SUBMITTED TO:

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NYLE HEAT- PUMP WATER HEATER EVALUATION

FINAL REPORT

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Executive Summary

In November 2000, Northeast Utilities (NU) commissioned AIL Research to evaluate the performance of 15 heat-pump water heaters (HPWHs) that had been installed as part of NU's Hot Shot program. The HPWHs were the Nyletherm-1, a relatively new model that is manufactured by Nyle Specialty Products. The primary objectives of this evaluation were to (1) determine the energy and demand savings achieved by the HPWHs, and (2) identify possible operational problems caused either by improper installation, unusual site conditions (e.g., air-borne lint from an improperly vented clothes dryer) or manufacturing defects.

The 15 HPWHs were monitored for the 9-month period starting in January 2001. At 13 of the 15 sites, the HPWHs operated for the entire test period; at two sites (Sites 239 and 243), the HPWH developed operational problems and it was taken out of service before the end of the test.

As shown in the table to the right, hot water use at the test sites ranged from 30.6 gallons per day to 167.7 gallons per day, with the average being 74.5 gallons per day. Excluding the two sites where the HPWHs were taken out of service, the HPWH COPs ranged from 1.7 to 2.0. At these efficiencies, the HPWHs reduced energy use for hot water from between 40% to 50% of the value for a conventional resistance water heater.

Site	daily kWh	DHW per-day gals	COP	Annual saving kWh
231	3.2	31.8	2.0	1180
232	13.5	167.7	2.0	4501
233	8.8	84.4	1.9	2366
234	10.1	107.5	1.9	3284
235	5.8	65.2	1.7	1567
236	8.8	86.7	1.7	2156
237	5.0	43.8	2.0	1792
238	6.6	73.5	1.8	1823
239	9.9	97.6	1.6	2539
240	5.6	64.4	1.9	1869
241	3.4	37.0	1.9	1015
242	8.2	93.0	1.9	2628
243	8.5	66.3	1.6	1587
244	7.4	67.7	1.7	1826
245	3.5	30.6	1.8	974
AVG	7.2	74.5	1.8	2074
*AVG	6.9	73.3	1.9	2076

* average w/o 239 and 243

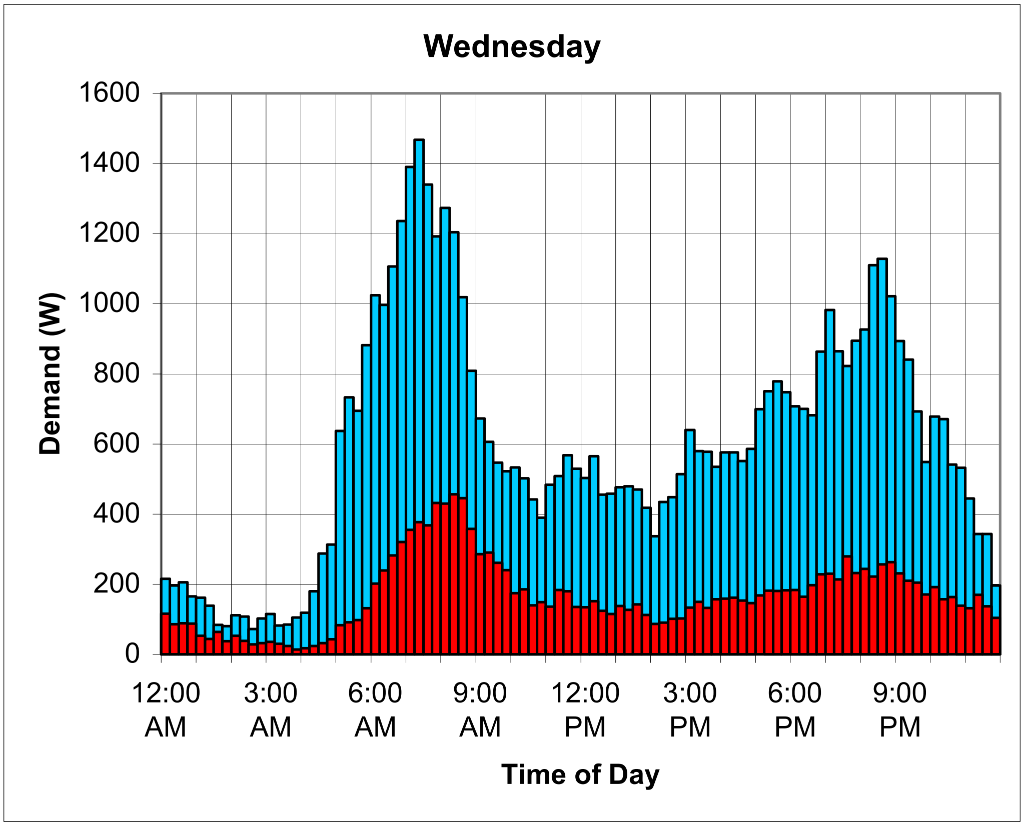
Since the COPs for the HPWHs were in a fairly narrow range, energy savings was almost proportional to energy use. Site 232, with a daily hot water use of 167.7 gallons had savings of 4,488 kWh per year. Site 245, with a daily hot water use of 30.6 gallons had savings of 971 kWh per year.

Prior to this field test, 30 HPWHs manufactured by Crispaire were tested using the same protocol. The average COP for the Crispaire units was essentially the same as that for the Nyle units. The Crispaire units were slightly more efficient (about 10%) when the ambient temperature was high, but they were less efficient by about the same amount when the ambient temperature was low.

The Nyle HPWHs tended to require less defrosting than the Crispaire HPWHs. Some Nyle units were able to operate at 45°F ambient without defrosting. For the Crispaire HPWHs, all units required some defrosting below 54 °F.

The HPWHs significantly reduced the electrical demand for water heating. Using the WATSIM computer model, which was developed by the Electric Power Research Institute for simulating the performance of water heaters, the electrical demand for the fifteen test sites was calculated assuming that each site had a conventional resistance water heater. As shown in the following figure, the HPWH reduced the morning peak on Wednesdays by about 1,000 W. The evening peak was reduced by about 800 W. Demand reductions on the other weekdays were about the same as these values with average reductions being 890 W in the morning and 840 W in the evening.

Average Demand for Resistance Water Heaters (blue upper curve) and Heat Pump Water Heaters (red lower curve)



Introduction

In November 2000, Northeast Utilities (NU) commissioned AIL Research to evaluate the performance of 15 heat-pump water heaters (HPWHs) that had been installed as part of NU's Hot Shot program. The HPWHs were the Nyletherm-1, a relatively new model that is manufactured by Nyle Specialty Products. The primary objectives of this evaluation were to (1) determine the energy and demand savings achieved by the HPWHs, and (2) identify possible operational problems caused either by improper installation, unusual site conditions (e.g., air-borne lint from an improperly vented clothes dryer) or manufacturing defects.

The 15 HPWHs were monitored for the 9-month period starting in January 2001. At the end of the evaluation period, all customers were called to determine his/her level of satisfaction and impressions of the HPWHs.

Each site had a data logger that monitored the following parameters:

Cold water inlet temperature
Hot water outlet temperature
Air temperature
Hot water flow rate
Electrical power to water heater (both resistance and HPWH)

Data was sampled every five seconds and average or accumulated values were stored every minute. Data was transferred from the sites to our central computer nightly. The data collection proceeded with no problems throughout the test; there was almost no lost data due to problems with the instrumentation, data loggers or transmission procedures.

It is important to note that the HPWHs that were tested were a relatively new model for the manufacturer. Some of the operational problems that were observed can be attributed to their "immaturity". It is expected that these problems will be corrected as the manufacturer upgrades his manufacturing procedures.

