



White Paper Heat Pump Water Heaters

Savings Potential in Minnesota

**Conservation Applied Research & Development (CARD)
FINAL REPORT**

**Prepared for: Minnesota Department of Commerce,
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Executive Summary

Introduction

Heat pump water heaters (HPWHs) take heat out of the air surrounding the unit and transfer it to water stored in its tank to be used for domestic hot water (DHW). The heat is transferred through a reverse refrigeration process. Because electricity is used to transfer heat instead of generate it, as done in a traditional electric resistance water heater, energy consumption can be substantially reduced. In recent years HPWHs have begun a resurgence into the residential water heating market. HPWHs were added to the U.S. Environmental Protection Agency ENERGY STAR® in 2008 and several major manufacturers have since developed models for the US residential market.

There are several climate-specific issues that may affect performance and energy savings in Minnesota's heating-dominated climate: the type of space heating, the presence of air conditioning, and whether the installation location is actively or passively conditioned or completely unconditioned. These items will all affect water heating energy consumption as well as net whole house energy consumption when using a HPWH.

Method

The project used existing research from field studies and laboratories across the country to make engineering calculations to determine the performance of HPWHs in MN. These calculations focused on the energy use necessary for typical Minnesota hot water usage patterns and the potential impacts of HPWHs on space conditioning for several different unit installation configurations. These calculations were used as the basis to develop two applications design to assist homeowners and utility program managers to make informed decisions about HPWH total energy savings and peak demand reduction.

Results

HPWH energy and cost savings have been estimated for a wide range of operating conditions in Minnesota. The amount of hot water used, current water heating fuel source, and location of the water heater have the largest impact on the savings. A home that uses around 50 gallons of hot water per day and has an existing electric resistance water heater installed completely isolated from the conditioned space can expect to save a little over \$215 a year, approximately a 6 year payback. The same water heater installed in the basement of the home or a mechanical room adjacent to conditioned space can expect a small penalty on the space heating energy use, reducing savings to around \$175 per year. The savings application considers all of these parameters, input by the user and calculated for a site specific savings estimate.

Conclusions

Nationally, HPWHs are gaining a market presence. HPWHs are generally seen as the preferred water heating solution in many warm and humid climates. Recently, HPWHs have seen increased installations in colder climates in the Northeast and Northwest. Several electric cooperative, municipals, and utilities offer HPWH rebates in Minnesota, but to date very few have been installed. While further research is recommended to determine the specific savings and peak reduction potential and verify performance in actual installations, analysis indicates that HPWHs are an attractive option for many Minnesota homes with electric water heating. Cold climate installations that would require installing the HPWH directly in occupied, conditioned space with temperature control (i.e. a thermostat) should be avoided, but typical basement installations in Minnesota are good HPWH applications.

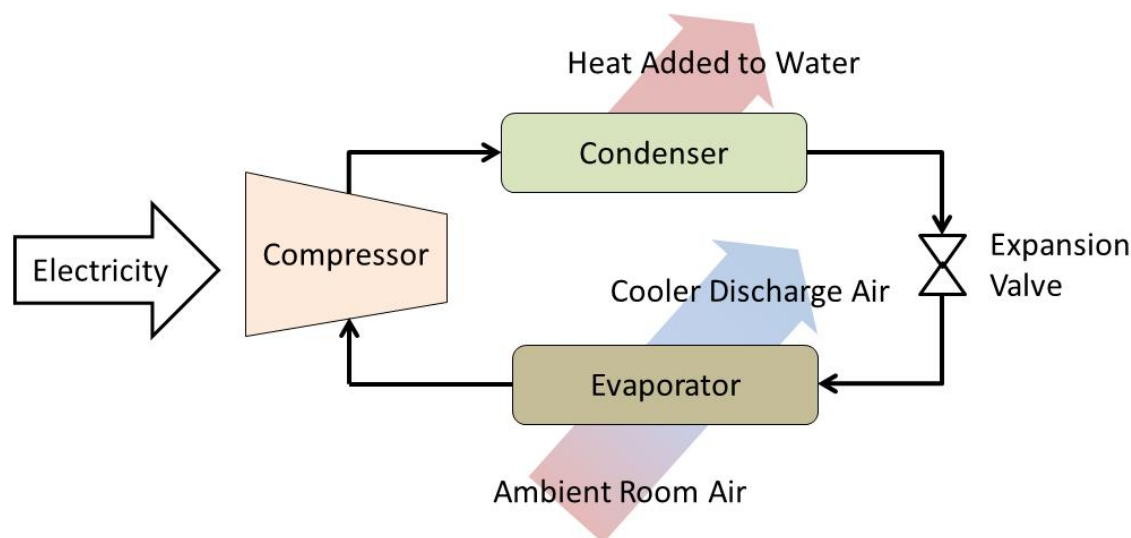
Introduction

In recent years heat pump water heaters (HPWHs) have begun a resurgence into the residential water heating market. In 2008 U.S. Environmental Protection Agency ENERGY STAR® added HPWHs to their labeling program and several major manufacturers have since developed models for the US residential market. While the majority of installations have been in warmer western and southern US climates, they are starting to spread across the country. There are several climate-specific issues that may affect performance and energy savings in Minnesota's heating-dominated climate: the type of space heating, the presence of air conditioning, and whether the installation location is actively or passively conditioned or completely unconditioned. These items will all affect water heating energy consumption, as well as net whole house energy consumption when using a HPWH. In addition, recent laboratory studies suggest that the Energy Factor (EF), the federal water heater efficiency rating value, may not accurately reflect the installed performance and energy savings potential of these units.

Heat Pump Water Heater Equipment

HPWHs use a reverse refrigeration cycle to take heat out of the air surrounding the unit and transfer it to water stored in its tank (Figure 1). The heat pump uses a cyclical process that transfers heat from the air to a vaporized refrigerant in the unit's evaporator. The compressor then increases the pressure and temperature of the refrigerant. The heated refrigerant passes through the condenser coil in the tank, transferring heat to the water. Delivering heat to the water cools and condenses the refrigerant. It then passes through an expansion valve and the cycle repeats.

Figure 1: Heat pump operational cycle



HPWHs, like all residential water heaters, are required to provide two ratings. The first is an EF (Department of Energy 2008), which is a measure of the unit's efficiency described by a ratio of the amount of energy produced in hot water to the amount of energy consumed in electricity under a specific 24 hour usage pattern. The second is a measurement of capacity, also known as

the first hour rating. This rating is the number of gallons the water heater can produce in one hour. For more information on rating metrics see the “Performance Metric” section below.

ENERGY STAR criteria require electric water heaters to have an EF of 2.0 or greater and a first hour rating of 50 gallons or more. Additionally, residential HPWHs must meet criteria for residential storage water heaters as well as UL safety criteria (Department of Energy 2008). As of January 2014 the ENERGY STAR database lists 30 HPWH models (Table 1) (Department of Energy 2014). All 30 of these models are “hybrid” HPWHs. Hybrid water heaters are shipped from the manufacturer with a heat pump, storage tank, and back-up electric resistance elements fully integrated. The ENERGY STAR qualified HPWHs account for nearly all residential HPWHs installed in the US. All the HPWHs listed in the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) residential database qualify for the ENERGY STAR label (AHRI 2014).

Table 1: ENERGY STAR certified HPWHs

Manufacturer	Brand Name	Model Number	Storage, Gallons	Input kW	Energy Factor	First Hour Rating
A.O. Smith	A. O. Smith	SHPT 50 100	50	4.5	2.75	67
A.O. Smith	A. O. Smith	PHPT 60 102	60	2.0	2.33	68
A.O. Smith	A. O. Smith	PHPT 80 102	80	2.0	2.33	84
A.O. Smith	American	HPSE10250H045DV 100	50	4.5	2.75	67
A.O. Smith	American	HPE10260H045DV 102	60	2.0	2.33	68
A.O. Smith	American	HPE10280H045DV 102	80	2.0	2.33	84
A.O. Smith	Kenmore	153.321151	50	4.5	2.75	67
A.O. Smith	Kenmore	153.321161	60	2.0	2.33	68
A.O. Smith	Kenmore	153.321181	80	2.0	2.33	84
A.O. Smith	Reliance	10 50 DHPST 100	50	4.5	2.75	67
A.O. Smith	Reliance	10 60 DHPT 102	60	2.0	2.33	68
A.O. Smith	Reliance	10 80 DHPT 102	80	2.0	2.33	84
A.O. Smith	State	SPX 50 DHPT 100	50	4.5	2.75	67
A.O. Smith	State	EPX 60 DHPT 102	60	2.0	2.33	68
A.O. Smith	State	EPX 80 DHPT 102	80	2.0	2.33	84
A.O. Smith	US Craftmaster	HPE2K60HD045V 102	60	2.0	2.33	68
A.O. Smith	US Craftmaster	HPE2K80HD045V 102	80	2.0	2.33	84
A.O. Smith	Whirlpool	HPSE2K50HD045V100	50	4.5	2.75	67
AirGenerate, LLC	AirGenerate	ATI66	66	5.5	2.35	70
AirGenerate, LLC	AirGenerate	ATI66DV	66	5.6	2.35	70
AirGenerate, LLC	AirGenerate	ATI80	80	6.8	2.20	80

Manufacturer	Brand Name	Model Number	Storage, Gallons	Input kW	Energy Factor	First Hour Rating
Bosch Corporation	Bosch	HP 200-1 E AI-F	50	4.5	2.20	58
Electrolux	Electrolux	EE66WP30PS	66	5.5	2.35	70
Electrolux	Electrolux	EE66WP35PS	66	5.6	2.35	70
GE Appliances	GE	GEH50DEED**	50	4.5	2.40	65
Rheem-Ruud	EcoSense	HB50ES	50	5.5	2.45	57
Rheem-Ruud	Rheem	HB50RH	50	5.5	2.45	57
Rheem-Ruud	Richmond	HB50RM	50	5.5	2.45	57
Rheem-Ruud	Ruud	HB50RU	50	5.5	2.45	57
Stiebel Eltron	Stiebel Eltron	Accelera 300	80	2.2	2.51	79

In the past reliability and maintenance were a major concern for HPWHs. One of the reasons for concern was that many of the manufacturers were small companies with limited or no warranty support. Since the creation of an ENERGY STAR label for HPWHs, several major manufacturers have developed units. These manufacturers bring improved warranties and more reliable manufacturing, as well as long term experience and success in the residential HVAC industry.

