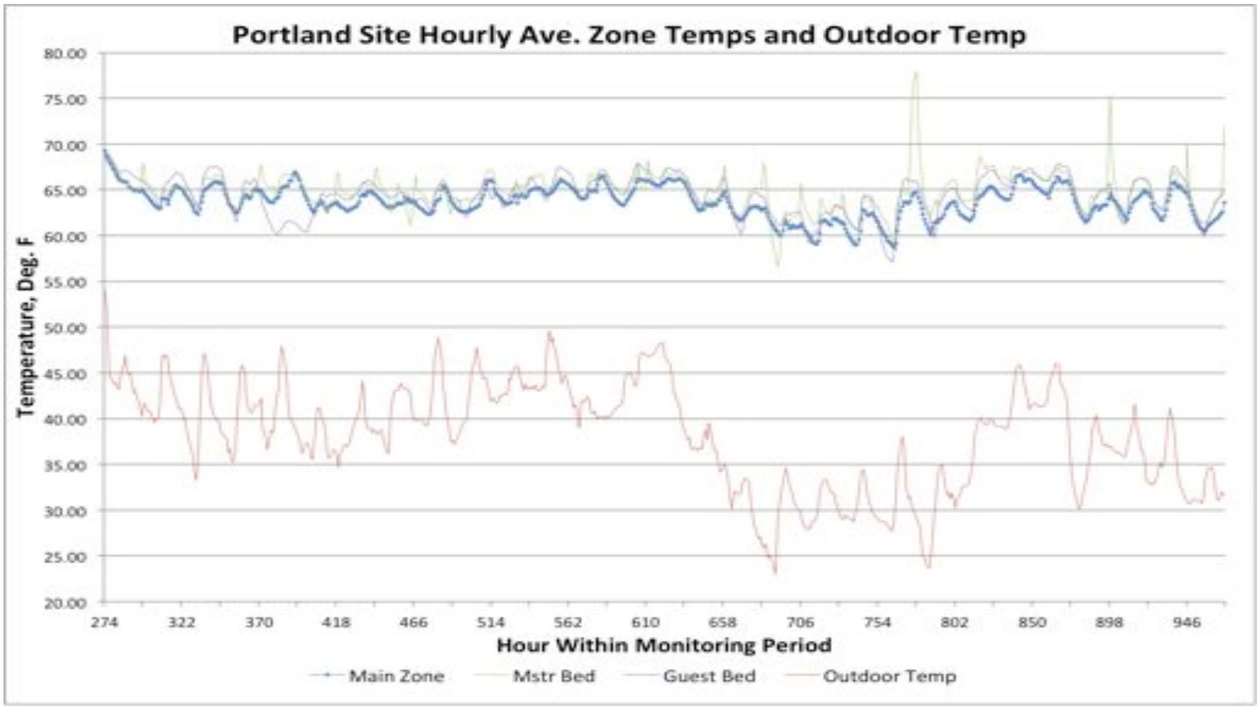


Figure 16. Portland site hourly zone temps and outdoor temp

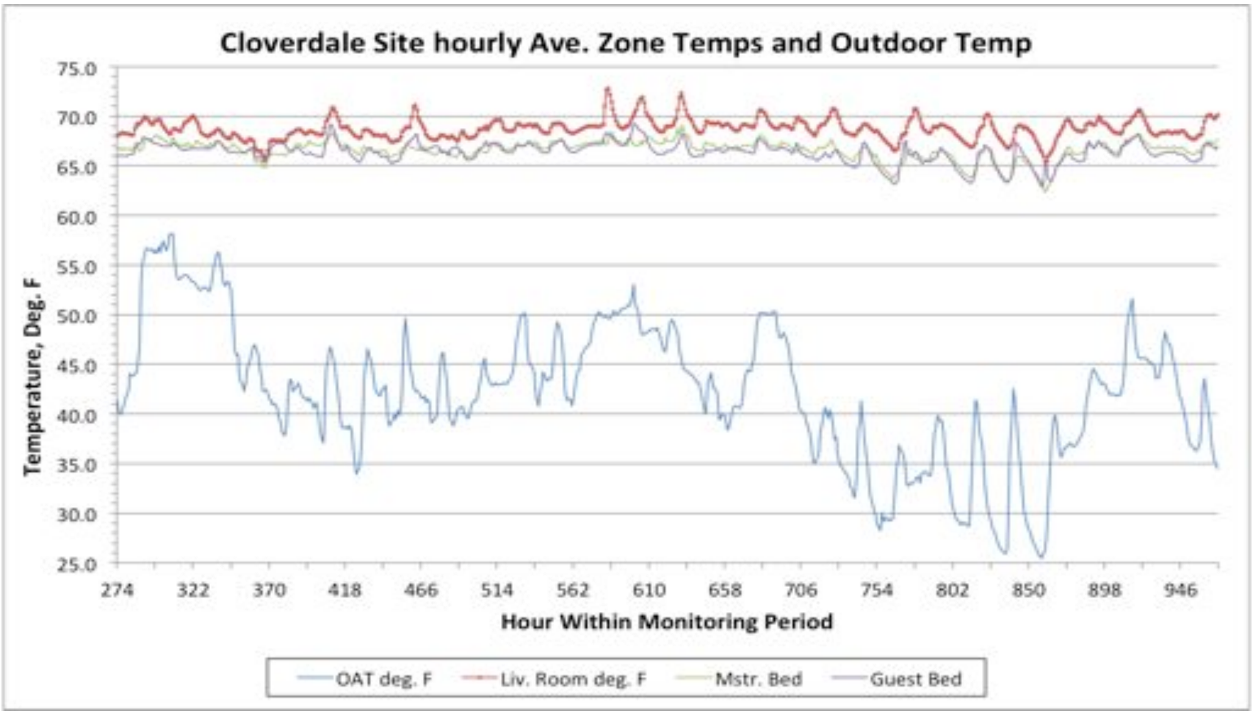


Figure 17. Cloverdale site hourly zone temps and outdoor temp

The differences in zone temperature were taken into account when calculating the average indoor temperature values in the data analysis. The average indoor temperature was determined by calculating the fraction of each home's U*A value could be attributed to each zone and multiplying that fraction by the temperature data for that zone. Adding the weighted temperatures from all the zones resulted in the weighted average indoor temperature.

Figure 18 shows the Portland site's total hourly electric resistance heating use over the entire 4,150-hour monitoring period. Note the logarithmic scale, used to make the 4,150 points on the graph visible. 3,448 of the data points fall below 0.01 kWh/hr, The total electric resistance heating measured in the bedrooms and bathrooms over the entire period was 250 kWh, which contrasts to just under 4,000 kWh used to heat the comparable zones at the Cloverdale site over the same period. Clearly, the DHP was able to supply a very significant portion of the heating load in the secondary zones. An example of the electric resistance heaters used in the bedrooms can be seen in figure 19.

The addition of a DHP to the Portland site home clearly resulted in a significantly more energy efficient heating system that delivers temperatures that are at least as even as those found in the conventional zonal electric home, if not more so. The owners of the Portland home reported no comfort issues related the DHP system that would not also be present in any other heating system.

