

IMPACT OF HPWH PLACEMENT ON WATER HEATING PERFORMANCE AND EFFECT ON AIR TEMPERATURE IN ITS IMMEDIATE ENVIRON

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Abstract: Heat pump water heaters (HPWHs) extract thermal energy from their surroundings to make hot water with two to three times better efficiency than conventional electric resistance water heaters. But, how much does HPWH placement influence its performance? This paper summarizes performance metrics of two 189 L (50 gallon) HPWHs – one placed within conditioned space, and the other placed in the garage of two separate, but similar research houses – each delivering approximately 208 L/d (55 gallons/d) hot water under simulated occupancy conditions. Both houses had space conditioning set points of 24.4°C (76°F) and 21.7°C (71°F) in Summer and in Winter, respectively, and hot water temperature setting of 48.9°C (120°F). Performance metrics are compared on a monthly basis for 2011. Performance is also compared to that of three HPWHs installed in occupied homes.

Key Words: *heat pump water heater, HPWH, performance, conditioned, unconditioned*

1 INTRODUCTION

Heat pump water heaters (HPWHs) are capable of delivering hot water at efficiencies two to three times higher than standard electric water heaters. This is achieved by using a vapor compression cycle to extract heat from the surrounding air and deliver it to the water that is being heated. Due to the fact that the HPWHs cool the surrounding air while operating, the HPWH operation will impact the house HVAC system energy use if it is located within the conditioned space. The effect that the ambient cooling has on space conditioning energy use has been previously investigated by the author and found to have only a small, 8%, reduction in overall HPWH savings compared to a standard electric water heater when operated with a high efficiency heat pump in a mixed humid climate (Munk, Ally, & Baxter, 2012). There have also been laboratory studies on the performance impact of tank temperature and ambient temperature on water heating efficiency (Sparn, Hudon, & Christensen, 2011). This study also measured performance of the HPWHs using two different draw patterns and found that the performance varied significantly between models. This was found to be due to differing control algorithms, HP capacities, and storage volumes. This report will evaluate the performance of two HPWHs from the same manufacturer; one installed inside the conditioned space and the other installed in an unconditioned garage. Both homes were unoccupied research houses that used similar hot water draw patterns to simulate occupancy.

2 EQUIPMENT DESCRIPTION

All HPWHs covered in this paper are from the same manufacturer and the same model. The HPWHs are integrated units with a hot water storage tank having a capacity of 189 L. The vapor compression system utilizes R-134a refrigerant and the condenser heat exchanger (HX) consists of refrigerant tubing wrapped around the exterior of the storage tank. The evaporator airflow is pulled in through the top of the unit and exhausted out the back. The units have two 4.5 kW resistance heating elements installed; one near the top and one near the bottom. The heat pump and resistance heating elements do not ever operate simultaneously.

3 HOUSE DESCRIPTION

One HPWH was installed in an unoccupied research house in the Campbell Creek subdivision of Knoxville, TN. This home is of typical construction relative to new homes in the area with the exception of upgraded windows, an unvented attic, and high efficiency heat pump (Christian et al. 2010). This house will be referred to as CC2 in the rest of this paper.

The second HPWH was installed in an unoccupied research house in the Wolf Creek subdivision of Oak Ridge, TN. This home had an exterior insulation finishing system (EIFS) for the walls, triple pane windows, an unvented and insulated crawlspace, infrared reflective shingles, and high efficiency heat pump (Miller et al. 2010). This house will be referred to as WC4 in the rest of this paper.

4 MEASURED PERFORMANCE

The two HPWHs were instrumented in similar fashion, with immersion thermistors installed on the tank entering cold water line and leaving hot water lines. The volumetric flow rate was measured with a turbine flow meter on the hot water line. The delivered water heating of the HPWHs was then calculated using equation 1.

$$Q_{WH} = V_{HW} \rho_{HW} c_w (T_{hot} - T_{cold}) \quad (1)$$

The energy used by the HPWH was also measured allowing the system coefficient of performance (COP) to be calculated. Since not all hot water draws trigger the HPWH to run and the draws are not necessarily coincident with the HPWH operation, the COP is calculated on a daily basis using equation 2 to ensure the data is averaged over a suitably long time period.

$$COP = \frac{\sum Q_{HW}}{\sum W_{WH}} \quad (2)$$

The temperature of the room where the HPWH was installed was monitored with a centrally located thermistor. This is used to determine the impact on the space temperature when the HPWH is running.