Most current residential HPWHs have three operating modes: heat pump only, hybrid, and resistance only. Hybrid is the most common operating mode. In this mode the heat pump is used as the primary source to meet the hot water demand. If the hot water demand exceeds the combined heat pump and storage capacity, electric resistance elements are used for quicker recovery of the tank temperature. When operating in heat pump only mode, the HPWH does not use the resistance elements. If the heat pump cannot meet the hot water demand, the outlet water temperature decreases until the demand decreases, allowing the heat pump to meet the load. Resistance only mode only uses the elements and prevents the heat pump from operating. This mode results in the HPWH operating in the same manner of a standard electric storage water heater.

Importance to Minnesota

The majority of HPWH installations have been in the warmer western and southern US climates. Installations have been spreading across the country to colder climates such as the Pacific Northwest and Northeast. The HPWH market in Minnesota has some unique constraints, such as semi-conditioned basement installations and a cold climate. Despite these constraints HPWHs have significant energy savings potential in Minnesota. HPWHs are designed for direct replacement of standard storage electric water heaters and over 30% of Midwestern homes use electricity as the primary fuel source for water heating (EIA 2009). In addition to existing electric homes, some new home builders in Minnesota are using electric water heaters to meet the venting and combustion safety requirements of the Minnesota Energy Code (Nelson 2010).

Project Objectives

The project objectives are to assess the applicability of HPWHs in Minnesota's climate and, if warranted, recommend next steps toward developing utility Conservation Improvement Program (CIP) programs to facilitate successful installations of the technology. The specific goals include:

- Defining the savings potential and technical feasibility of the installation and operation of residential HPWHs in Minnesota;
- Providing tools to assist utilities and utility customers to make appropriate decisions regarding the applicability of HPWHs in specific situations; and
- Providing tools to assist utilities to forecast the effects of HPWHs on utility load profiles.

Performance and Cost

Ratings and Metrics

Residential water heaters in the United States are all rated using the EF test. The EF value is an efficiency measured during a 24-hour period under a specific set of conditions. The energy consumption (in this case electricity) and hot water energy output are measured over 24 hours. There are six equal draws each separated by one hour with a total volume of 64.3 gallons following by 18 hours of idle time when there are no draws. The outlet water temperature is set to 135 °F with an ambient temperature of 67.5 °F. The EF value is the ratio of energy output to energy input during the test (Department of Energy 2001).

There are several aspects of the current EF rating method that cause it to generate an efficiency that is not representative of typical operation and can produce inaccurate comparisons of different technologies. The Department of Energy is currently developing a new EF rating method that is expected to be finalized in early 2014 (Energy Efficiency and Renewable Energy Office (EERE) 2011). The two most significant issues are the water draw pattern and the tank temperature. Six identical, large water draws is not representative of hot water draws in real applications and gives a benefit to water heaters that do not perform as well for small draws as for larger ones. However, the tank temperature is the most important rating condition for HPWHs. A water temperature set point of 135 °F has the potential to scald quickly and is higher than the typical value seen in real applications. This higher set point produces a more significant reduction in performance for HPWHs than for other technologies. The ambient temperature also has a large impact on HPWHs. When the units are installed in warmer or cooler conditions, the ambient temperature will cause significant differences in actual and rated performance of the system. The specified ambient temperature of 67.5 °F is reasonable for many applications, but a single point rating does not describe the effect the ambient temperature has on performance. These impacts are discussed in full in following sections.

For electric water heaters, installed efficiency is called coefficient of performance (COP) to differentiate from the EF value measured at specified conditions. Like the EF, the COP is the ratio of energy output in hot water to electrical consumption during the same time period. Unlike EF, the COP is calculated under the normal operating conditions for a given water heater in real world conditions.

Whole house energy saving is used as an additional metric for water heater performance. This metric combines the water heater efficiency for producing hot water and the impact of the HPWH on the operation of the whole house. HPWHs transfer heat from the air surrounding the unit into the stored water. Depending on climate and installation location, the cooling and dehumidification of the air surrounding the heater can impact the space conditioning load of the home. The whole house energy usage metric accounts for any impact the water heater has on the whole house energy consumption.

Performance

HPWHs can significantly reduce water heating energy consumption. The EF of HPWHs, 2.20 to 2.75, is much greater than that for the electric resistance water heaters (ERWH), 0.88 to 0.95, they often replace. The increase in EF corresponds to about \$350 annual savings, a greater than 60% savings. Table 2 compares the operating and installation costs of an ERWH and a HPWH for a daily average draw of 64 gallons. For these conditions the HPWH has a simple payback of less than 4 years.

Table 2: Estimated Annual Cost and Performance of HPWH vs ERWH

Water Heater	Daily Hot Water Usage Gallons	Energy Factor	Annual Energy Use KWh	Annual Energy Costs \$/year	Install Cost \$
Electric Resistance	64	0.93	4721	\$567	\$650
Heat Pump	64	2.40	1830	\$220	\$2,000

Note: Energy use and cost estimates come from the Energy Guide labels (which assumes \$0.12/kWh) (AHRI 2014) and the National Residential Efficiency Measures Database was used for installation cost data (National Renewable Energy Laboratory 2014a).

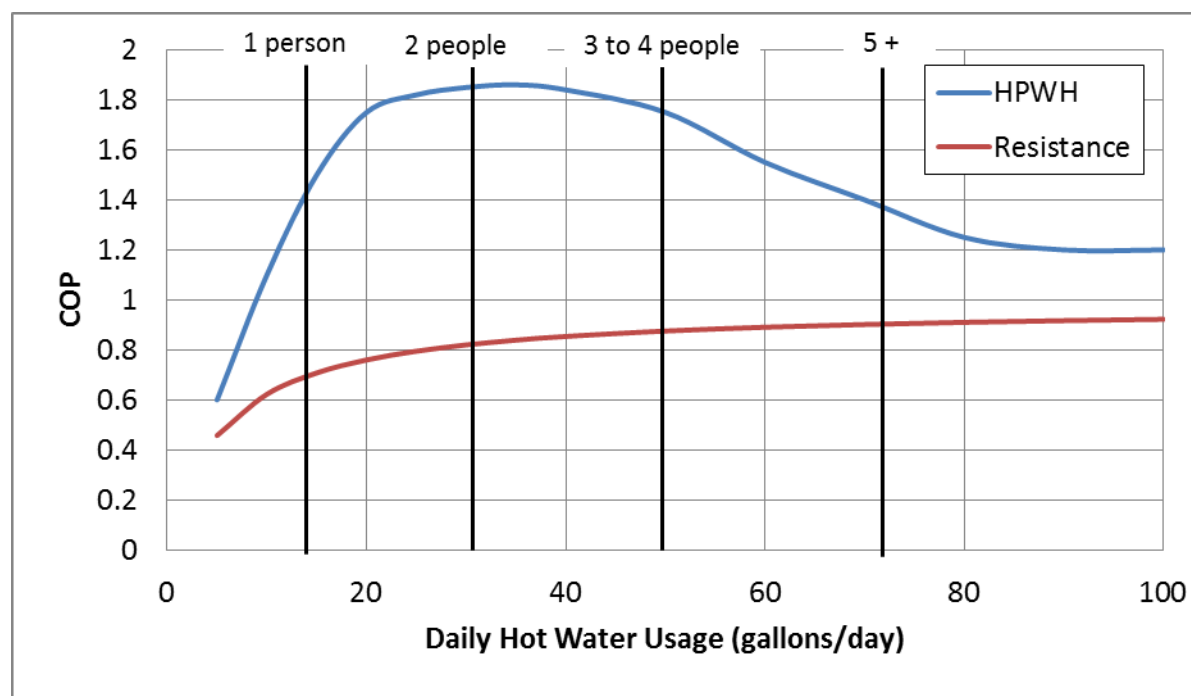
There are several key installation and use characteristics that impact the actual savings of HPWHs. Some of these characteristics impact all HPWH installations, while others are cold climate or Minnesota specific. The savings of all HPWHs depend on the hot water usage, water heater outlet temperature, and the space constrictions around the HPWH. The space heating characteristics of the home and how the HPWH interacts, as well as the air temperature and humidity near the water heater are parameters of particular importance to performance in Minnesota. The following sections describe each of these issues and provide important performance data. The magnitude of the impact on Minnesota installations is discussed in the “Performance in Minnesota: Savings” section and reflected in the HPWH Savings Application.

Performance Assessment through Field and Laboratory Testing

Hot Water Usage Pattern

Both the amount of hot water used and the pattern of use impact the efficiency of a HPWH (Shapiro, Puttagunta, and Owens 2012) (Glanville 2011) in several ways. For a 60 gallon HPWH these combined factors result in a maximum COP occurring between 20 and 30 gallons per day. Days with higher usage are much more likely to require electric resistance back-up, increasing electricity consumption. When DHW loads are smaller, the energy lost during stand-by is a substantial part of the total energy used, reducing efficiency. This relationship combined with detailed research of water heating loads in Minnesota (Bohac et al. 2010) was used to estimate the performance of HPWH for Minnesota usage patterns (Figure 2).

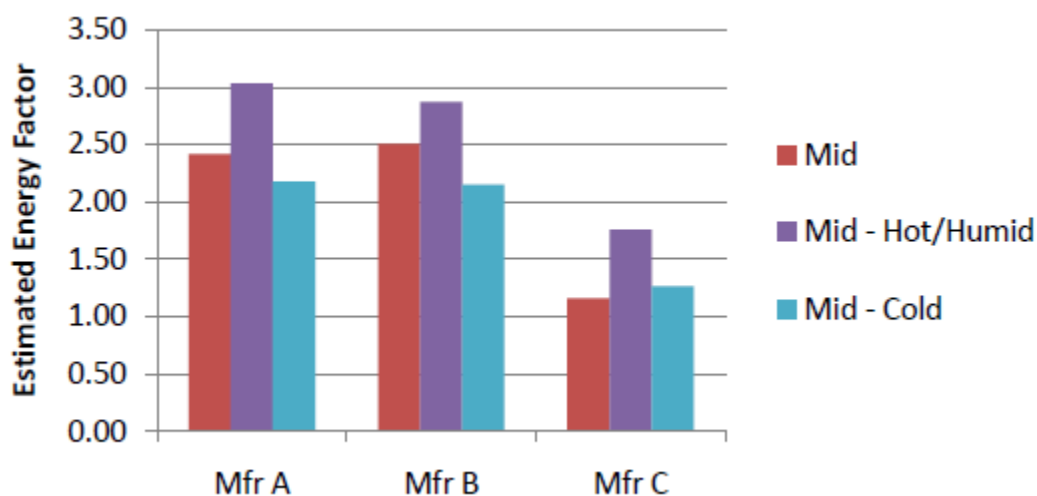
Figure 2: The relationship between water heater performance and hot water usage (Steven Winter, 2011) and typical hot water usage for Minnesota homes (CEE 2010)