Table 1

Site	no. occ.	tank gals	location of HPWH	dehum	HVAC system	state
231	2	80	unconditioned basement	N	oil furnace in basement	CT
232	4	80	full basement with boiler	N	hot-water boiler	CT
233	4	82	partial basement	N	electric baseboard	CT
234	5	50	closet	Y	oil furnace in basement/some elec.	CT
235	4	40	unconditioned basement	Y	gas forced hot air	CT
236	4	80	unconditioned basement	Y	electric furnace	CT
237	3	82	unconditioned basement	N	oil furnace in basement	CT
238	3	80	unconditioned basement	Y	oil furnace in basement	CT
239	10	65	unconditioned basement	N	oil furnace in basement	CT
240	4	80	unconditioned basement	N	oil furnace in basement	CT
241	2	50	unconditioned laundry room	Y	electric baseboard	CT
242	4	80	basement with boiler	N	hot-water boiler	CT
243	5	120	unconditioned basement	N	electric baseboard	CT
244	5	50	unconditioned basement	N	electric baseboard	CT
245	2	50	unconditioned basement	N	electric baseboard	CT

Performance Summary

The 15 sites that were monitored are referred to by site numbers running from 231 through 245. The number of occupants at the site and the size of the hot-water storage tank are shown in Table 1 for each site. For most of the sites, Table 1 also shows the location of the HPWH, the presence of a dehumidifier, and the type of central heating system.

HPWH Energy Savings

The energy savings and total energy use for each site are reported in Table 2 and Figure 1. In Figure 1, the electrical energy that would have used at each site if a conventional electric water heater had been used is shown by the height of each bar. The top segment of each bar is the savings achieved by the HPWH.

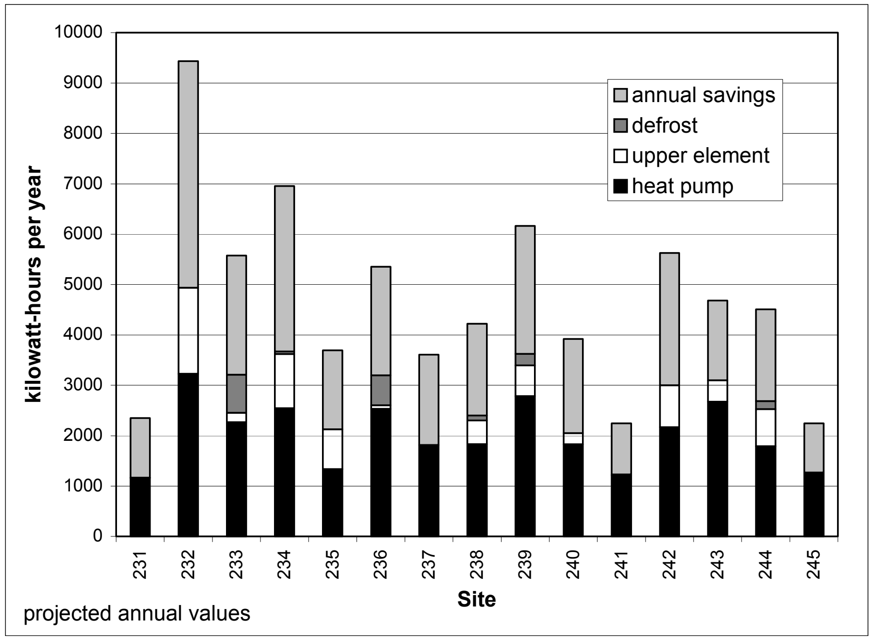


Figure 1 – Energy Use and Energy Savings for Each Test Site

The actual energy use measured at each site equals the sum of the three segments of the bar that are below the "savings" segment. These segments are as follows:

- Defrost – Energy used by the resistance elements while the HPWH was disabled for defrosting.
- Upper-element – Energy used by the upper resistance element during periods of very high hot-water use when the heating rate of the HPWH is inadequate to meet the demand.
- Heat-pump – energy used by the HPWH.

The energy savings that are shown in both Table 2 and Figure 1 are annualized values that have been calculated by multiplying the measured savings by 365/N, where N is the number of days of monitored HPWH operation. For the 15 sites, the annual energy savings averaged 2,074 kWh (5.7 kWh per day).

As shown in Figure 1, seven of the 15 sites have savings that exceed 45% of the energy that would have been used by a conventional water heater. These are Sites 231, 232, 234, 237, 240, 241 and 242. Only one site—243—had savings that were less than 40%. However, the HPWH at this site failed towards the end of the test, so the low savings may be attributed to poor performance prior to the failure.

HPWH COP

In this study, the COP of the HPWHs is defined as the ratio of the electricity that a conventional electric resistance water heater would have used at the site divided by the actual electricity used by the HPWH (including any supplemental resistance heating that may have been used during defrosting of the HPWH or during periods of very high hot-water use). The seven sites identified above as having the largest savings had COPs that ranged from 1.88 to 2.01.

Although far from perfect, the parameter that correlates most strongly with a high COP is the ambient air temperature. This is shown in Figure 2 where monthly-averaged data for all the sites is plotted. This correlation is expected since a heat pump will always work more efficiently when its source for heat is at a higher temperature.

Also shown in Figure 2 is the linear correlation of COP versus air temperature for the 30 E-Tech HPWHs that were monitored as part of NU's Hot Shot Program from September 1, 1998 through March 31, 2000. As shown in Figure 2, the COPs of the 15 Nyle HPWHs were very close to those for the E-Tech units. The E-Tech units were slightly more efficient at higher ambient temperatures and the Nyle units were slightly more efficient at lower ambient temperatures.

The data in Figures 3 shows that there is essentially no correlation between the HPWH COP and hot-water usage.

There is also a slight trend for the COP to increase as the inlet cold water becomes warmer, as shown in Figure 4. This trend is counter to what one would expect based on the thermodynamics of heat pumps—i.e., the efficiency of a heat pump decreases as the temperature of the medium that it is heating increases.

Table 2

Site	(during test) daily kWh	total kWh	DHW per-day gals	DHW total gals	RO total gals	DHW total kBtu	Annual saving kWh
231	3.2	873	31.8	8671	0	4725	1180
232	13.5	3693	167.7	45769	3723	22775	4501
233	8.8	2129	84.4	20435	297	10401	2366
234	10.1	2433	107.5	26013	38	14694	3284
235	5.8	1410	65.2	15767	355	7304	1567
236	8.8	2392	86.7	23659	0	12941	2156
237	5.0	1358	43.8	11970	0	7077	1792
238	6.6	1592	73.5	17787	13	8982	1823
239	9.9	1490	97.6	14644	3375	7393	2539
240	5.6	1533	64.4	17583	98	8734	1869
241	3.4	920	37.0	10105	29	4285	1015
242	8.2	2245	93.0	25401	693	13265	2628
243	8.5	1537	66.3	12001	0	7077	1587
244	7.4	2008	67.7	18492	143	10167	1826
245	3.5	950	30.6	8364	38	4397	974
AVG	7.2	1771	74.5	18444	587	9614	2074
*AVG	6.9	1810	73.3	19232	417	9981	2076