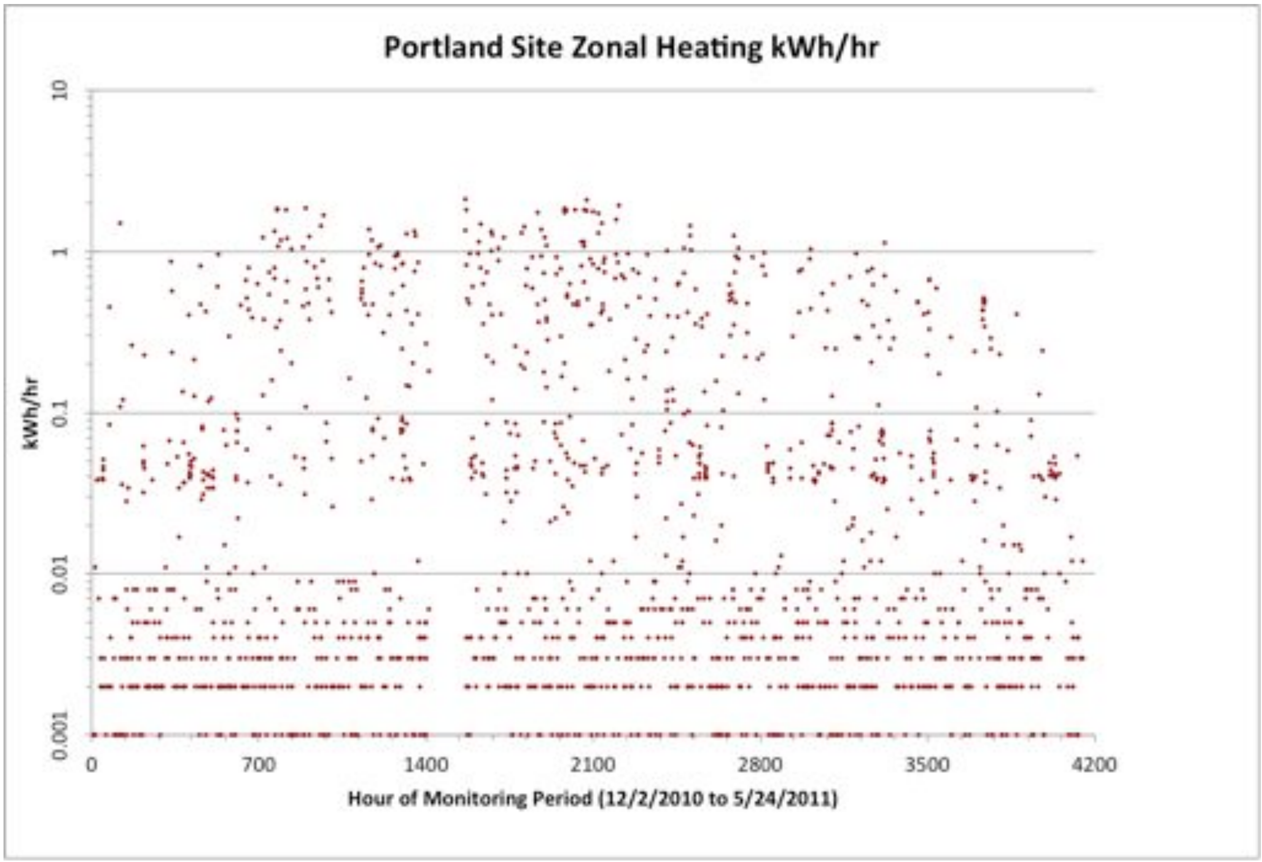


Figure 18. Portland site electric resistance heating kWh/hr

6.5 Utility Implications

Figures 20 and 21 present cumulative heating energy use by heat source in 24 hourly bins. In essence these figures present the heating season average load profiles for the two study homes. The Portland DHP home presents a very flat usage (and demand) curve, while the Cloverdale electric resistance home shows a strong peak during the morning business hours. Note the different scales on the vertical axis of the figures.

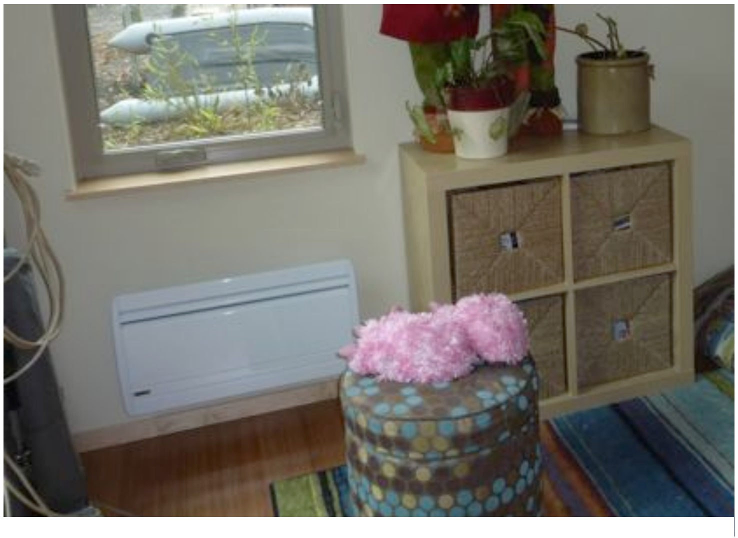


Figure 19. Electric resistance wall heater in bedroom

The figures also include domestic hot water loads, because the tankless electric water heaters used in the homes afford one the opportunity to view the actual time and magnitude of hot water use. While the hot water load clearly is secondary, compared to space heating, in the Cloverdale home, the opposite is true for the Portland DHP home.

The project's extremely small study size makes it impossible to draw any definite conclusions about actual usage or demand profile implications, but the Portland DHP home's highest use-hour for space and water heating is about on par with the Cloverdale home's lowest use-hour, despite strong similarities in home construction, occupancy schedule and overall use of the homes.