Ambient Conditions

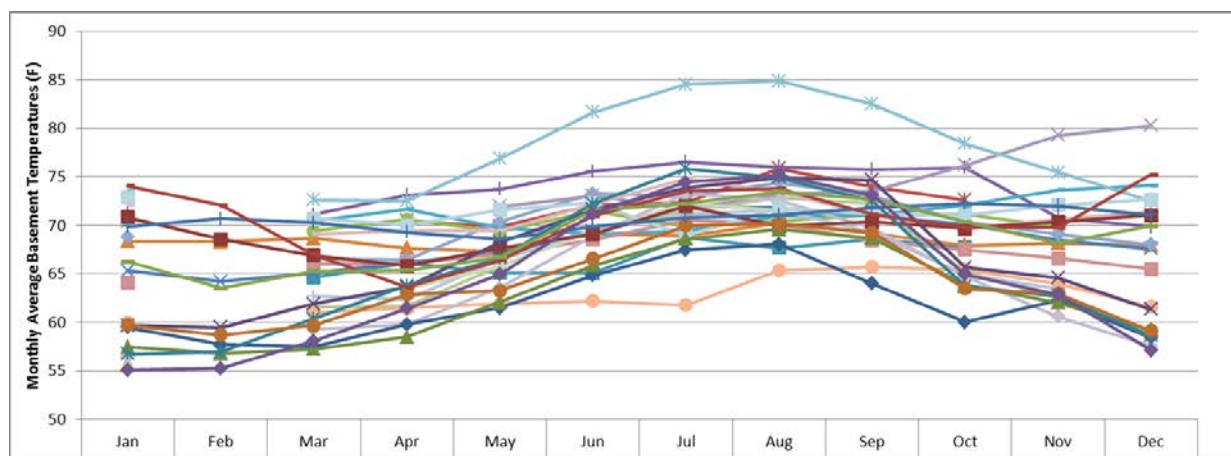
HPWHs transfer heat from the surrounding air into water stored in the water heater tank. The temperature and relative humidity of the air impact the performance of the water heater. Warmer and more humid air allow for greater heat transfer and improved performance. The heat pump will only operate between air temperatures of about 45 °F to 110 °F (different models have slightly different ranges). Air temperatures outside this range will force the unit into electric resistance only mode. As air temperatures approach the lower temperature limit the performance of the HPWH decreases. These results in lower heat pump capacity, reduced COP, more electric resistance operation, and increased energy usage. The impact on performance can be considerable. The Gas Technology Institute (Glanville 2011) has conducted HPWH tests of the EF rating method applied at various ambient air conditions (Figure 3). The EF test's specified ambient conditions are 67.5°F and 50% relative humidity. Tests were also run at 90 °F and 65% relative humidity (hot/humid) and 50°F, 70% relative humidity (cold). For all three manufactures tested, the EF dropped by almost a full point (from 3.0 to 2.2) between the hot/humid and cold test conditions.

Figure 3: Energy Factor test results at various ambient conditions



CEE monitored basement temperatures near water heaters in 29 homes in the Twin Cities metropolitan area. The average annual temperature in these homes was 68 °F, the same temperature used in the EF rating method. This indicates that the ambient air dry bulb temperature for the rating conditions is consistent with the average for Minnesota water heaters. However, field data varied from home to home (Figure 4). The annual temperatures varied from 60 °F to 75 °F for individual homes and in the winter temperatures at some sites dropped to around 55 °F. The water heater locations in these homes varied from basements that were totally unfinished and unconditioned to smaller unconditioned mechanical areas. No statistically significant trend was found between basement type and average annual temperature.

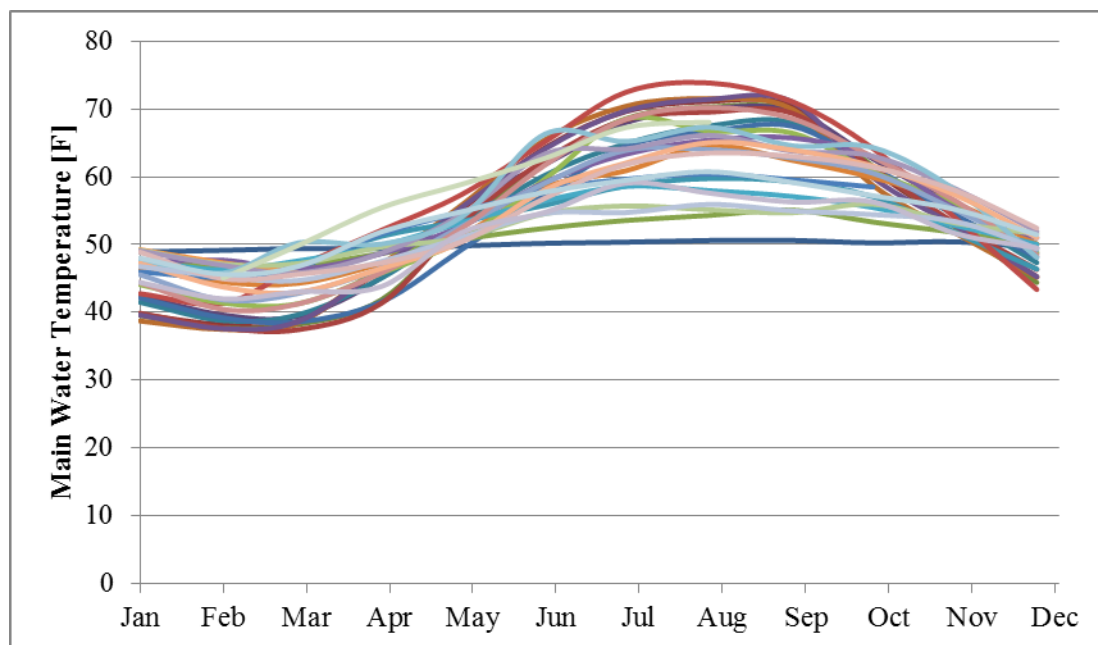
Figure 4: Twin Cities metro area basement temperatures



The water temperature entering the home also impacts the water heater performance. Colder inlet water requires more energy to heat the water to usable temperatures, increasing the DHW load. CEE has collected inlet water temperature data at 29 Minneapolis/St. Paul metro area homes since 2010. Data was collected and analyzed to create annual water temperature profiles for the water entering each home (Figure 5). Average annual inlet temperatures ranged from 50

°F to 60 °F. Average inlet water temperatures vary from home to home due to changes in local ground temperature, depth of the buried main pipe, the source of water (surface versus well), and the different processes run at the treatment plants. Homes connected to wells had less seasonal temperature variation than homes supplied by surface water. For the entire set of houses the winter inlet temperatures ranged from 38 °F to 50 °F, while summer temperatures were between 50 °F and 70 °F.

Figure 5: Inlet water temperature profiles for 29 homes in the Minneapolis/St. Paul metro area.



Installation and Space Conditioning

The HPWH location in the house can impact performance. HPWHs transfer heat from the air around the unit to the water. A sufficient supply of air is required in order to efficiently transfer heat. Manufacturers typically require the room volume to be at least 750 ft³. Installing the heater in a small mechanical close (about 450 ft³) has been shown to reduce the HPWH COP by 30% (Shapiro, Puttagunta, and Owens 2012). Installation in larger rooms, or the use of louvered doors, is necessary to achieve optimal HPWH performance.

The concern with placing HPWHs in smaller spaces is that the heaters cool the surrounding air. Air exhausted from HPWHs is typically 5 °F to 7 °F cooler than air entering the unit. A HPWH supplying 50 gallons of hot water per day will produce 1.0 ton-hours of cooling (R. A. Davis 2010). Depending on the installation location and space conditioning needs of the home, this cooling can be a benefit or a drawback. When the HPWH is installed inside the conditioned space the cooling effect will interact with the space conditioning systems. During the heating season the HPWH will increase the space heating load. If the home has air conditioning, the HPWH will reduce the load in the cooling season. If the home does not use air conditioning, the HPWH will deliver some no-cost cooling and dehumidification. In Minnesota, water heaters are often installed in semi-conditioned basements. Basements typically have minimal insulation

and limited heating/cooling supply registers. When this is so, combined with the cooler ground temperatures Minnesota basement temperatures typically range from 55 °F to 75 °F. A HPWH installed in a typical Minnesota basement will have an impact on the space conditioning load. Basements typically are not directly conditioned (no supply registers) or controlled (no thermostats). The impact on the heating and cooling load will be indirect. Colder basement temperatures will impact the heat transfer from the basement into the first floor of the home. The basement temperature will also impact the heat loss of ducts and pipes providing space heating distribution, which typically run through the basement.

The impact will be less important in homes with higher efficiency heating and cooling systems. For example, if the heating system of a home uses electric resistance baseboards as the primary heating source, any make-up heat that must be added to the home due to the HPWH will be added at the baseboards efficiency, about 95%. If the same home used an air source heat pump system with a COP of 2.50, the make-up heat for the water heater would consume about the same as the electric resistance case.

Most current HPWHs have additional intake air and venting kits. The primary use of these kits is to improve the performance of HPWHs in small mechanical spaces. The venting and intake air kits allow installers to duct the exhaust and air sources from adjacent rooms. However, these kits could be used to duct exhaust and/or intake air from unconditioned spaces or from outside. These venting options can eliminate the space conditioning penalty. When using ducting kits, pressure impacts must be considered. If HPWH exhaust is ducted to the outside to avoid the space heating impact, depressurization may cause increased infiltration of outside air when the heat pump is running. In cold climates the increased infiltration is a larger penalty than the heat pump exhaust.

Outlet Water Temperature

Laboratory testing of three different HPWHs showed that lowering the set point of HPWHs reduced the units' capacity, but increased their COP (Glanville 2011). The first hour rating was reduced because less energy was stored in the hot water when the set point temperature was reduced. The COP was higher because there is an upper limit for the water temperature for the process used to transfer heat from the air to water. Set point temperatures greater than 125-130 °F cannot be met by the heat pump alone and require some electric resistance to achieve the higher temperatures.