5 MEASURED PERFORMANCE AT CC2

The HPWH at CC2 was installed in its 37.2 m² unconditioned garage. Although the garage was unconditioned, the temperatures remained relatively mild throughout the year. The garage has a conditioned bonus room above it and shares two walls with the conditioned living space. This likely reduces the temperature extremes it sees in the winter and summer. Figure 1 shows a plot of the daily COP of the HPWH versus the average garage temperature measured while the unit was running. There is a distinct trend between the COP and the garage temperature that shows a reduction in COP as the ambient temperature drops. There is a small grouping of low COP outliers at the lower garage temperatures. The size of the data points represent the maximum of the 15-minute average of the power consumed by the HPWH during the day. These low COP points all correspond to days when the HPWH used some backup resistance heat as seen by their maximum power over 4kW. Per the manufacturer, this unit will switch over to resistance heating when the air entering the evaporator falls below 7.2°C. These points all had 15-minute average garage temperatures that were 11.4°C or lower. This fact and the fact that the garage temperature was measured centrally while the HPWH was located next to a side wall explain the discrepancy between the manufacturer's HP cutoff temperature and what was seen in the data. It was also noted that opening the garage door during cold days often resulted in enough heat loss from the garage to reduce the HPWH entering air temperature and initiate resistance heating. The

frequency that this occurred in our unoccupied research house was very low; however in a real house this may happen more often.

The color of the data points indicate the volume of hot water drawn during each day, with red points representing higher hot water use and blue points representing lower hot water use. Since the hot water draws were on a schedule for this house with the only daily variations being caused by the dishwasher and clothes washer schedules and the mains temperature, there is very little variation in hot water demand compared to an occupied house. Despite this small variation, it can be seen that when there was larger hot water use, the daily COP was slightly higher. This can be contributed to the fact that there is some standby power use for electronics and water heating to offset tank losses. The more hot water used, the less impact these penalties have on the daily COP.

When looking only at the data points that did not include resistance heat use, the data indicates a 10% increase in daily COP for an 8 °C increase in ambient temperature above 20 °C. Likewise, an 8 °C decrease in ambient temperature yields a 10% decrease in daily COP.

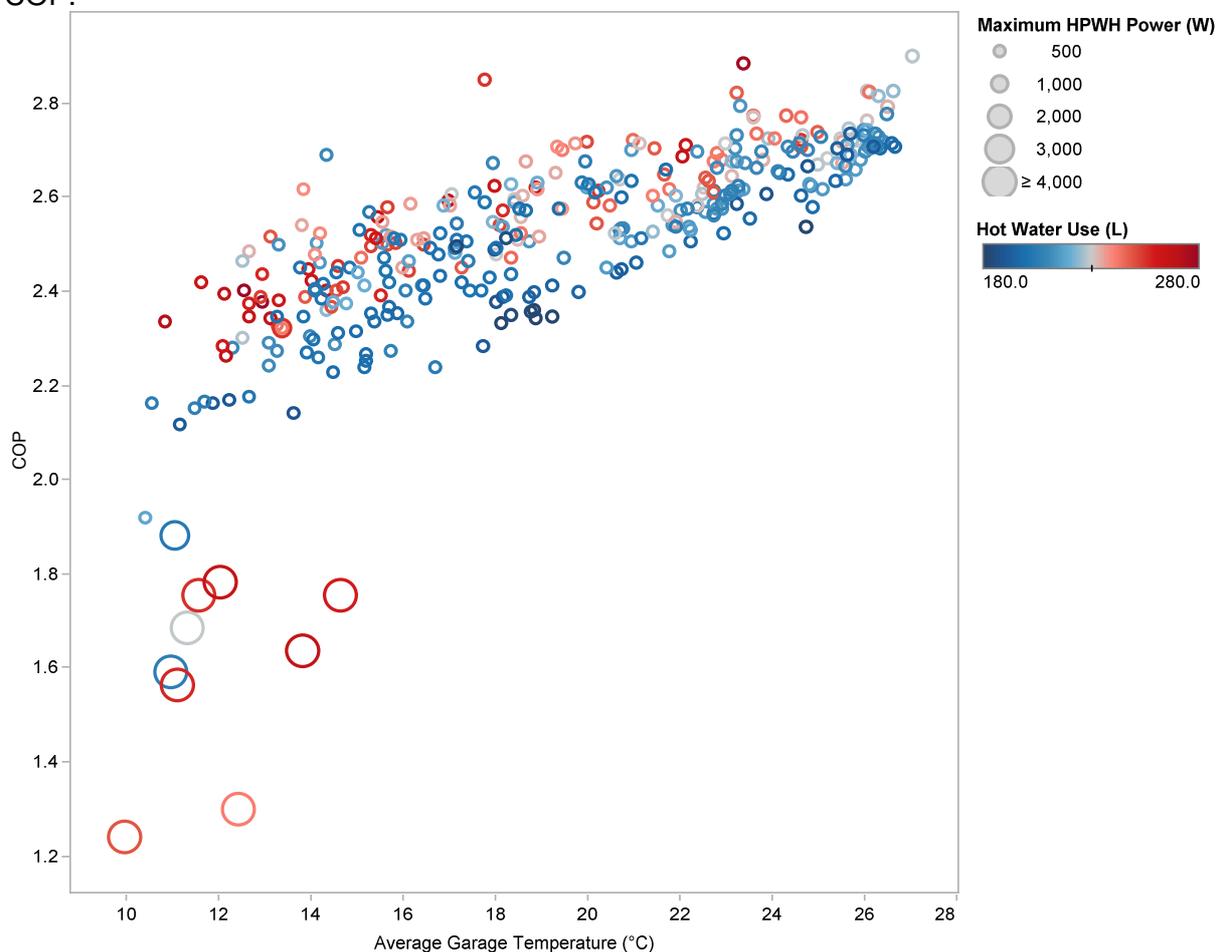


Figure 1: CC2 HPWH Daily Performance

The HPWH typically cooled the garage temperature down by about 1.4-1.7 °C per heating cycle as seen in Figure 2. This reduction typically has a small impact on the COP of the HPWH, ~3%. However, if the garage is already close to the 7.6 °C HP shutoff temperature, the additional cooling by the HPWH could activate the resistance heat and reduce the system COP.