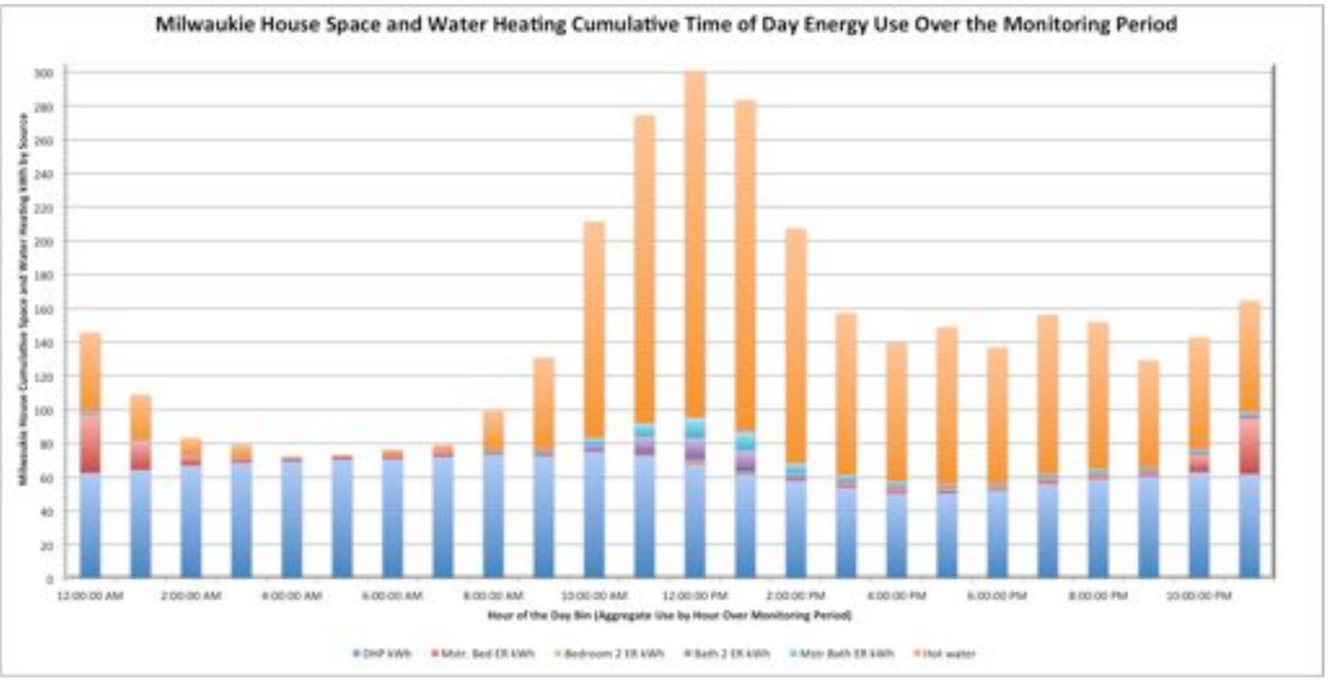


Figure 20. Portland Site Space and Water Heating Time of Day Use

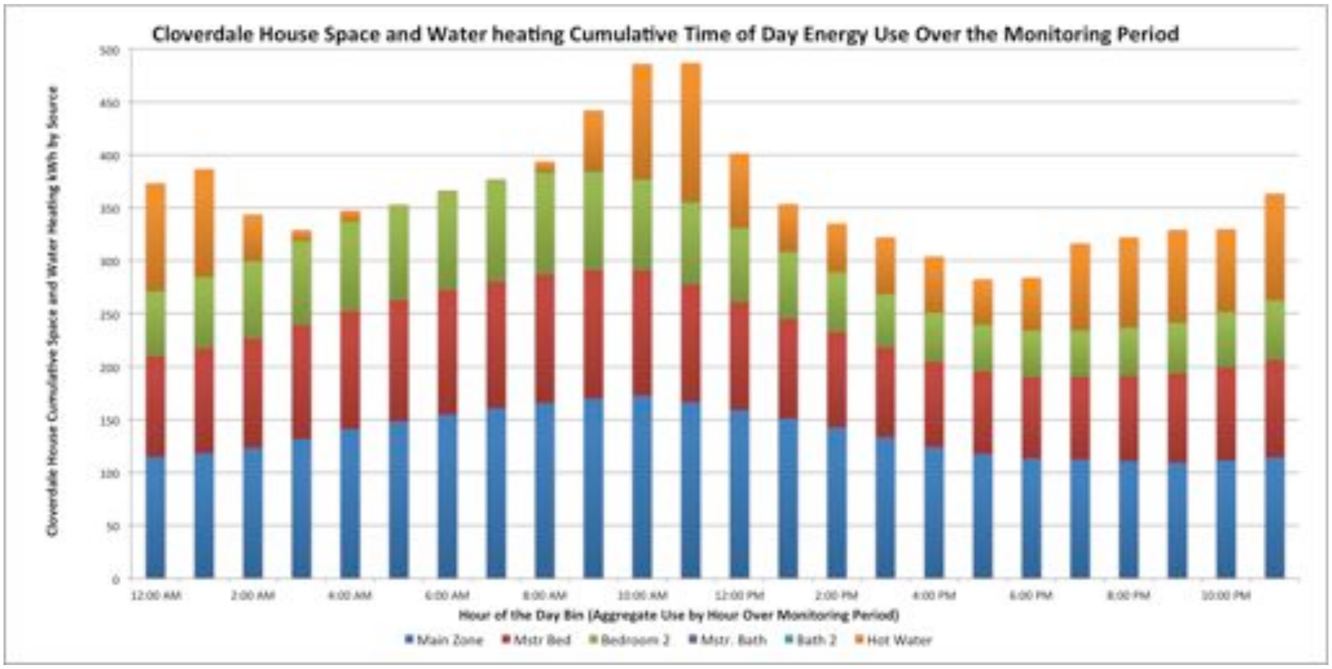


Figure 21. Cloverdale Site Space and Water Heating Time of Day Use

Appendix A. Field protocol

Name:	Date:
Address:	Technician(s):
Phone:	Organization:
Utility:	

Homeowner Acknowledgment:
I acknowledge that I have given permission for Ecotope, Inc. or its representative to test my heat pump system and house as part of Northwest Energy Works' research. Ecotope and its subcontractors are covered by $2 million professional liability insurance. Ecotope will repair or cause to be repaired any damage caused as the result of the testing.

_______________________________________ ______________
Homeowner signature Date

By signing below, I allow Ecotope, Inc. to request and use utility billing information to evaluate the energy performance of heat pumps. The information will be kept strictly confidential and only used for pooled summaries of results.

_______________________________________ ______________
Homeowner signature Date

Electric utility account #(if available):___________________

Account holder name (if different from above): ___________________________________

House type:	Rambler 2 story Split level attached Garage Mfd Other (specify):	Year house built	
		Indicate major remodel details/dates (especially if weatherization occurred):	
		Location of DHP(s): LR DR FamRm Other:	

Homeowner interview:

How many people live here full-time? Adults (age 12 or over):_____Children (under 12):______

Does your house experience brownouts or other power problems? Y N
How many times/year?_________

How much wood do you burn in a typical winter?_________

What is your water heat fuel _______________________________________

Does the house have a LPG fireplace ____ or stove/oven _______ or dryer _____?
About how many gallons of LPG do you use per year?_______

Other auxiliary electric loads: well pump____ extra refrig/freeze ________
shop equipment ____ Spa/hot tub ______