* average w/o 239 and 243

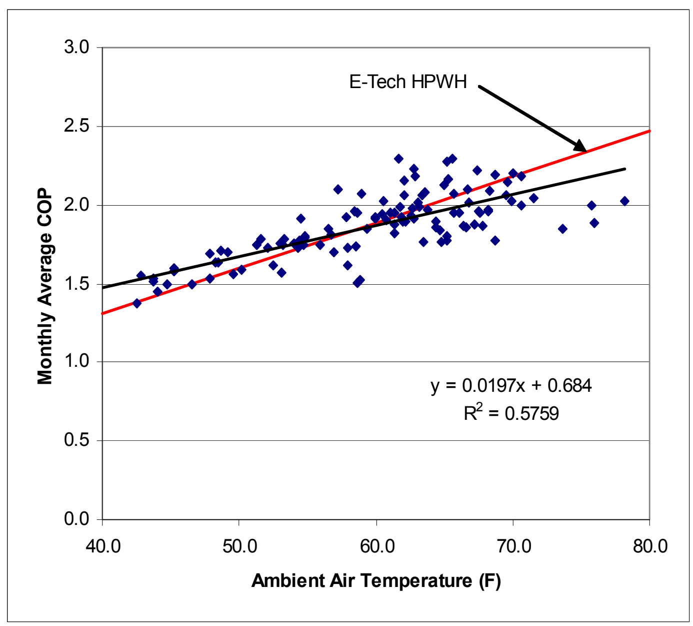


Figure 2 - Correlation of HPWH COP with Ambient Air Temperature

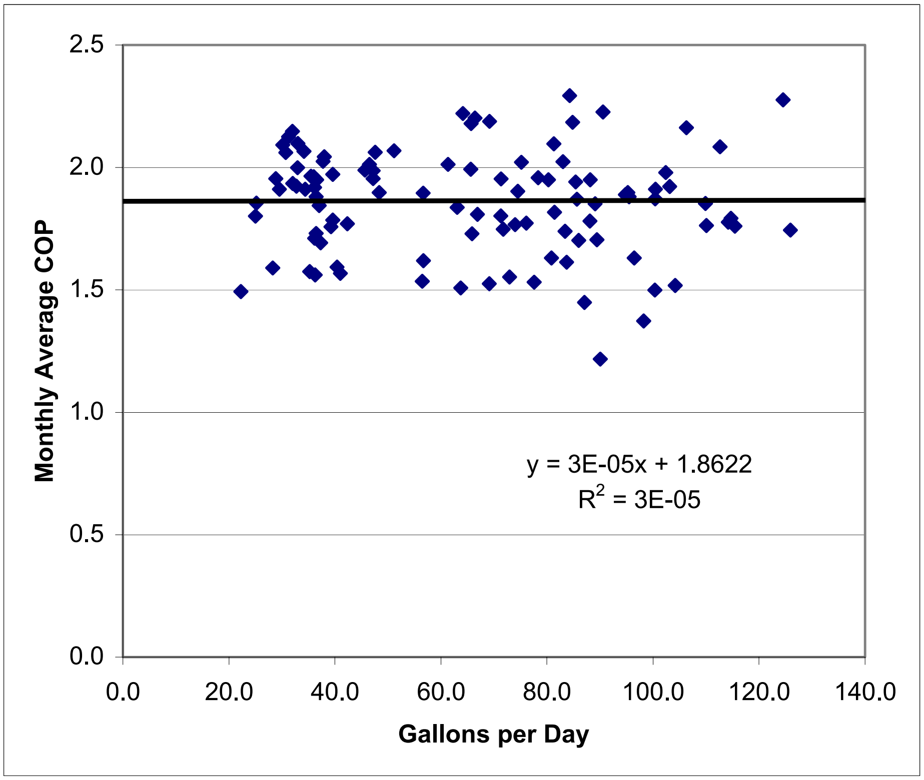


Figure 3 – Correlation of HPWH COP with Hot-Water Use

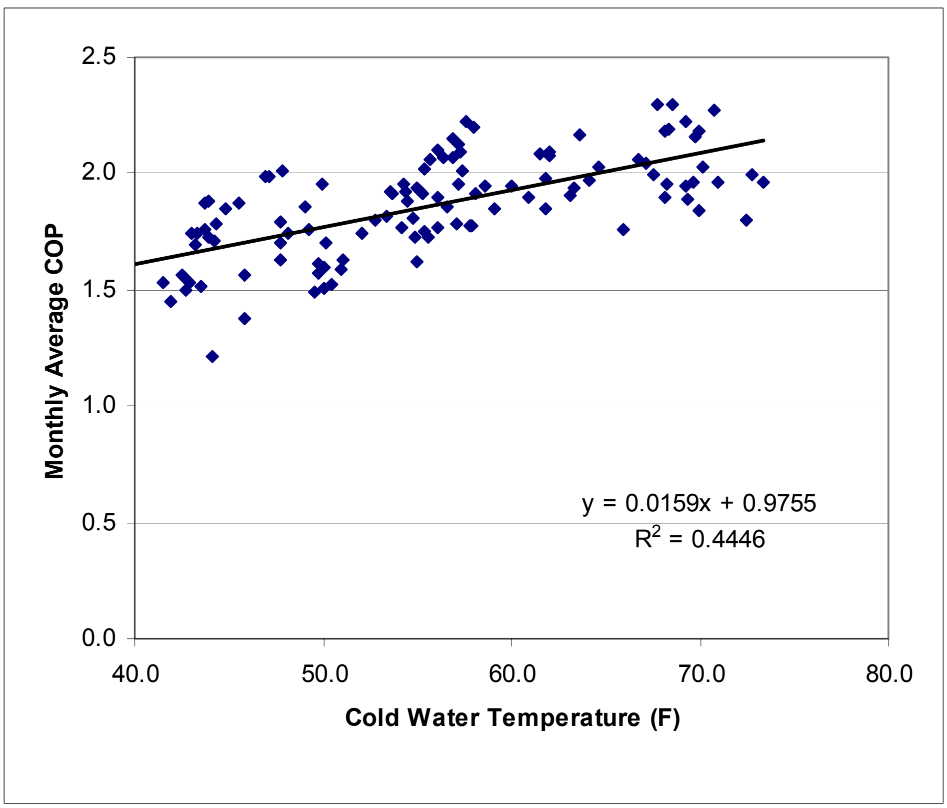


Figure 4 – Correlation of HPWH COP with Inlet Cold Water Temperature

However, there is a fairly strong positive correlation between air temperature and inlet cold water temperature. This masks the effect of inlet cold water temperature on COP, making it appear as if there is a positive correlation between them.

Seasonal Effects

Figure 5 shows the average monthly energy savings for all sites except Sites 239 and 243. (As noted later in this report, the HPWHs at these sites experienced operational problems before the end of the test.) Energy savings are fairly uniform though out the year, with at most a 20% difference between the highest and lowest month. Savings tend to be the greatest when entering water temperatures are the lowest, which tends to increase hot water use. This behavior is shown in Figure 6 as a fairly strong negative correlation between energy savings and inlet water temperature. Figure 7 shows a similar correlation between hot-water use and inlet water temperature.

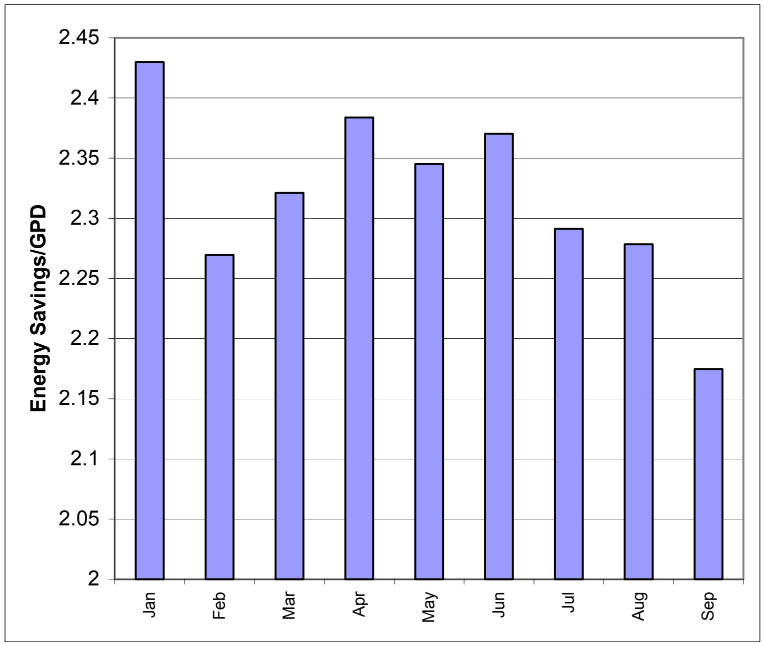


Figure 5 - Seasonal Changes in Energy Savings

Hot-Water Run-Outs

Run-outs of hot water (defined as water delivered at less than 105°F) were not a problem at any of the test sites. For both Sites 232 and 239, Table 2 shows that run-outs for the HPWH exceeded 3000 gallons for the 9-month test period. However, both these sites used a coil within a boiler as the final stage of water heating. The HPWHs at these two sites only preheated the water that entered the boiler.

Average Hot-Water Use

For the 15 test sites, the daily average use of hot water ranged from 31 gallons to 168 gallons with an average of 74.5 gallons. Figure 9 shows the very weak correlation that exists between hot-water use and family size. The correlation shows that the average use for each site that is independent of the number of occupants is 53.5 gpd. Each occupant adds on average 6.3 gpd to the site's usage.