Performance Assessment through Modeling

Well-developed models allow program managers, designers, installers, and homeowners to quickly access the changes in performance in various scenarios. This ability can help guide decision-making about HPWH installations and program design. Several different software programs can be used to model HPWH performance. They fall into two basic categories. The first category is detailed transient models, such as TRNSYS (University of Wisconsin - Madison 2013) and a model developed by Ecotope (Larson, Logsdon, and Baylon 2011). These models are capable of simulating many aspects of HPWH performance, but require very complex inputs and are labor intensive. The second category is simpler models, such as BEopt (National Renewable Energy Laboratory 2014b) and EnergyPlus (Building America 2014). These models

were developed based on laboratory data and other, more detailed models. Because simple models require less computation and have fewer inputs, they require much shorter run times than the more detailed models.

Heat transfer calculations in basements present a challenge to all building models. The interactions between the basement and the living space and/or the soil are very difficult for any building energy applications to model, and little field data exists to calibrate these models. Typical residential Minnesota water heater installations are in the basements, which impacts the accuracy of HPWH models in Minnesota.

Detailed Models

The detailed models offer several benefits. They map HPWH performance with lab and field data over a range of ambient temperatures, inlet water temperature, and outlet water temperatures. They can also analyze specific housing details, such as the building characteristics, space heating loads, and hot water usage. These models are transient, allowing them to analyze variations in space conditioning, weather data, and water heating over time. While not a focus for this study, these models also have a capability to assess different venting configurations, installation restrictions, and control strategies.

The main disadvantages of detail models are the time and effort required to setup and run them. These models take a long time to develop and require a large amount of experience with the modeling software. Simulation times can be very long due to the transient interactions being modeled. Detailed models require a large amount of data to run accurately. Several hours or more is often necessary to develop and enter this input data. This means that detailed hot water usage patterns can be hard to create due to the large variability of use in real homes.

Simple Models

The biggest benefits of the simple models are their ease of use. They can be run without a large amount of set-up and/or knowledge of the software. Simple models also have short simulation times. The BeOpt and EnergyPlus models were developed from a combination of results of many TRNSYS simulations that were calibrated with laboratory and field data. The model accounts for ambient air temperatures, inlet water conditions, and hot water use.

The disadvantages of these models are that they have limited choices on water heat installation conditions, venting choices, and hot water usage profiles. Variations in these characteristics impact the water heater performance, capacity, and impact on the space conditioning load. However, the values for those characteristics typically cannot be adjusted and may not properly compute performance for the actual installation conditions.

Applying Models to Minnesota

Both detailed and simple models may be useful tools for utilities in developing or modifying HPWH rebate programs. Both models can be used to look at the installed performance of heat pumps with operating conditions and installations typically found in Minnesota. However, there are some specific areas where these models can be improved. The models could be improved by using more realistic hot water draw profiles and modeling the impacts of enclosed

area installations. Minnesota specific factors that should be addressed include the interaction between heat pump water heaters and the space conditioning load of the home, especially for basement installations.

Most models are built around either the Department of Energy rating standard's hot water usage pattern or an independently developed hot water usage pattern. However, the Department of Energy pattern does not represent realistic residential energy use (six equally-spaced draws of about ten gallons each) and the independently developed patterns lack consistency. Test standard development by Department of Energy and ASHRAE is in the process of creating standard usage profiles for different sized loads (small, medium, and large use homes). The usage volume and pattern significantly impact the performance of a water heater. A well-developed set of standard patterns would improve the consistency of HPWH modeling.

Field testing has shown that the COP of HPWHs can be significantly reduced if the unit does not have access to enough clearance and enclosed area. A model to assess the impact of installing a HPWH in an enclosed area, such as a mechanical room or closet, would benefit installers, homeowners, and program managers.

The impact of HPWHs on the space heating load can have a significant impact on homes in heating dominated climates. Detailed building models have recently started to characterize these impacts. However, modeling the heat transfer surrounding the HPWH is a complex problem. These interactions become increasingly difficult for typical Minnesota installations. Basement heat transfer modeling has been challenging to accurately incorporate into building energy models and the wide range of basement configurations and heating controls complicate interactions between the water heater and the space heating load. These complexities show the need for models to be calibrated and checked against real world data. That data is not currently available. The University of Minnesota research is currently measuring heat loss in basements and foundations of various construction types. This work is being conducted in part to support the development of improved heat transfer modeling in basements.

Performance in Minnesota

The performance of HPWHs installed in Minnesota is characterized by two metrics. The first metric is the coefficient of performance, which measures the efficiency of heating the hot water. The second metric is the impact of the HPWH on the whole house space conditioning load, which combines the increase of the HPWH on the space heating loads and reduction of cooling loads. The COP and impact on conditioning characteristics can be combined to determine the annual energy savings and paybacks for HPWHs.

Coefficient of Performance

The COP is a ratio of the energy delivered by the water heater to the electrical energy consumed by the process. The COP is impacted by many of the characteristics discussed in the report. The impact on COP was estimated using data collected in Minnesota and information from US laboratory and field research projects. The three characteristics that had the largest impact were: the HPWH operation mode, the hot water usage of the home, and the ambient conditions surrounding the water heater.

HPWHs are intended to be run in hybrid mode. This mode provides significant energy savings while ensuring the availability and delivery of hot water. Because this is the most common and the intended mode of operation, the analysis assumed the unit would be used only in the hybrid mode. If the unit were to be operated in heat pump only mode, the savings would be slightly increased, but the increase in savings would likely come with a reduction in hot water delivery quality. If the unit were operated in electric resistance mode, there would be no savings.

Table 3 shows the estimated HPWH performance under Minnesota operating conditions. Data from a field and laboratory research project (discussed earlier) was compiled and adjusted to reflect ambient conditions and water usage patterns for typical Minnesota residents. The total hot water volume and the clustering of large uses impact the HPWH performance. If large DHW events, such as baths and showers, occur simultaneously or back to back, the HPWH tank temperature decreases without time for the heat pump to meet the load. The electric resistance will turn on, reducing the COP. When showers are spread out throughout the day, the heat pump will have more time to recover from the draws, reducing the need to resistance heat and improving the COP. The table also reflects average Minnesota basement conditions.

Table 3: Coefficient of performance and estimated savings for HPWHs.

Occupants	Showers Clustered?	Daily Hot Water Volume Gal/Day	COP	Energy Consumption		Savings (DWH Only)		
				kWh/yr	\$/yr	kWh/yr	\$/yr	%
1	No	24	1.92	777	\$93	918	\$110	54%
2 to 3	No	48	1.86	1605	\$193	1785	\$214	53%
4	No	54	1.74	1927	\$231	1887	\$226	49%
5 and up	No	80	1.37	3640	\$437	2010	\$241	36%
2 to 3	Yes	48	1.76	1696	\$203	1694	\$203	50%
4	Yes	54	1.64	2044	\$245	1770	\$212	46%
5 and up	Yes	80	1.27	3926	\$471	1724	\$207	31%

Note: These savings do not account for space conditioning effects.

Whole House Energy Savings

Estimating the whole house energy impact of a HPWH is a four step process.

Step one. The first step is to use the hot water usage of a home to determine the amount of cooling the HPWH delivers (Figure 6)(R. Davis 2010). This cooling effect reduces the air temperature around the HPWH.

Figure 6: Relationship between daily hot water usage and HPWH cooling

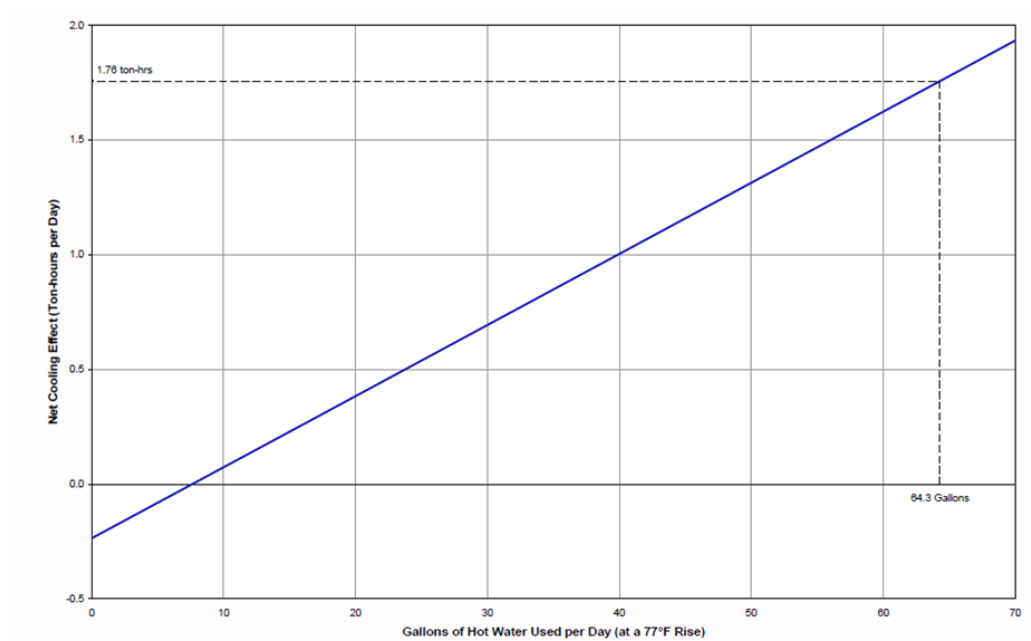
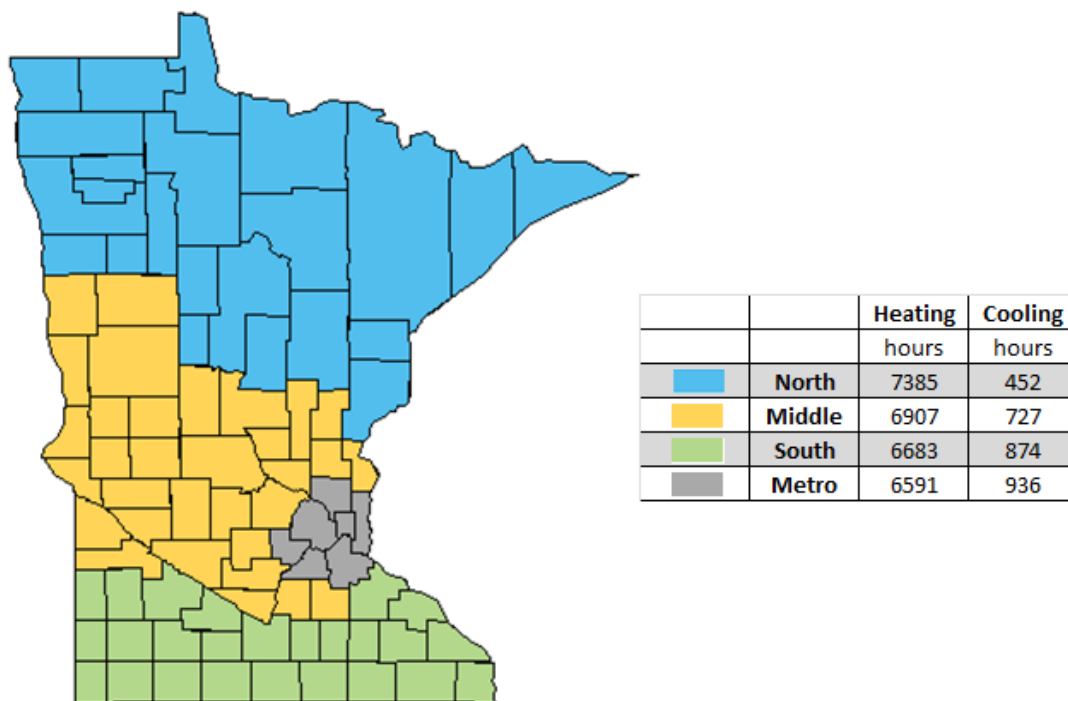