Other_______________________________________

Do you have a whole house ventilation system? ___yes ___no
If yes, what type: ____spot fan on timer ___other whole house fan ___AAHX
other________________

Do you have any problems to report with your DHP heating system?

Which of the following types of improvements have you made to your home during the past year?

( ) refurbished the outside of your home
( ) updated your kitchen
( ) updated a bathroom
( ) added a room or more living space
( ) none of the above

Which of the following energy reduction measures did you make during the past year?

( ) added insulation
( ) installed more energy efficient windows or doors
( ) replaced an appliance or appliances with energy efficient appliances
( ) installed new energy efficient light bulbs
( ) caulked windows and doors
( ) installed solar panels
( ) other: _______________________________

Have you participated in any other energy-related programs in the last year, such as a home audit or incentives for an energy-efficient purchase? [If yes, describe] ______________________________
____

Before the DHP installation, approximately what temperature did you set:

The main living space _______°
The bedrooms _________°
Other spaces_________________°
____________________________°
____________________________°
____________________________°

Since the DHP installation, approximately what temperature do you set:
The main living space _______°
The bedrooms _________°
Other spaces_________________°
____________________________°
____________________________°
____________________________°

How many window air conditioner units do you have in your home, if any?
_____________ # OF WINDOW AC UNITS
In the year prior to the DHP installation, in which months did you use your air conditioner? ____

Though you just recently installed your DHP, I'd like to know how your experience has been with DHP so far. Please rate your satisfaction of the following aspects using a 5-point scale, where 1= "very dissatisfied," 3= "neither dissatisfied nor satisfied," and 5= "very satisfied."