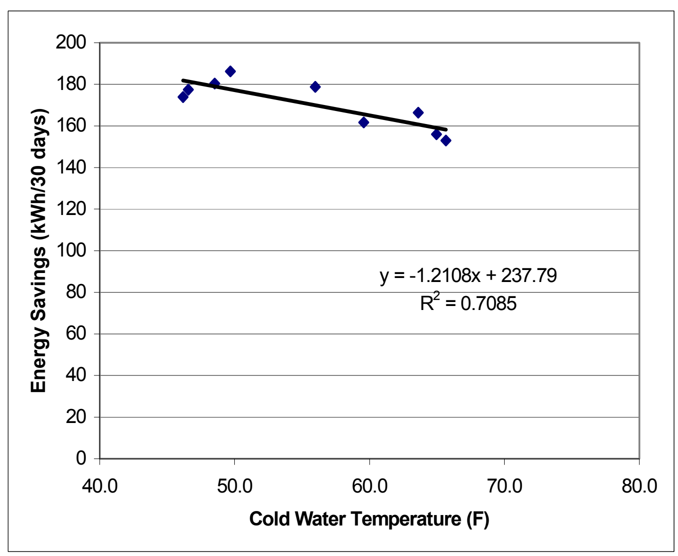


Figure 6 – Correlation between Energy Savings and Cold Water Temperature

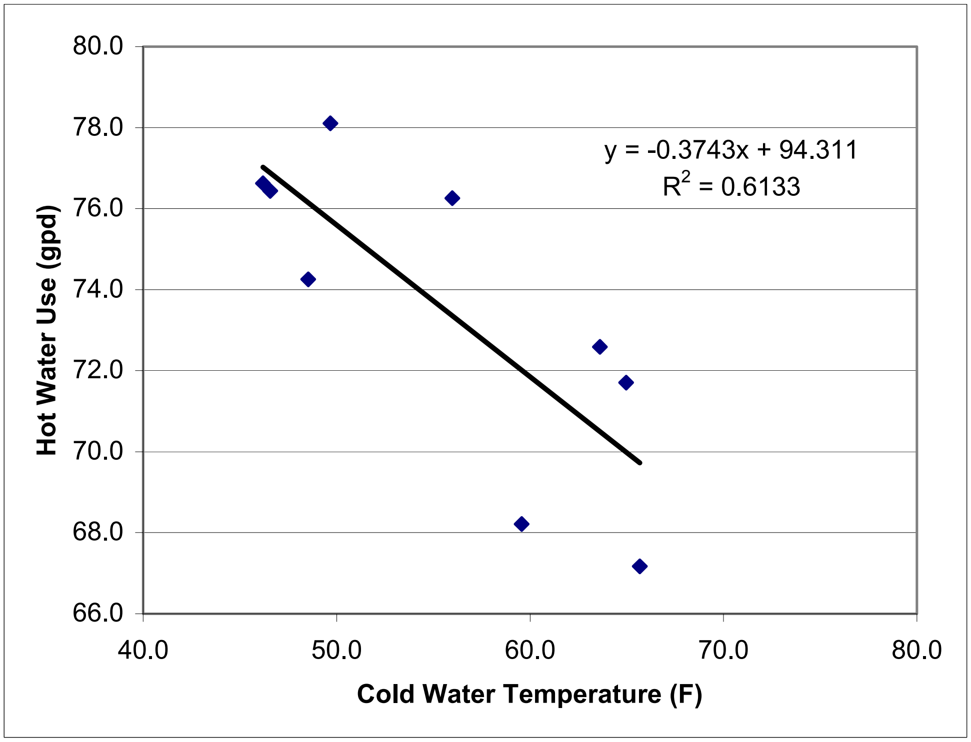


Figure 7 – Correlation between Hot Water Use and Cold Water Temperature

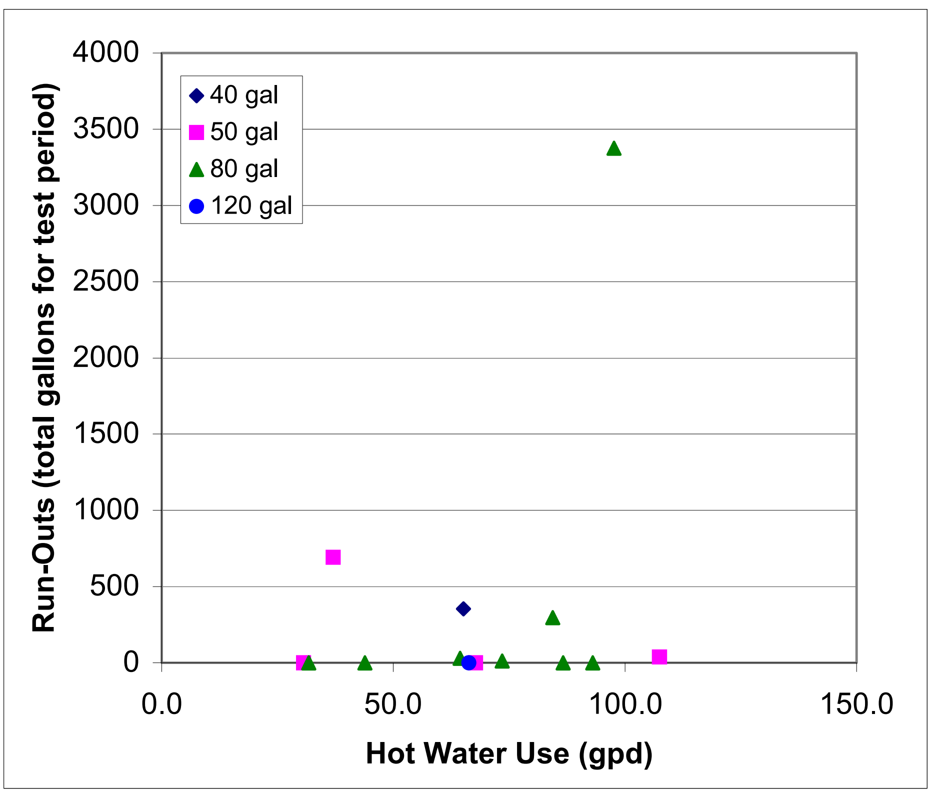


Figure 8 - Correlation between Run-Outs and Hot-Water Use

Average Energy Use and Savings

As noted above, the average hot-water use for the 13 sites where the HPWH operated with no problems through out the test was 74.5 gpd. The average energy use for meeting this hot-water demand with the HPWHs was 6.88 kWh per day. The average energy savings achieved by the HPWHs was 5.7 kWh per day.

Figure 10 shows the daily energy use of the HPWHs as a function of the daily hot-water use at the sites. The straight line shown on this figure is a linear regression of the data that is constrained to pass through 1 kWh at zero gallons usage (i.e., the energy needed to make up standby losses). The slope of the regression line shows an average of 0.0826 kWh needed for each gallon of delivered hot water.