Figure 7: Minnesota space conditioning regions



Step two. The second step is to use the geographical location of the home to determine the amount of time spent in heating and cooling. National Oceanic and Atmospheric Administration weather data from 1981 to 2010 was used to determine the normal heating and cooling hours for 219 weather stations in Minnesota. These weather norms were grouped into four regions by similar heating and cooling seasons: North, South, Middle, and Metro (Figure

7). The HPWH cooling effect is considered a potential penalty when in heating and a potential benefit during space cooling. Locations with longer heating seasons have more potential penalties from HPWH cooling than homes with less heating needs.

Step three. The third step is to use installation location within the home to determine the demand on the space conditioning systems due to the HPWH cooling effect. There are several ways the HPWH cooling can interact with the space conditioning load. If the HPWH is in a space with a thermostat or other temperature control, the space cooling effect will be directly measured and the full impact of the cooling will affect the space conditioning loads. If the space is not actively controlled, the temperature will be allowed to drift without direct impact on the space conditioning system. However, the lower temperature in this space will interact with the adjacent conditioned spaces. If the water heater area is well connected to the rest of the home the impact will be greater than if the space is isolated from the rest of the home. If a water heater is installed in an area with no thermostat that is sometimes occupied (a finished basement, for example), the occupant may manually adjust the temperature in the space. Table 4 shows the different combinations of installation location characteristics and the impact on space conditioning.

Table 4: Impact of HPWH cooling effect on the space conditioning load of the home

Installation Characteristics			Impact
Thermostat	Finished Space	Supply Register	
No	No	No	Indirect
No	No	Yes	Indirect
No	Yes	No	Indirect
No	Yes	Yes	When Occupied
Yes	No	No	N/A
Yes	No	Yes	Direct (100%)
Yes	Yes	No	N/A
Yes	Yes	Yes	Direct (100%)

Note: Options with a thermostat but no supply resistor are listed as N/A, because they should not occur in practice.

Step four. The final step is to use the heating and cooling system characteristics and computed loads to compute the change in space conditioning energy use. For space heating, the system efficiency will be used to determine the increase in energy use necessary to meet the increase in heating caused by the HPWH. The fuel type will determine the cost of that energy increase. On the cooling side, the system efficiency is necessary to determine the reduction in energy consumption, as is an indication of how the system is operated. For homes that use window A/C units and only operate them occasionally, the reduction in energy use will be much smaller than for a central system with continuous operation.

Table 5 provides a summary of the savings for a HPWH replacing an electric resistance water heater in a Twin Cities metropolitan area home. The calculations assume the home has an air source heat pump for space heating, a central air conditioning system that is always on, and a

HPWH installation in an unfinished basement with no thermostat. Cost savings information for other conditions are presented in the HPWH Calculator section.

Table 5: Summary of Savings matrix for a metro area HPWH install

People	Showers Clustered	Hot Water Volume Gal/Day	COP	Energy Use kWh/yr	Savings (DWH Only)		Heat-ing Impact kWh/yr	Cool-ing Impact kWh/yr	Whole House Savings	
					kWh/yr	%			kWh/yr	\$/yr
1	No	24	1.92	777	918	54	186	-18	750	\$90
2 to 3	No	48	1.86	1605	1785	53	359	-35	1461	\$175
4	No	54	1.74	1927	1887	49	379	-37	1545	\$185
5 & up	No	80	1.37	3640	2010	36	440	-43	1613	\$194
2 to 3	Yes	48	1.76	1696	1694	50	340	-33	1387	\$166
4	Yes	54	1.64	2044	1770	46	357	-35	1448	\$174
5 & up	Yes	80	1.27	3926	1724	31	408	-40	1356	\$163

Note: Assumes replacement of a EF=0.89 ERWH, an Air-source heat pump and central A/C

In addition to water heating and space cooling, HPWHs also provide some dehumidification of the surrounding air. The amount of dehumidification varies with inlet air condition and hours of operation. In basement installations this additional dehumidification can be a significant benefit and in some cases may reduce humidifier energy use. An accurate estimate of the dehumidification savings potential requires knowledge of a large number of parameters about the operation, control, and performance of existing dehumidification systems. Modeling and/or field research is needed on the dehumidification potential of HPWHs and how dehumidifiers are typically operated in Minnesota.

Cost

The National Renewable Energy Laboratory maintains a database on the costs of retrofit installation of energy efficient technologies for residential buildings (National Renewable Energy Laboratory 2014a). The database lists total costs for replacing a typical ERWH with a HPWH. The large 80 gallon HPWHs are significantly more expensive to install than smaller models (\$3,300 compared for 80 gallon models to \$2,100 for the 50 and 60 gallon models), primarily due to the additional cost of the HPWH itself. Recent research by Shapiro and Pattagunta (2013) found similar installation costs in their field research. These installations were in a cold climate that is relatively new to HPWH installations and the costs should be representative of Minnesota HPWH installations (Table 6).

Table 6: Electric water heater installation costs

Source	Installed Cost	
	50 to 60 Gallon HPWH	80 Gallon HPWH
NREL Database	\$2,100	\$3,300
Shapiro and Puttagunta, 2013	\$1,900 to \$2,100	\$3,300 to \$3,500

Table 7 shows the simple paybacks for the incremental costs of a HPWH installed under typical conditions in Minnesota. The payback is about 5 years when the unit is installed in a space that is not directly controlled by a thermostat and where DHW loads are between 30 and 80 gallons per day. Paybacks double with large DHW loads that require the use of a more expensive 80 gallon unit and with small DHW loads (less than 30 gallons) with reduced COP and total usage.

Table 7: Simple payback for HPWHs in Minnesota

Occupants	Showers Clustered?	Daily Hot Water Volume gallons/day	Whole House Savings		Incremental Cost \$	Simple Payback years
			kWh/year	\$/year		
1	No	24	750	\$90	\$1,100	10.0
2 to 3	No	48	1461	\$175	\$1,100	5.1
2 to 3	Yes	48	1387	\$166	\$1,100	5.4
4	No	54	1545	\$185	\$1,100	4.9
4	Yes	54	1448	\$174	\$1,100	5.2
5 & up	No	80	1613	\$195	\$2,300	9.5
5 & up	Yes	80	1356	\$163	\$2,300	11.1

Note: Assumes replacement of an EF = 0.89 ERWH, and an air-source heat pump w/ central A/C

Impact of HPWHs on Peak Demand

While there are significant hour to hour and house to house variations in hot water usage, there are common patterns when groups of houses are considered in aggregate. In most homes, there are significant peaks in hot water usage due to shower and sink draws and also in the evening around dinner time. This pattern is not universal, but it is common. These hot water clusters align with the peaks use for most utilities. Figure 8 shows typical hot water usage profiles at several Minnesota homes (Bohac et al. 2010). Typical storage water heaters fire for one to two hours following a high demand. Gas use from the morning hot water peak frequently occurs during the higher rate period for MN utilities with time of day rates (Xcel Energy 2013 and MN Power 2015).

The reduction in energy consumption for the HPWH will reduce the peak load for DHW. Figure 9 shows the energy consumption for a HPWH and an ERWH under the same usage pattern. The electricity consumption for this example was estimated using a simple model. A simple model was created based on laboratory and field data (as previously described in this report) for storage water heaters and HPWHs. The figure shows much larger capacity of the electric resistance elements (4,500 Watts) compared to the smaller consumptions of the HPWH compressor and fans (600 Watts). The HPWHs run for a longer period of time, but at a much lower rate.

Figure 8: Typical Weekday Hot Water Usage Profile for MN Homes (Bohac et al 2010)