DHP	1	2	3	4	5	DK
More energy efficient than regular electric heat						
Indoor unit(s) is quiet						
Reducing your energy bill						
More comfortable than traditional electric heat						
Provides heating and air conditioning in a single unit						

Record house UA (no infiltration) here: ___________________Btu/ft^2 ºF

Record heated floor area here: _______________ ft^2

Record house volume here: _________ft^3

2-Point Blower Door Test

Depressurize to near 50 and 25 Pa with respect to outside. Note the house pressure WRT outside doesn't have to be exactly 50 or 25 Pa; the actual values will be corrected to 50 Pa during analysis.

Make and model of blower door used

____

Blower Door (BD) Depressurization Test Procedure:
Close all windows and doors to the outside. Open all interior doors and supply registers. Close all dampers and doors on wood stoves and fireplaces. Seal fireplace or woodstove as necessary to prevent ash disaster.
Make sure furnace and water heater can not come on during test. Put water heater and/or gas fireplace on "pilot" setting. Make sure all exhaust fans and clothes dryer are off. Make sure any other combustion appliances will not be backdrafted by the blower door.
Make sure doors to interior furnace cabinets are closed. Also make sure crawlspace hatch is on, even if it is an outside access. Check attic hatch position. Put garage door in normal position.
Set fan to de<u>de</u>pressurize house. Run pressure tap out through door shroud.
Depressurize house to –50 Pa or thereabouts. Record house pressure, BD flow pressure, and BD ring (below). If you cannot reach –50 Pa, get as close as possible and record information.
Now take the house down to –25 Pa WRT outside and record information.

Blower Door Tests	House P near 50 Pa (P_{50})	BD fan pressure	BD Ring	BD flow near 50 Pa (Q_{50})	House P near 25 Pa (P_{25})	BD fan pressure	Ring	BD flow near 25 Pa (Q_{25})
Test 1								
Test 2								

To check test, calculate the flow exponent, n. Use the following formula, $n = \ln(Q_{50}/Q_{25})/\ln(P_{50}/P_{25})$*. Note* Q_{50} *and* Q_{25} *are the flows through the blower door at the testing pressures (which are denoted* P_{50} *and* P_{25}*. Depending on the test, you may not get the house to exactly –50 or –25 Pa WRT outside. Use the exact ΔP you measure when checking the flow exponent. For example, if the house gets to –48 Pa for the high ΔP, use this as the* P_{50} *in the equation. If the flow exponent is not between 0.50 and 0.75, repeat the test.*

Note testing conditions (if windy, inaccessible room(s), garage door open or closed, etc):

DEVICE	S/N	NOTES
Dent Elite		Channel 1:
		Channel 2:
		Channel 3:
		Channel 4:
Dent Elite		Channel 1:
		Channel 2:
		Channel 3:
		Channel 4:

METERING DETAILS

Onset ODT/VLT temp logger Model #:

Onset IDT logger 1 (U12-011) Location:

Onset IDT logger 2 (U12-011) Location:

Onset IDT logger 3 (U12-011) Location:

Onset IDT logger 4 (U12-011) Location:

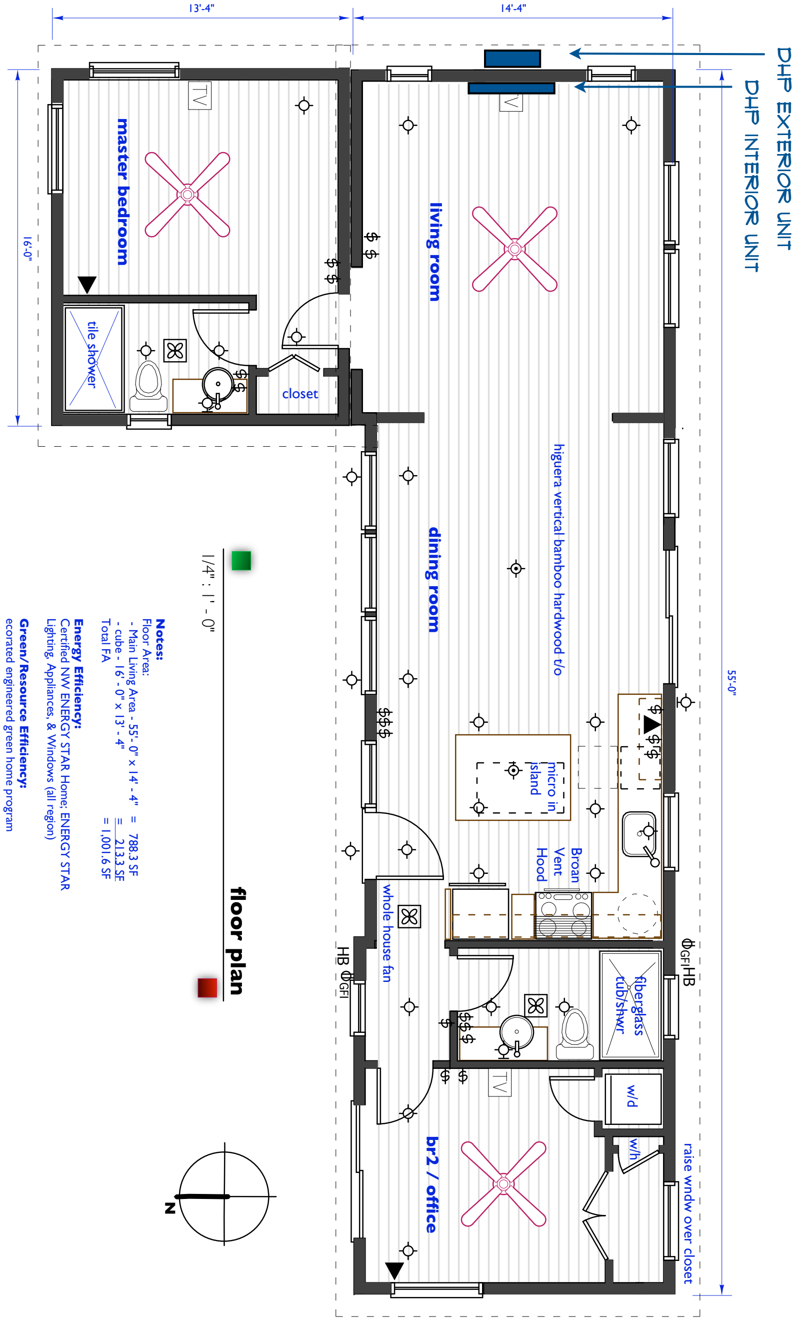
DHP outdoor unit make/model:

ID unit make/model:

More notes on installation (CT connections, extra panels, 120V heater circuits, etc.):

Appendix B. Cloverdale Floorplan

Appendix C. Portland Floorplan



Notes:
Floor Area:
- Main Living Area - 55'- 0" x 14' - 4" = 788.3 SF
- cube - 16' - 0" x 13' - 4" = 213.3 SF
Total FA = 1,001.6 SF

Energy Efficiency:
Certified NW ENERGY STAR Home; ENERGY STAR Lighting, Appliances, & Windows (all region)

Green/Resource Efficiency:
ecorated engineered green home program

ideabox

milwaukie, OR

16 April 10

prefab

Appendix D. Ductless Heat Pump Specifications

MITSUBISHI ELECTRIC
HVAC Advanced Products Division

Mr.SLIM®
Split Zoning A/C and Heat Pumps

SUBMITTAL DATA: MSZ-GE15NA & MUZ-GE15NA

15,000 BTU/H WALL-MOUNTED HEAT-PUMP SYSTEMS

Job Name:
Location:
Date:
Purchaser:
Engineer:
Submitted to:
For ☐ Reference ☐ Approval ☐ Construction
System Designation:
Schedule No.:

GENERAL FEATURES

- Wall-mounted indoor unit
- Standard Hybrid Catechin Prefilter is included with indoor unit
- Quiet operation
- Choice of fan speeds: Quiet, Low, Medium, High, and Super High; Auto fan speed control also included
- Wireless remote controller is included; PAR-21MAA wired remote controller can be installed as an option
- Indoor unit powered from outdoor unit using A-Control
- Auto restart following a power outage
- Base heater is available as an option
- Limited warranty: five years on parts and defects and seven years on the compressor

OPTIONAL ACCESSORIES

Outdoor Unit

- Base Heater (MAC-640BH-U)
- Drain Socket Assembly (MAC-860DS)

Indoor Unit

- M-NET Control Adapter (MAC-399IF)
- MA Contact Terminal Interface (MAC-397IF)
- Wired Remote Controller (PAR-21MAA; requires MAC-397IF)
- Condensate Pump (230V; SI3100-230)
- Anti-allergy Enzyme Filter (Two pieces per set; MAC-408FT-E)