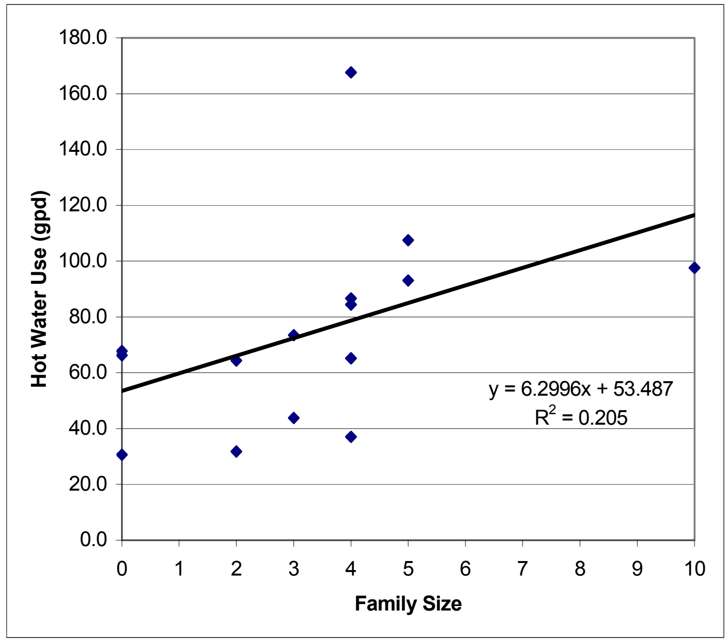


Figure 9 - Correlation between Hot-Water Use and Family Size

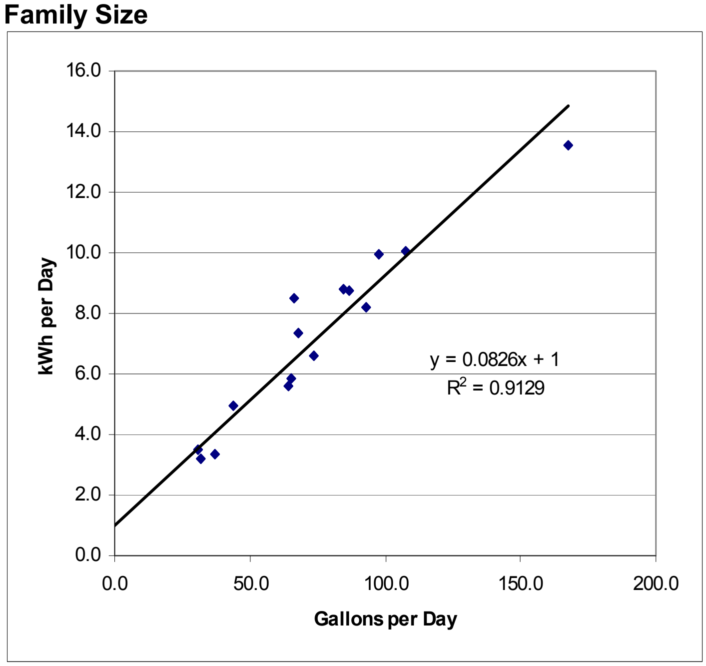


Figure 10 – Correlation between Energy Use and Hot-Water Use

Defrosting

Figure 11 shows that defrosting (i.e., the need to turn off the HPWH so that ice that is accumulating on its evaporator can melt) is not needed during months when the ambient air temperature averaged 62°F or higher. For average air temperatures between 45°F and 62°F, some sites needed defrosting and others did not. No sites were able to operate without some defrosting when air temperatures averaged less than 45°F.

Defrosting penalizes the operation of the HPWH because during defrost cycles, water is heated by the conventional resistance elements that are in the storage tank rather than with the high-efficiency heat pump. (The alternative of not defrosting the HPWH when ice accumulates on the evaporator is a much larger penalty since the ice interferes with heat transfer from the air to the evaporator.) The energy used by the resistance elements during defrosting each month is shown in Figure 12 as a function of the ambient air temperature.

Figure 1 shows for each site the energy use of the resistance elements during periods when the HPWH was disabled for defrosting.

Impact of HPWH on Diversified Electrical Demand

Compared to a conventional resistance unit, the HPWH greatly reduces the diversified electrical demand for heating hot water. This demand reduction was calculated by first averaging the electrical demand for the HPWHs over 15-minute intervals on each day of the week. This averaging was performed for all days within the monitoring period excluding the weeks that contained the Fourth of July and Memorial Day holidays. Figures 13 through 19 show the diversified electrical demand for the HPWHs for each day of the week (the lower red curves in each figure).

The electrical demand that would have occurred if conventional resistance water heaters were used at the test sites was calculated using EPRI's WATSIM computer model. (WATSIM calculates the minute-by-minute operation of electric and gas water heaters under actual water heating loads.) WATSIM was run using the measured hot water use for each site and the volume of the site's water heater. The output from WATSIM was averaged to give the 15-minute diversified demand curves for the conventional water heaters on each day of the week. These demand curves also appear in Figures 13 through 19 (the upper blue curves in each figure).

As shown in Figures 13 through 19, the HPWH reduces the weekday morning peak demand from an average value of 1,313 W to 424 W—a savings of 889 W. For the evening peak, the demand dropped from 1,102 W to 262 W—a savings of 840 W.

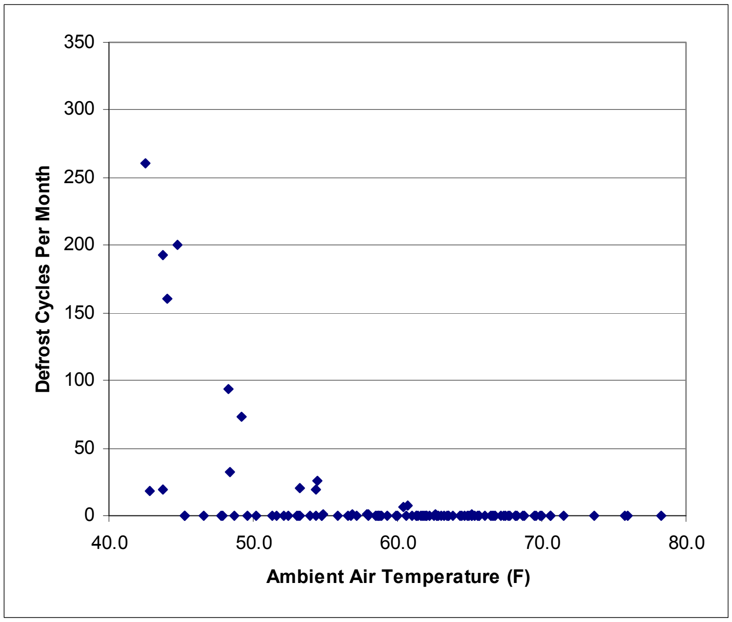


Figure 11 – Defrost Cycles per Month as a Function of Ambient Air Temperature

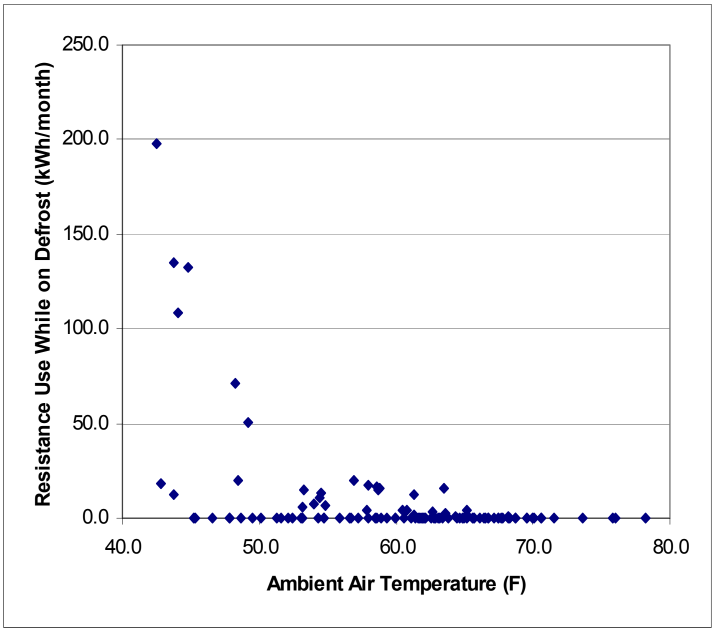


Figure 12 – Resistance Element Energy Use during Defrost Cycle

Impact of HPWH on Ambient Temperatures

The HPWH moves heat from its surroundings into the water in the storage tank. In doing this, the HPWH cools its surroundings. As shown in Table 3, the magnitude of this cooling effect is small. In this table there are two columns under the heading "Air Temp". The first, which is labeled "HP", is the average temperature of the air near the HPWH during times when the HPWH is running, and the second, which is labeled "all", is the average air temperature measured at the same location for the entire test. For the 15 test sites, the difference between these two temperatures averaged 1.8°F.

(The preceding analysis does not completely answer the question of how much the HPWH affects the ambient temperature because the ambient temperature does not immediately return to a "no HPWH" level when the HPWH turns off. A more valid test would operate periodically turn the HPWH off for extended periods—e.g. one week enabled and one week disabled—and compare the average ambient temperatures during these periods.)

Problem Sites

The only significant site-related problem to occur during the test was a hot-water leak that developed at Site 233 on March 15 and persisted to the end of the test. Although it was possible to measure the flow rate of hot water for the leak, the measurement of the temperature of the hot water leaving the tank is low by between 6°F and 10°F. The quantity of leaked hot water was between 10% and 15% of the total usage for the site.

HPWH Operational Problems

Two heat pumps developed operational problems during the test and were removed from service. These heat pumps were at Sites 239 and 243. The problems appeared as short cycling of the HPWHs in the monitored data. The cause of the problems will be determined by either NU or Nyle personel.

Table 3

Site	Air Temp (F) HP	all	Water Temp (F) cold	hot
231	57.8	63.7	55.2	121.9
232	57.6	58.6	56.4	116.4
233	52.1	53.9	58.2	120.5
234	58.5	59.1	54.4	122.3
235	57.5	58.4	56.2	116.0
236	52.9	55.0	57.0	123.1
237	65.2	65.4	56.3	127.5
238	54.1	56.9	57.6	118.2
239	64.3	65.7	55.1	116.8
240	57.4	60.3	56.1	116.0
241	56.8	59.0	57.5	112.1
242	69.6	71.2	56.5	119.6
243	54.2	55.4	53.1	124.7
244	59.1	60.6	52.5	119.6
245	47.0	54.6	53.0	117.6
AVG	57.6	59.8	55.7	119.5
*AVG	57.4	59.7	55.9	119.3

* average w/o 239 and 243

Interview Results

The occupants at thirteen of the fifteen test sites were surveyed at the end of the monitoring period to determine their attitudes towards the HPWH. (Surveys were not conducted at one of the two test sites where the HPWH failed and at one site where the user was not available.)