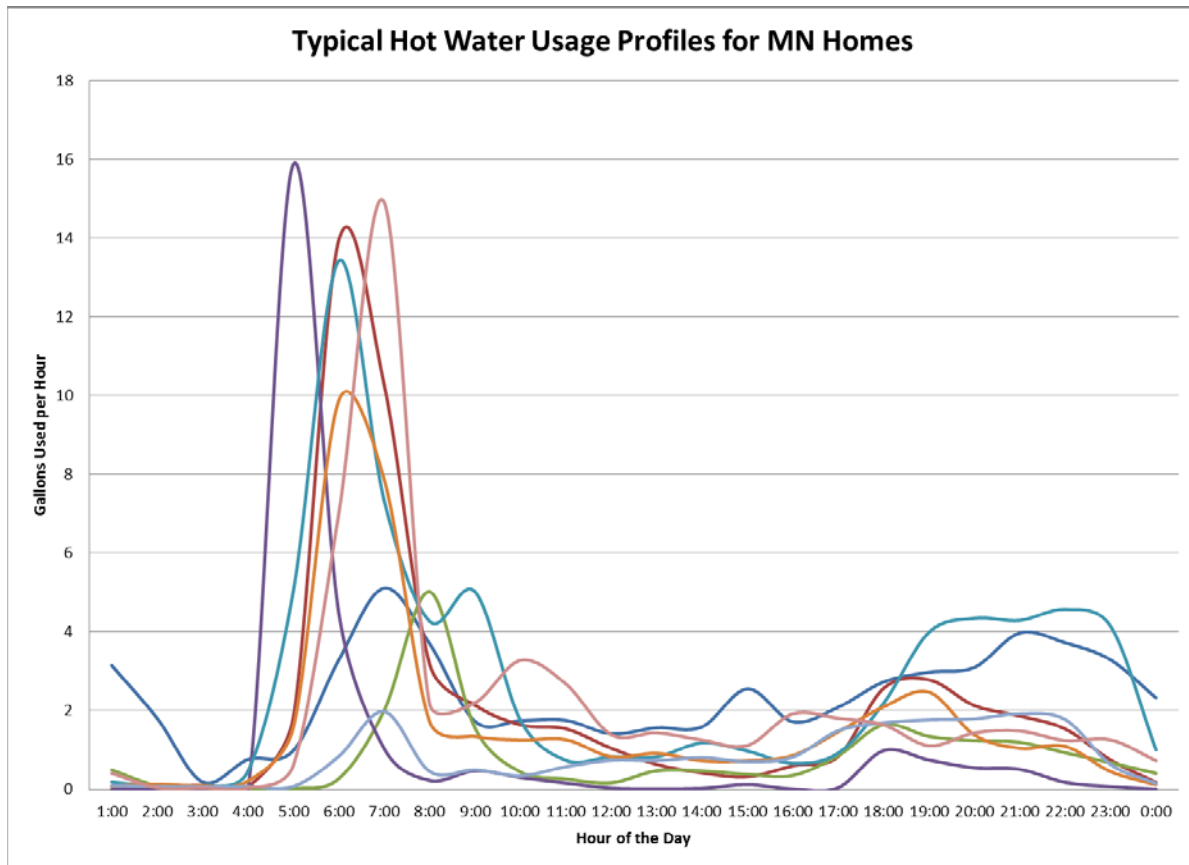
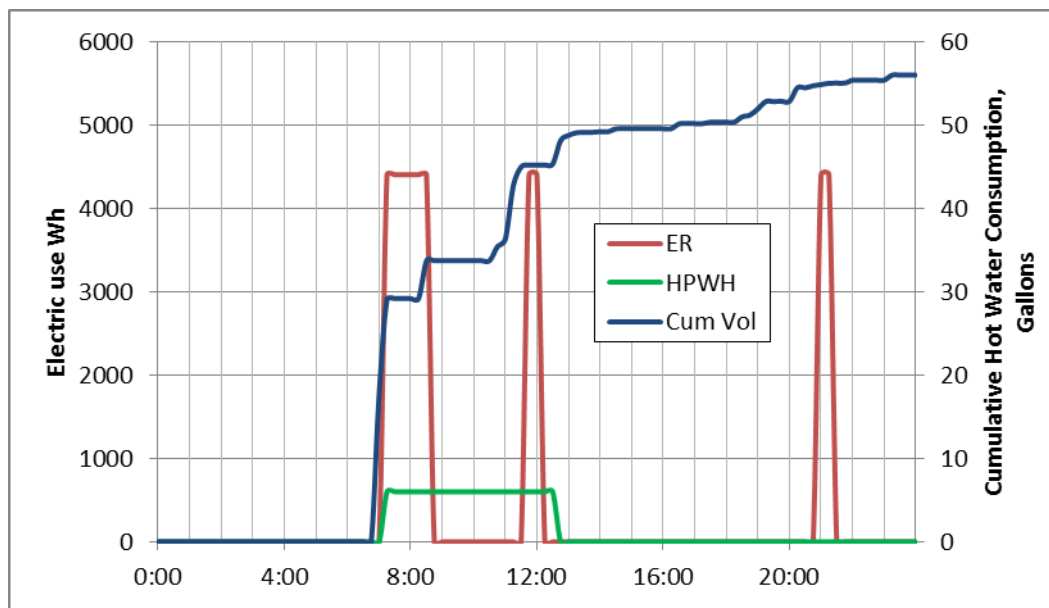


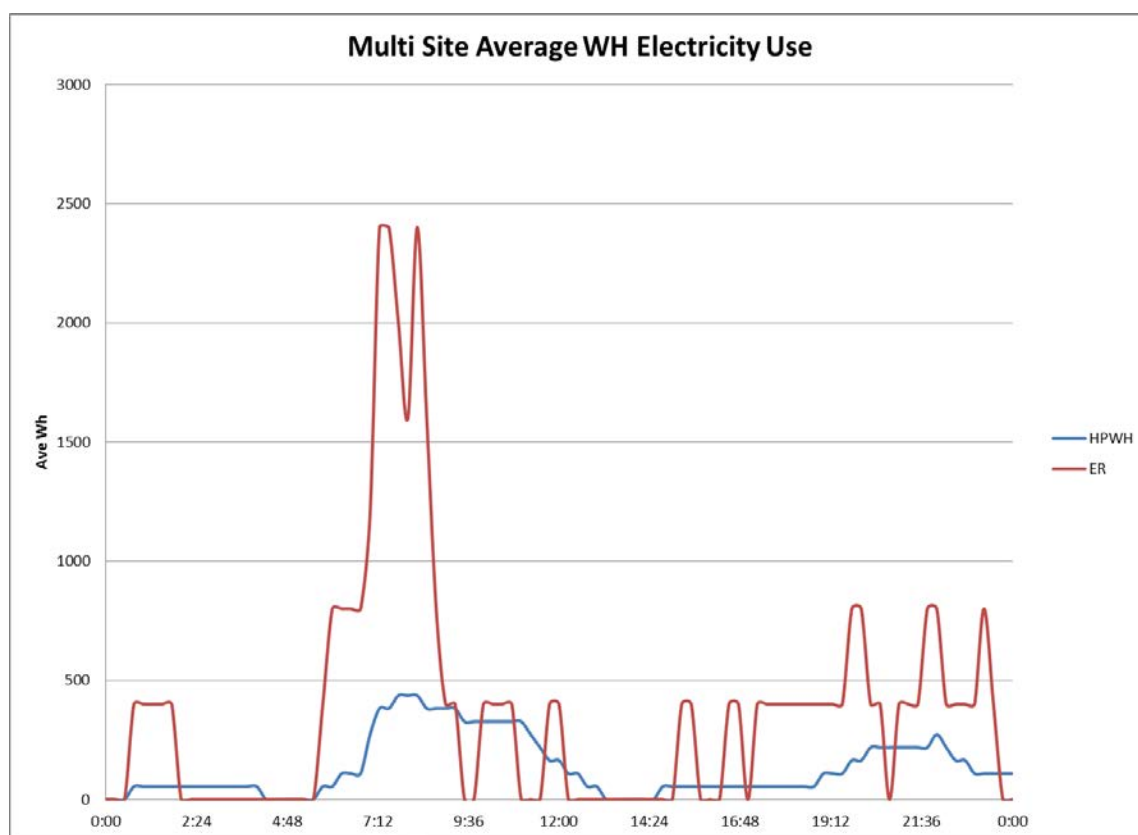
Figure 9. Fifteen minute electricity consumption for a HPWH and an ERWH for the same day



CEE has collected over 10,000 days of DHW usage data from 30 Twin Cities metro area homes. 20 days were selected randomly from this data set. The 20 days of DHW use were used to

represent the use for 20 individual houses. The electric consumption was then computed for each of the 20 days for both a HPWH and an ERWH. The combined profile for the ERWHs and HPWHs simulate the peak reduction of a neighborhood or group of 20 homes that convert to HPWHs. Figure 10 shows the average consumption per home for 20 combined profiles. The figure shows the typical morning peak behavior with increased consumption for both the HPWH and the ERWH. During the morning high use period peak, 15 minute consumption was approximately 2 kWh lower per home for the HPWH compared to the ERWH, which translates to a peak demand reduction of about 500 watts per home. The evening peak was also reduced by 300 Wh per home for a demand reduction of 75 watts per home.

Figure 10. Comparison of the average electricity usage for 20 homes



HPWH Savings Applications

Two HPWH savings applications were developed to enable homeowners and utility program managers to compare HPWH performance to ERWHs.¹ The homeowner application requires the user to input information about a specific home. The application estimates the water heater

¹ The [Heat Pump Water Heat Calculator tool](http://mncee.org/HPWHsave) (<http://mncee.org/HPWHsave>) for homeowners and the [Utility Heat Pump Water Heater Impact tool](http://mncee.org/HPWHutil/) (<http://mncee.org/HPWHutil/>) for utilities are available on the Center for Energy and Environment's website.

efficiency, impact on space conditioning, and energy and cost savings potential for that home. The utility application requires inputs about the utility service territory. This application delivers information based on the energy savings and the peak reduction for various levels of HPWH penetration.

This section provides an overview of the calculations made by the applications. Specific formulas and lookup tables are provided in “MN HPWH Calculation” spreadsheet (available from the Division of Energy Resources upon request).

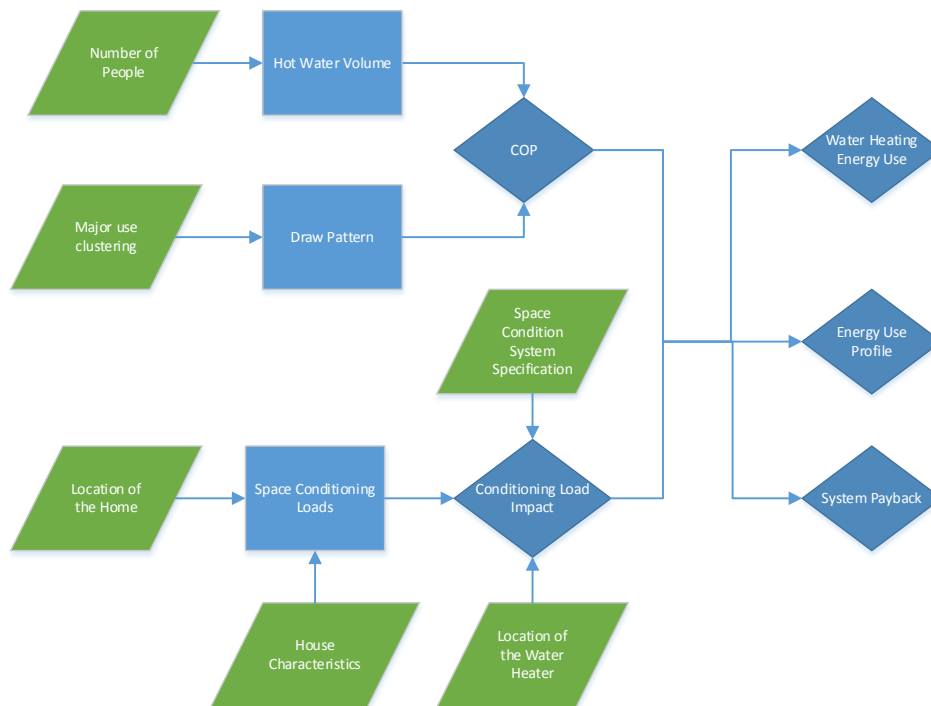
Homeowner Application

Figure 11 shows an input screen of the homeowner version of the HPWH calculator. The application requires the user input information about the home’s location, number of occupants, hot water usage characteristics, water heater installation location, and space conditioning system characteristics. The input questions were designed to collect the data necessary to estimate the performance of a HPWH. Inputs are used to characterize the impacts discussed in the previous sections of this report. Two metrics are used by the application: the water heater coefficient of performance and the impact on space conditioning. Figure 12 is a flow chart of HPWH savings application calculations.