Cooling*

Rated Capacity	14,000 Btu/h
Minimum Capacity	3,100 Btu/h
SEER	21.0 Btu/h/W
Total Input	1,080 W

Heating at 47°F*

Rated Capacity	18,000 Btu/h
Minimum Capacity	4,800 Btu/h
HSPF	10.0 Btu/h/W
Total Input	1,600 W

Heating at 17°F*

Rated Capacity	11,300 Btu/h
Rated Total Input	1,150 W
Maximum Capacity	15,900 Btu/h
Maximum Total Input	1,950 W

* Rating Conditions (Cooling) - Indoor: 80ºF (27ºC) DB, 67ºF (19ºC) WB; Outdoor: 95ºF (35ºC) DB, 75ºF (24ºC) WB.
(Heating at 47ºF) - Indoor: 70ºF (21ºC) DB, 60ºF (16ºC) WB; Outdoor: 47ºF (8ºC) DB, 43ºF (6ºC) WB.
(Heating at 17ºF) - Indoor: 70ºF (21ºC) DB, 60ºF (16ºC) WB; Outdoor: 17ºF (-8ºC) DB, 15ºF (-9ºC) WB.

Electrical Requirements

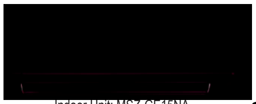
Power Supply	208 / 230V, 1-Phase, 60 Hz
Breaker Size	15 A

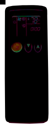
Voltage

Indoor - Outdoor S1-S2	AC 208 / 230V
Indoor - Outdoor S2-S3	DC 12-24V
Indoor - Remote Controller	Wireless

OPERATING RANGE

		Indoor Intake Air Temp.	Outdoor Intake Air Temp.
Cooling	Maximum	90°F (32°C) DB, 73°F (23°C) WB	115°F (46°C) DB
	Minimum	67°F (19°C) DB, 57°F (14°C) WB	14°F (-10°C) DB
Heating	Maximum	80°F (27°C) DB, 67°F (19°C) WB	75°F (24°C) DB, 65°F (18°C) WB
	Minimum	70°F (21°C) DB, 60°F (16°C) WB	-4°F (-20°C) DB, -5°F (-21°C) WB


Indoor Unit: MSZ-GE15NA


Wireless Remote Controller


Outdoor Unit: MUZ-GE15NA

Indoor Unit

MCA	1 A
Fan Motor	0.76 F.L.A.

Airflow (Quiet - Lo - Med - Hi - Super Hi)

Cooling	205 - 272 - 335 - 420 - 533 Dry CFM 170 - 237 - 300 - 385 - 498 Wet CFM
Heating	205 - 247 - 304 - 367 - 463 Dry CFM

Sound Pressure Level (Quiet - Lo - Med - Hi - Super Hi)

Cooling	26 - 32 - 38 - 44 - 49 dB(A)
Heating	26 - 30 - 35 - 40 - 46 dB(A)

DIMENSIONS	UNIT INCHES / MM
W	31-7/16 / 799
D	9-1/8 / 232
H	11-5/8 / 295

Weight	22 lbs. / 10 kg
External Finish	Munsell No. 1.0Y 9.2 / 0.2
Field Drainpipe Size O.D.	5/8" / 15.88 mm
Remote Controller	Wireless (Optional Wired Remote Controller PAR-21MAA; see Data Submittal Sheet)

Outdoor Unit

Compressor	DC Inverter-driven Twin Rotary
MCA	12 A
Fan Motor	0.50 F.L.A.

Sound Pressure Level

Cooling	49 dB(A)
Heating	51 dB(A)

DIMENSIONS	INCHES / MM
W	31-1/2 / 800
D	11-1/4 / 286
H	21-5/8 / 549

Weight	80 lbs. / 37 kg
External Finish	Munsell No. 3Y 7.8 / 1.1

Refrigerant Type	R410A
Refrigerant Pipe Size O.D.	
Gas Side	1/2" / 12.7 mm
Liquid Side	1/4" / 6.35 mm
Max. Refrigerant Pipe Length	65 ft. / 20 m
Max. Refrigerant Pipe Height Difference	40 ft. / 12 m
Connection Method	Flared

R410A INVERTER

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All photographs and figures in this report were prepared by Northwest Energy Works unless otherwise noted.