The surveys, which are summarized in Table 4 at the end of the report, showed that most homeowners were pleased with the operation of the HPWHs: ten of the thirteen people interviewed were either satisfied or very satisfied with the operation of their HPWH. At Site 232, the homeowner was not satisfied with the HPWH because it had not been reliable (i.e., one unit was replaced and a second was repaired at the site.)

At site 245, the wife was unhappy with the HPWH because it overcooled the basement. She also reported that the HPWH was too slow in reheating the water tank.

The homeowner at site 240 was dissatisfied with the HPWH because he did not believe it reduced his utility bills.

Most homeowners were aware of noise from the HPWH, but considered the noise to be acceptable. One homeowner reported the noise from the HPWH to be bothersome. However, the homeowner reported that the HPWH produced an annoying squeak, which may have indicated a problem with the HPWH's operation. (The homeowner was told to report the problem either the installer or NU.)

More than half of the people interviewed (7 of the 13) were aware of the dehumidification provided by the HPWH and considered it to be an important benefit.

Conclusion

The field test has shown the HPWH to be a very efficient way to provide hot water to a house. Compared to a conventional electric water heater, the HPWH can be expected to decrease energy use by between 40% and 50%. For the heaviest user of hot water in this test, the higher efficiency of the HPWH produced annual savings of 4,500 kWh; for the lightest user, savings were 974 kWh.

On weekdays, the HPWH will reduce the morning peak demand by about 890 W and the evening peak demand by about 840 W.

Several of the HPWHs in the test did have operational problems. At two sites, the HPWHs failed before the end of the test period, and they were taken out of service. At two sites the HPWH was replaced either before the start of the monitoring period or during the first month. It is important to note that the HPWHs that were tested were a new model for the manufacturer, and operational problems should decrease as the model matures.

Most of the participants in the field test had a favorable impression of the HPWH. Slightly more than one-half of those surveyed (7 out of 13) believed that the HPWH reduced their utility bills. The same number considered the dehumidification provided by the HPWH to be an important benefit.

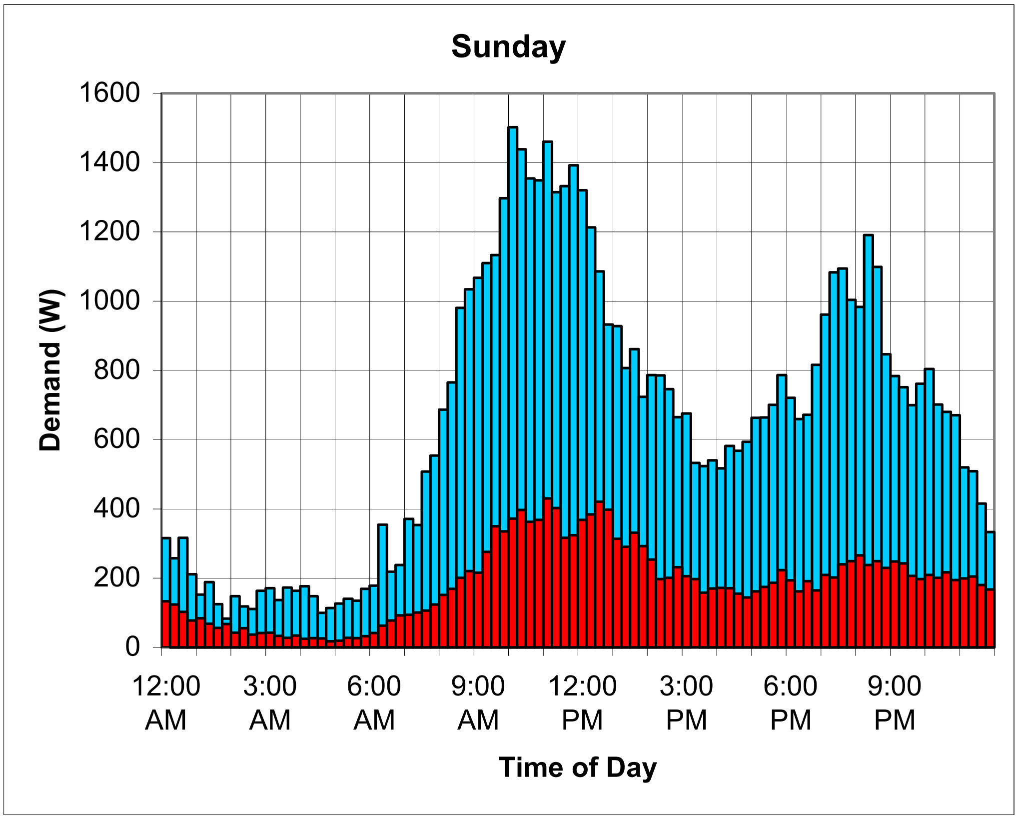


Figure 13 – Diversified Electrical Demand Sunday
Resistance Water Heater (blue upper curve) and HPWH (red lower curve)

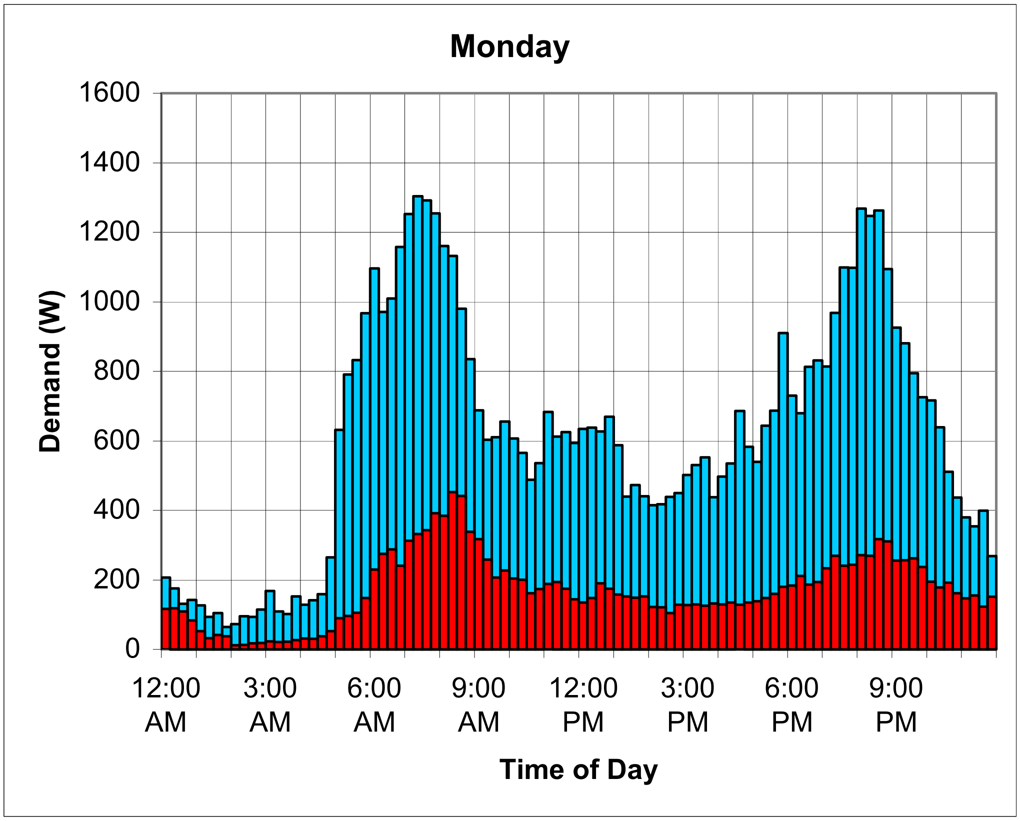


Figure 14 – Diversified Electrical Demand Monday
Resistance Water Heater (blue upper curve) and HPWH (red lower curve)