Figure 11. Homeowner Heat Pump Water Heater Calculator

The screenshot displays the 'Heat Pump Water Heater Calculator' interface. On the left is a navigation menu with links to Home, Projects, Resource Center (Technical Reports, Videos, Webinars, Presentations, Data & Reference, Info Visualization, Browse All Resources), Events & Webinars, About the Innovation Exchange, and Staff. The main content area is titled 'Heat Pump Water Heater Calculator' and includes a brief introduction about heat pump water heaters. It features three main input sections: 'House location' with four map icons for North, Central, Metro, and South; 'Heating Source' with four icons for Electric, Natural Gas, Propane, and Fuel Oil; and 'Cooling Source' with three icons for Central, Window, and Fan. Below the Cooling Source section, there are four bar charts representing frequency of use: Never, Rarely, Occasionally, and Always.

Figure 12. Flow chart of HPWH Savings Application calculations (Note: Green represents user input and blue shows calculations made)

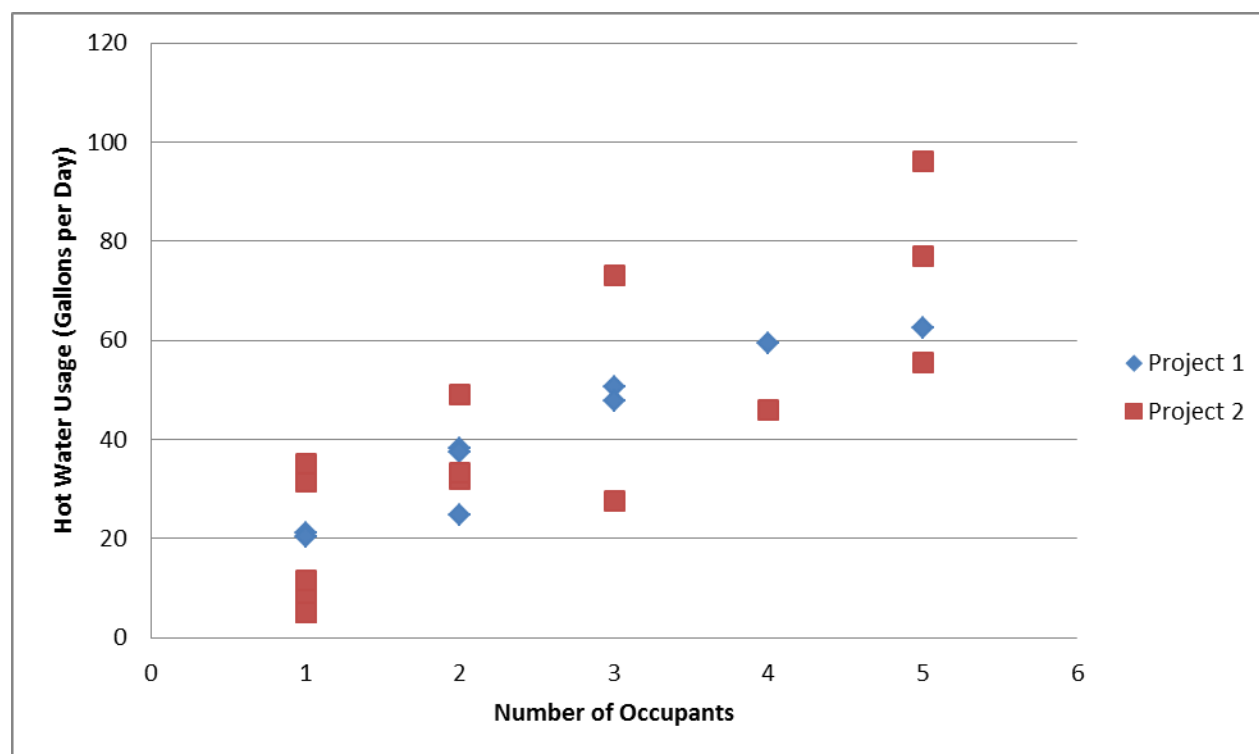


Coefficient of Performance

The savings application asks for information about the number of household occupants and the clustering of hot water data. These inputs are used to estimate the coefficient of performance for the home.

First the number of occupants is used to estimate the daily hot water volume used. Minnesota field studies (Schoenbauer et al. 2014 and Bohac et al. 2010) characterized the hot water usage profiles in 29 different homes (Figure 13). The field data was used to create a hot water volume per occupant relationship, which is used by the HPWH savings application. These relationships also align with other cold climate hot water usage data (Thomas 2008). The daily hot water usage data was used to determine the HPWH COP for Minnesota as shown previously in Figure 2: The relationship between water heater performance and hot water usage (Steven Winter, 2011) and typical hot water usage for Minnesota homes (CEE 2010). It also shows the relationship between water heater performance and hot water usage (Steven Winter, 2011) and typical hot water usage for Minnesota homes (CEE 2010).

Figure 13: Average daily hot water usage from 29 monitored homes in Minnesota.



The pattern of use can also impact the coefficient of performance. Using large volumes of hot water in a short period of time can deplete the storage tank of hot water and exceed the rate at which the HPWH heater can meet the load. In these high load scenarios electric resistance heating is used to meet the load, reducing the COP of the water heater. Very specific water usage data is necessary to determine the impact for a specific home. Data from a large Electric Power Research Institute (EPRI) field study (Amarnath and Bush 2012) was used to determine an average reduction in COP for homes with clustered use (Table 8).

Table 8: Impact of clustered hot water draws on COP.

Hot Water Use GPD	COP no clustering	% COP Reduction clustered events
24	1.92	0.0%
48	1.76	-5.7%
54	1.64	-6.1%
80	1.27	-7.9%

Impact on Space Conditioning

The HPWHs impact on the space condition costs of the home depends on: the cooling delivered by the HPWH; the interaction between the HPWH and the home's conditioned and occupied areas; and the energy use impact on the space conditioning system. The process of estimation was described in the "Whole House Energy Savings" section and shown in Figure 14.

Figure 14: Calculations made to estimate the impact of HPWHs on space conditioning

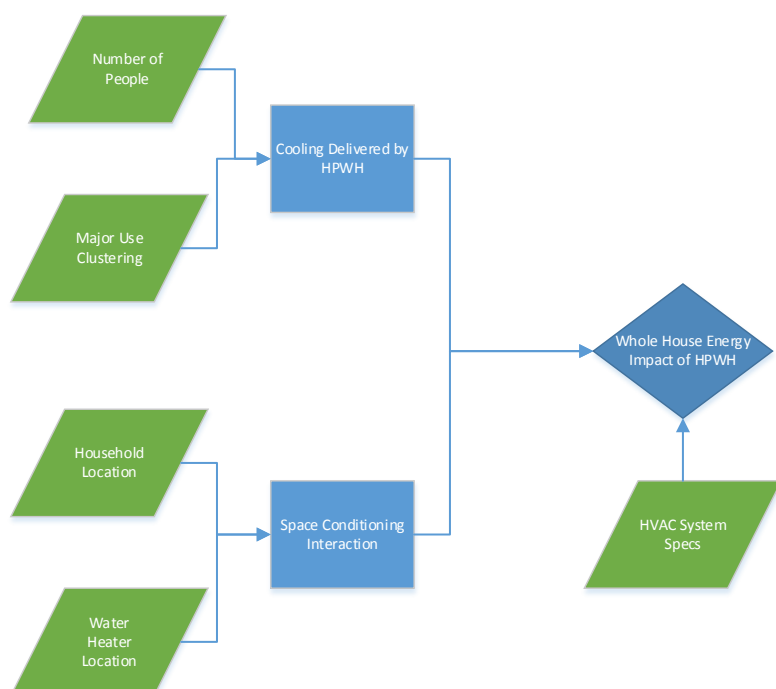


Table 9 shows the range of hot water usage inputs and the corresponding maximum cooling output by the HPWH. The maximum cooling value is the amount of heat removed from the space by the HPWH to produce hot water. This maximum value would have full impact if the space surrounding the heat pump was maintained at temperature continuously. The impact is reduced during periods of time when the conditioned space is not actively conditioned (Figure 7). For example, this would occur during the shoulder season where the outdoor temperature and desired indoor temperature are the same. The impact is also reduced by the location of the water heater installed in the home. Table 10 shows the level of interactivity estimated in the HPWH Savings Application.

Table 9: Calculated maximum cooling delivered by a HPWH

User Inputs		Calculated Values	
Number of People	Shower Grouping	COP	Max Cooling Delivered Therm/y
1	Night <i>and</i> Day	1.92	51
2	Night <i>and</i> Day	1.86	99
3	Night <i>and</i> Day	1.86	99
4	Night <i>and</i> Day	1.74	104
≥5	Night <i>and</i> Day	1.37	121
1	Night <i>or</i> Day	1.92	51
2	Night <i>or</i> Day	1.76	93
3	Night <i>or</i> Day	1.76	93
4	Night <i>or</i> Day	1.64	98
≥5	Night <i>or</i> Day	1.27	112

Table 10: Interaction of the HPWH and space conditioning based of WH install

Supply Register	User Inputs		Look Up Value Space Conditioning Modifier
	Thermostat	Finished space	
Yes	Yes	Yes	100%
Yes	Yes	No	100%
Yes	No	Yes	50%
Yes	No	No	40%
No	Yes	Yes	N/A
No	Yes	No	N/A
No	No	No	40%
No	No	Yes	40%

Utility Application

The second HPWH savings application was designed for program managers. This application asks similar questions to the homeowner version, but also asks the program manager to enter demographic information that should be set to represent the service territory of the potential program. Figure 15 shows an example of the input screen for the heating system characteristics. Slides can be set to characterize the housing stock of a potential market.

These characteristic inputs determine the energy savings, paybacks, and operating cost data for the average home, as well as information about the demand profile for various levels of HPWH implementation. Figure 16 shows the water heating demand profile if 100%, 50%, 25%, of 0% of the Minneapolis market installed HPWHs.