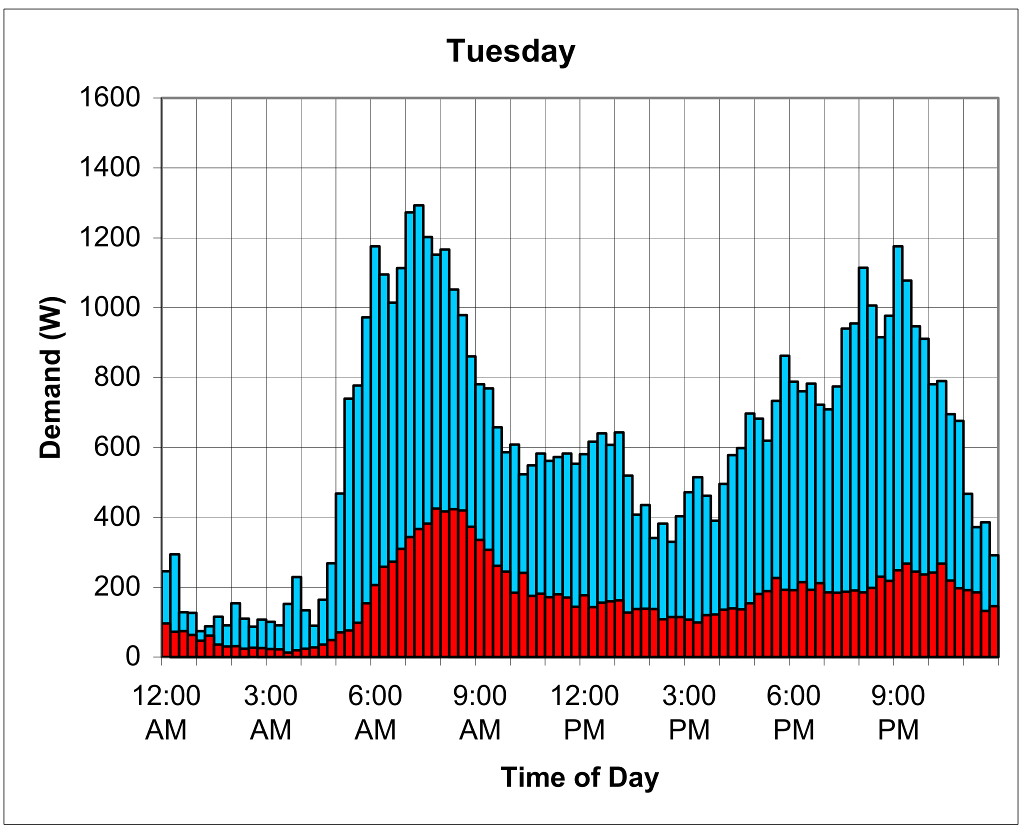


Figure 15 – Diversified Electrical Demand Tuesday
Resistance Water Heater (blue upper curve) and HPWH (red lower curve)

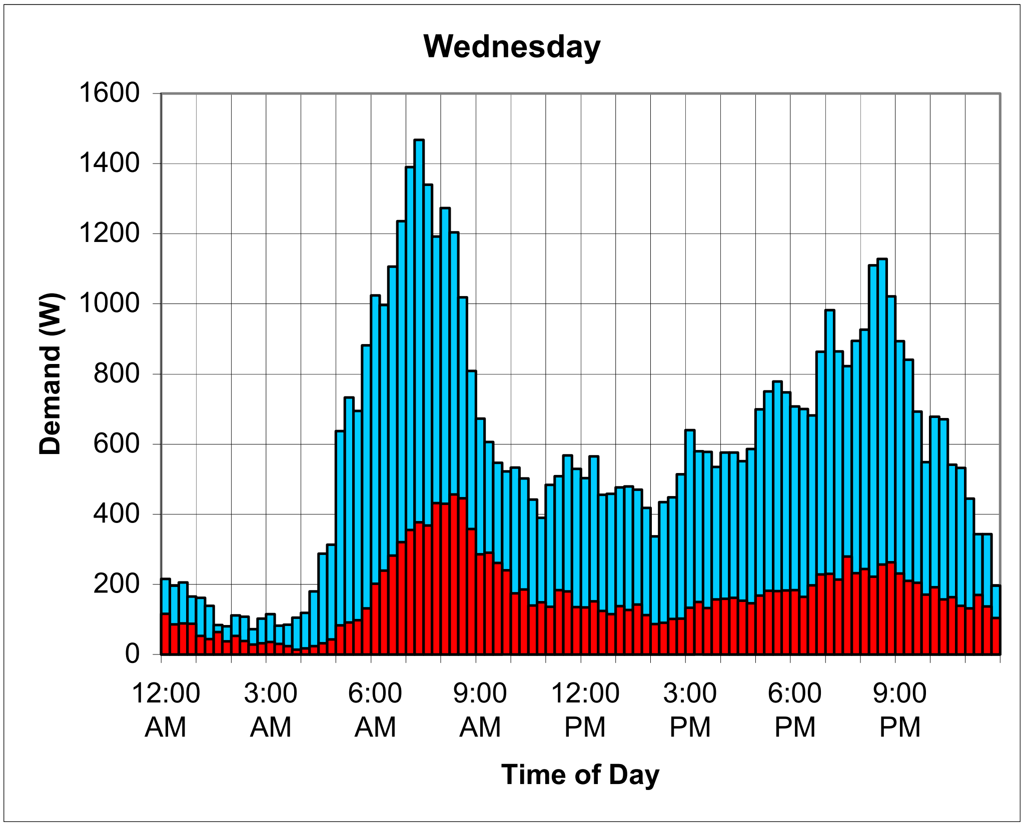


Figure 16 – Diversified Electrical Demand Wednesday
Resistance Water Heater (blue upper curve) and HPWH (red lower curve)

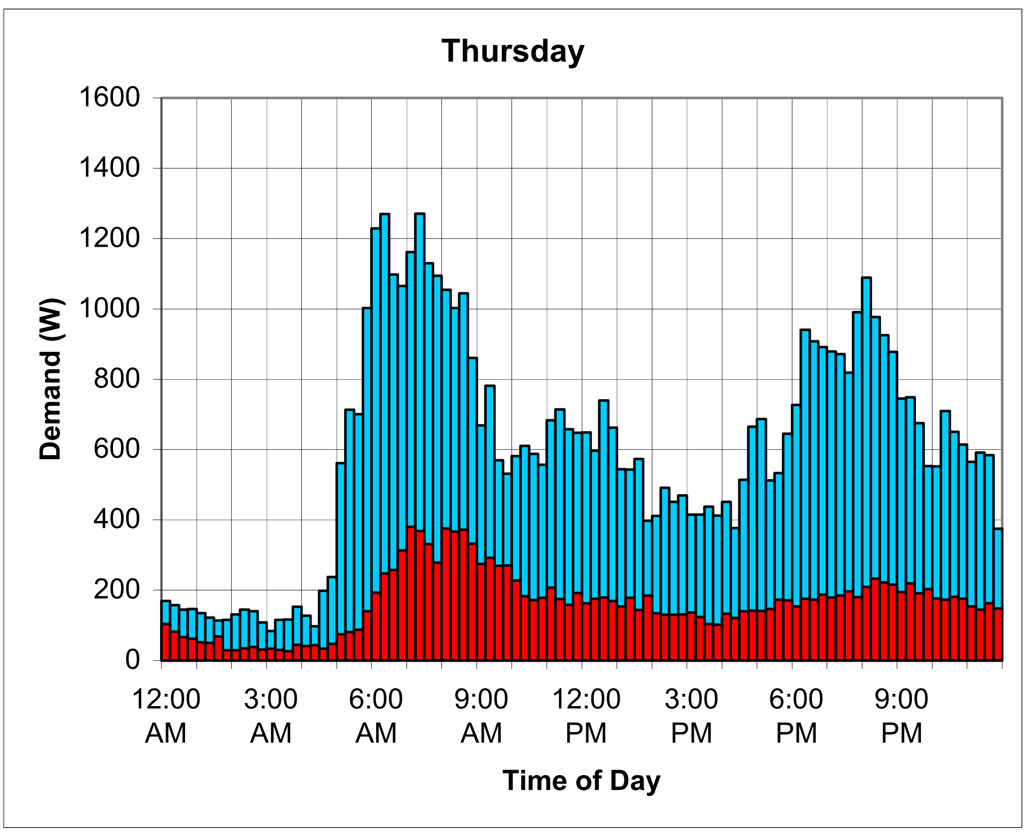


Figure 17 – Diversified Electrical Demand Thursday
Resistance Water Heater (blue upper curve) and HPWH (red lower curve)