Figure 15: Example of the input entry screen for the utility application

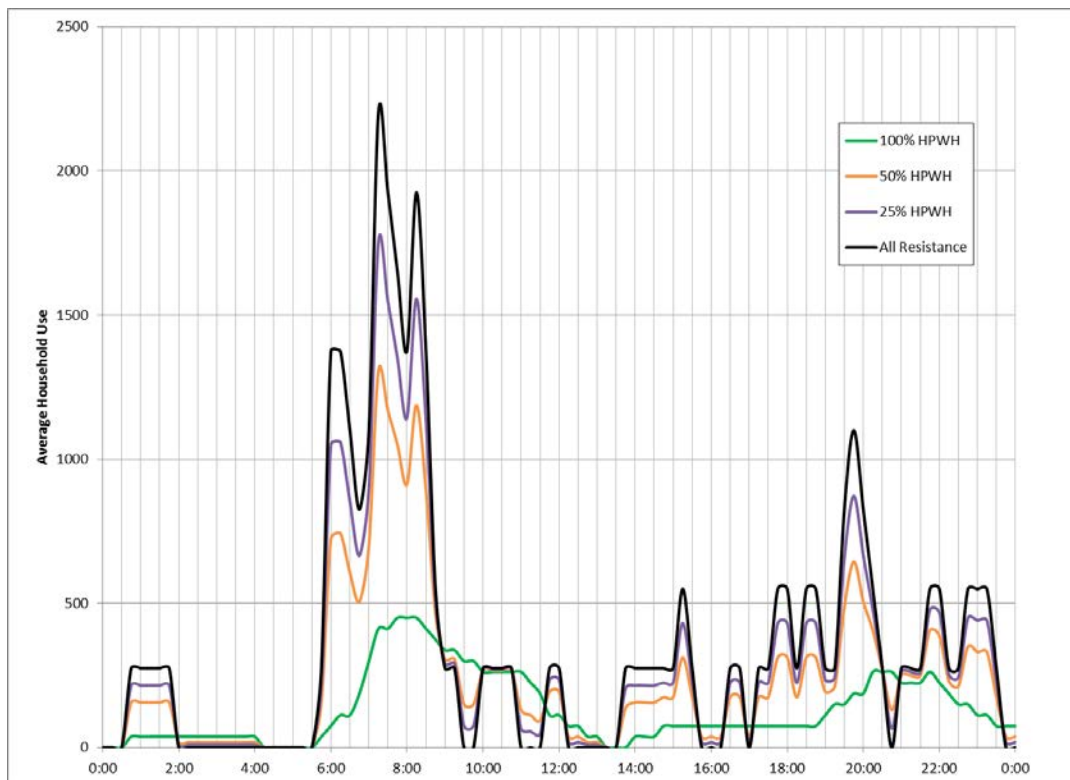
Heating Source

Each fuel type below makes up what percentage of the overall mix of fuels used within the service area, and what portion of the units using that fuel are standard versus high efficiency units?

Fuel Type	Percentage of Mix	Standard Efficiency	High Efficiency
Electric	25%	50%	50%
Natural Gas	25%	50%	50%
Propane	25%	50%	50%
Fuel Oil	25%	50%	50%

Icons for Electric, Electric Resistance, ASHP, Natural Gas, Standard Efficiency, High Efficiency, Propane, and Fuel Oil are shown next to their respective input fields.

Figure 16: Electric water heating demand based on the factor of HPWH installations



Future Applications

Further Peak Reduction

For many electric utilities, peak demand reduction is a higher priority than energy use savings. Electric thermal storage water heaters (ETSWHs) are commonly rebated and promoted for peak shifting. ETSWHs are large (typically 60 to 80 gallons) ERWHs with a controller that prioritizes heating the stored water to a temperature of 160°F and higher at off-peak times. This stored water is then used throughout the day, at a user set reduced temperature, limiting the electricity usage during peak times. Current research is being conducted to develop similar control strategies for HPWHs (Upadhy 2013). Since the heat pump has a lower heating rate than the electric resistance element, it is less effective for short term charging. However, HPWHs can be set to charge during longer off-peak periods (overnight, for example), shifting peak usage while still reducing the total electricity usage.

Venting and Integrated Installations

New homes are becoming more advanced with full home automation systems and controls, including integrated HVAC systems. There are many different sources of waste heat in homes from HVAC equipment, refrigerators, and freezers, as well as exhaust air from bathrooms, kitchens, and whole house ventilation systems. In an integrated, advanced home this excess heat could be used to increase the temperature of the air supplied to a HPWH, boosting the COP. Additionally, during heating season capturing waste heat could replace conditioned space air as the source of DHW heating, which would remove the space conditioning penalty. The built in storage capacity of a water heater also allows heat to be collected when available and stored until hot water is needed. Using laboratory test data from HPWH testing and some assumptions about bathroom exhaust air, a HPWH is estimated to save 5% to 20% of its annual electricity use by utilizing the bathroom exhaust air during daily showers use to boost COP. System integration of this degree is complex and new. These designs, while showing significant potential, need more research and development before being considered for energy conservation programs.

Heat Pump Water Heaters and the Conservation Improvement Program

Existing Heat Pump Water Heater Utility Programs

As of November 2013 there were seven municipals and cooperatives in Minnesota offering HPWH rebates (Table 11). Approximately 25 rebates were issued in Minnesota between 2009 and 2013. This translates to an average of about two rebates per program per year. The low number of system rebates indicates a lack of penetration of HPWHs in Minnesota. Rebate program managers highlighted several areas where the lack of information and understanding has caused concern among utilities, homeowners, and contractors. These concerns likely reduce both homeowner interest and installer recommendation for new water heater installations. The biggest areas of need identified by program managers for improved information were:

1. The impact of HPWHs on the space conditioning load.
2. The impact of cooler water heater space ambient temperatures on HPWH efficiency and capacity.
3. Space needs and the impacts of the installation location on performance.
4. Reliability and maintenance.
5. Simple tools and guidance about the benefits and drawbacks of HPWHs.

Table 11: Summary of Minnesota HPWH rebate programs

Utility	Rebate	Installations (per year)	Electric Savings (kWh/yr)	Peak Reduction (kW)
Alexandria Light and Power	\$300	0	2,800	0.3
Great River Energy	\$200	3	1,200	0.6
Dakota Electric	\$100-\$200	0	1,200	0.6
Lake County Power	\$200	0	1,200	0.6
Marshall Municipal Utilities	\$500	4	2,830	
Missouri River Energy Services	\$300	4	2,800	0.3
Wright-Hennepin Co-op	\$100-\$200	5	1,200	0.6

Additional Recommendations for CIP

Residential water heaters are used by many of Minnesota's electric co-ops, municipals, and utilities to manage the peak loads on their systems. ETSWH has been the preferred method for managing water heating loads. HPWHs should also be considered by these utilities for this purpose. HPWH's can provide considerable peak load reduction, while also reducing the total electricity consumption of the water heater (see section *Impact of HPWHs on Peak Demand*). HPWHs could be controlled to run during non-peak times to further increase their peak reductions. While this paper outlines the potential, the demand reductions and performance need to be determined through a pilot project and/or field monitoring.

The cold climate effects on HPWHs are the most common concern of installers and program managers. Both the impact of colder Minnesota basement temperatures and the added space heating load were commonly cited as reasons HPWHs were not commonly installed in Minnesota. This paper estimates the impacts of these effects for typical Minnesota installations. While the savings of HPWHs are reduced in Minnesota compared to a hot humid climate, the savings are still significant and paybacks are short. Field research of installed systems is necessary to determine the actual performance in Minnesota homes, but, as long as HPWHs are installed properly, they appear to be a good option for Minnesota homes with electric water heating.

Contractor training and education is also recommended for successful HPWH implementation. This will provide two benefits. First, installers are typically the point of sale for residential water heaters. If they are knowledgeable and comfortable with HPWHs, they are more likely to offer them as a desirable option and homeowners are more likely to pay the added cost for the systems. Second, proper installation is necessary for HPWHs to function correctly. Installers must be aware of the simple requirements for HPWHs to ensure a high quality installation.

Future Research Needs

The literature and research available on the performance of HPWHs has grown considerably in the last few years. However, there are still a few climate specific areas in Minnesota that could benefit from further research. This paper outlines and estimates the Minnesota climate impacts, but there would be added benefit for utilities and CIP to measure these impacts specifically in Minnesota homes.

The biggest need is an evaluation of the ability of HPWHs to control demand in normal operation and in off-peak operation. This control and peak reduction should be characterized and compared to the performance of ETSWHs.

The second area that would benefit from further research is the measured COP under actual loads in Minnesota homes. The impacts of daily hot water usage, ambient temperature, and humidity on HPWH COP have been measured and analyzed in laboratory settings. These results were analyzed considering typical basement conditions, but there are still questions on how real world interaction between these characteristics impact performance and whether the lab performance is the same as installed performance in Minnesota.

The third area for potential research is the integration of HPWHs into advanced systems in new construction. The performance of HPWHs in Minnesota homes could be significantly improved through the use of excess/waste heat from other residential systems. Higher inlet air temperature would improve the COP and reduce the impacts of space heating from the heat pump operation. More research is necessary to determine the best practices and what systems are best for integration.

Finally, several manufacturers have released third generation HPWH models. Some of these units were designed to improve performance in cold climate applications by increasing ducting options. Several models are now available with EF ratings of 2.75. As models improve under laboratory test conditions there is a need for verification in the field to determine whether these new advancements in technology translate to improved performance in real homes.

Conclusions

HPWHs are gaining a market presence in cold climate applications. While several electric cooperative, municipals, and utilities offer HPWH rebates in Minnesota, to date very few have been installed. Concerns about the impact of the HPWH on the space heating load and the reduction in performance due to Minnesota basement conditions have been the primary reasons for the limited market penetration. Existing national research on HPWHs and data collected from DHW systems in Minnesota were combined to estimate these effects. For typical Minnesota installation conditions HPWHs can save 30 to 50% of DHW electric use. Simple paybacks are around 5 years under these scenarios.

This white paper has used manufacturer data and research from various US sources, with Minnesota specific climate, usage, and water heating data to analyze HPWHs for Minnesota. Performance concerns were evaluated and analyzed. This analysis found that HPWHs provide significant energy savings for Minnesotans with electric water heating. The predicted savings for Minnesota installations is reduced by cold-climate effects, but HPWHs still provide 30 to 50% of DHW electric use savings and short paybacks of 5 to 10 years. This guidance and the expected savings for most types of Minnesota installations are summarized in this paper.

While some further research is recommended to determine the specific savings and peak reduction potential and verify performance in actual installations, the existing research indicates that HPWHs are an attractive option for Minnesota homes with electric water heating.

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