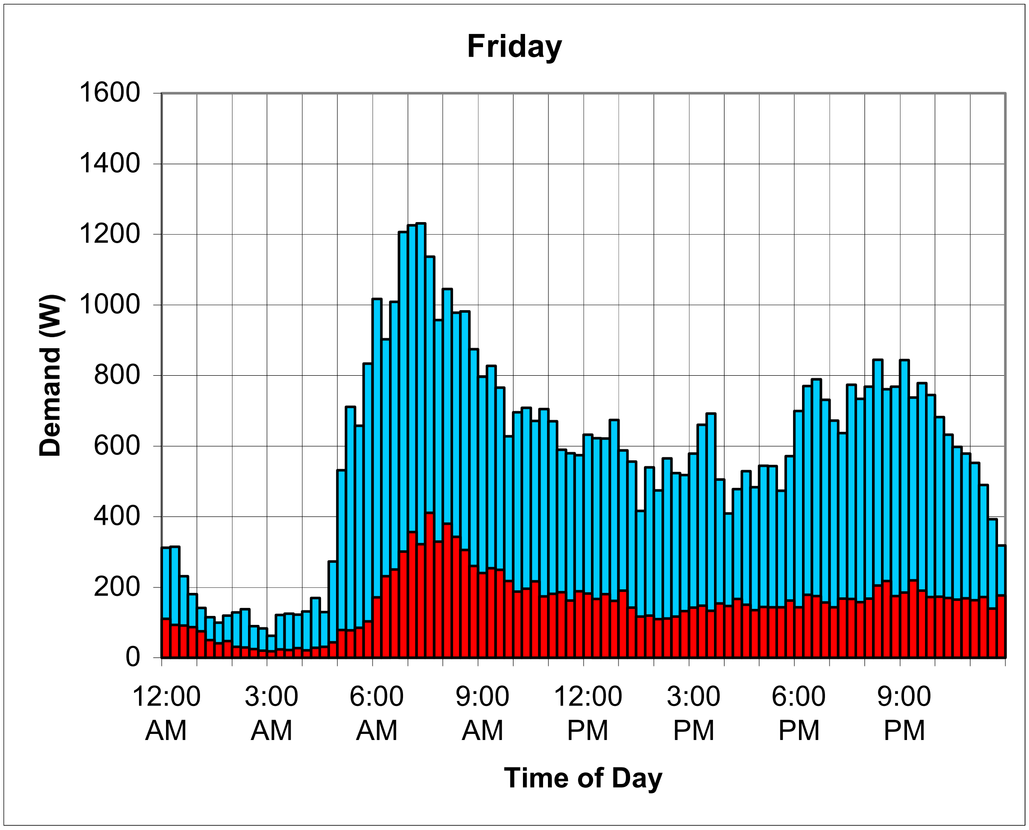


Figure 18 – Diversified Electrical Demand Friday
Resistance Water Heater (blue upper curve) and HPWH (red lower curve)

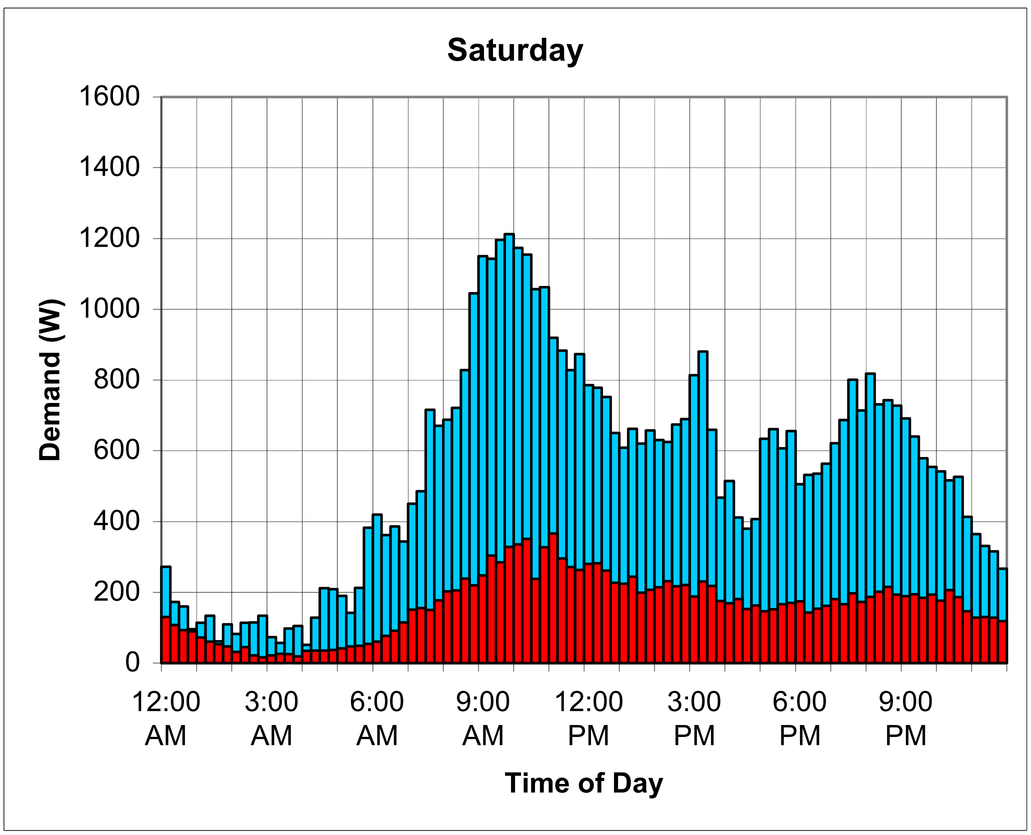


Figure 19 – Diversified Electrical Demand Saturday
Resistance Water Heater (blue upper curve) and HPWH (red lower curve)

Table 4

Site Number	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245
Satisfied overall?	Y	N (k)	(r)	Y	Y (s)	Y	YY	Y	Y(b)	N (m)	Y	Y	(h)	Y	N (o)
Run-outs?	N	Y		N	N	N	N	N	N	N	N	N		Y	N
Too hot?	N	N		N	N	N	N	N	Y(d)	N	N	N		N	N
Hot enough?	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	N
Aware of cooling?	Y	Y		Y	N	N	Y	(p)	Y	N	N	N		N	Y
Benefit?	Y			Y			Y		Y						
Bothersome?	N						N		N						YY
Aware of Dehumidification?	N	Y		Y	N	N	Y	(p)	Y	N	Y	Y		N	Y
Benefit?		Y		Y			Y		Y		Y	Y			Y
Notice savings?	Y	(q)		N	Y	N	Y	Y	N	NN	Y	Y		N (n)	N
Amount?	(i)				$30/$50		$25				10%	$15			
Sound?	1	2		2	2	2	1	2	(f)	1	2	1		3 (l)	2
Problems?	N	Y (k)		N	N (s)	N	(j)	N	Y	N	N	N		N	N
Maintenance?	N			(c)	N	N	N	N	N	N	(c)	N		(c)	N
Inconvenienced by data?	N	N		N	N	N	N	N	N	N	N	N		N	N

1 - VERY QUIET
2 - NOTICEABLE BUT ACCEPTABLE
3 - BOTHERSOME
4 - TOTALLY UNACCEPTABLE

Y - yes
YY - yes; very positive
N - no
NN - no; very negative

a) not sure, cannot tell if there are any savings
b) when it operates properly
c) occasionally cleans filter
d) HPWH is upstream of a coil-in-tank boiler; HW can be too hot when HPWH not operating properly
e) no longer needs to run dehumidifier in basement
f) quieter than the E-Tech unit
g) in room with oil furnace
h) HPWH failed during test, homeowner not interviewed
i) not sure of amount
j) installation problems: first unit replaced, condensate drain not installed properly on second unit
k) HPWH replaced once and repaired once
l) squeaks
m) no savings
n) hard to tell; four people moved in at start of test
o) doesn't heat fast enough; basement is too cold
p) possibly
q) slight savings
r) as of November 18, 2001, occupant not available for interview
s) satisfied after initial unit was replaced