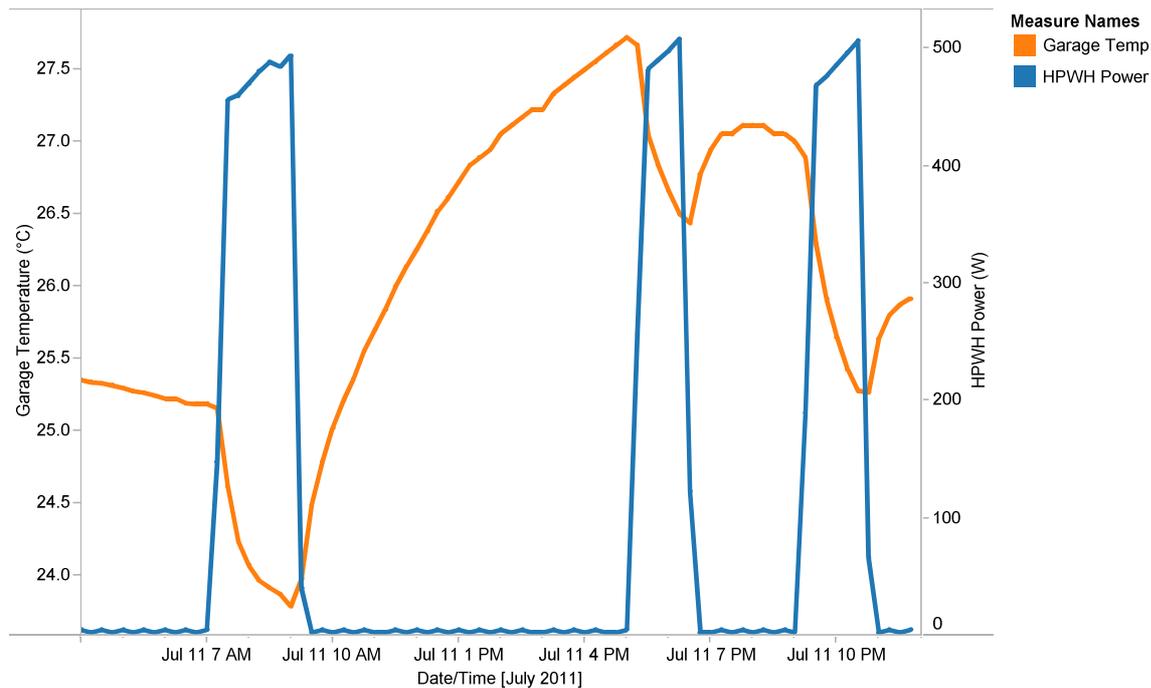


Figure 2: CC2 HPWH Impact on Ambient Temperature

6 MEASURED PERFORMANCE AT WC4

The HPWH in WC4 was installed inside the conditioned space in a 2.8 m² utility room. The utility room was adjoined by a 5 m² laundry room with two louvered doors. Also located in the utility room was the fan coil for the space conditioning heat pump, which typically overheated or overcooled the small space due to supply duct leakage. The performance of the HPWH is shown in Figure 3. Since this unit was installed inside the conditioned space, it experienced a narrower range of ambient temperatures. This makes it more difficult to distinguish the variation in efficiency with ambient temperature, but the efficiency is still generally increasing with an increase in ambient temperature. As with the unit at CC2, the days with higher hot water consumption yielded higher HPWH efficiencies. This unit did not ever use resistance heat because the ambient temperature never fell below 7.9°C and the hot water draw schedule did not contain large enough draws to trigger the resistance heat.

Since the HPWH was located in a utility closet with louvered doors adjoining the laundry room, the door to the laundry room was opened and closed occasionally to measure the impact this had on the unit. Figure 4 shows the utility room temperature and HPWH power use during a day in which the laundry room door was closed around 11:00 am. When the unit ran between 8:00 am and 10:00 am with the laundry room door open, the temperature drop in the utility closet was only ~2.7°C. However, after the door was closed, the temperature drop during subsequent cycles increased to about 4-5.5°C. This reduction in temperature may only have a small impact on HPWH performance, but could have a large impact on homeowner comfort depending on the installed location. Laundry rooms are typically not occupied for extended periods of time, so the level of discomfort caused by this cooling may be low in this situation.

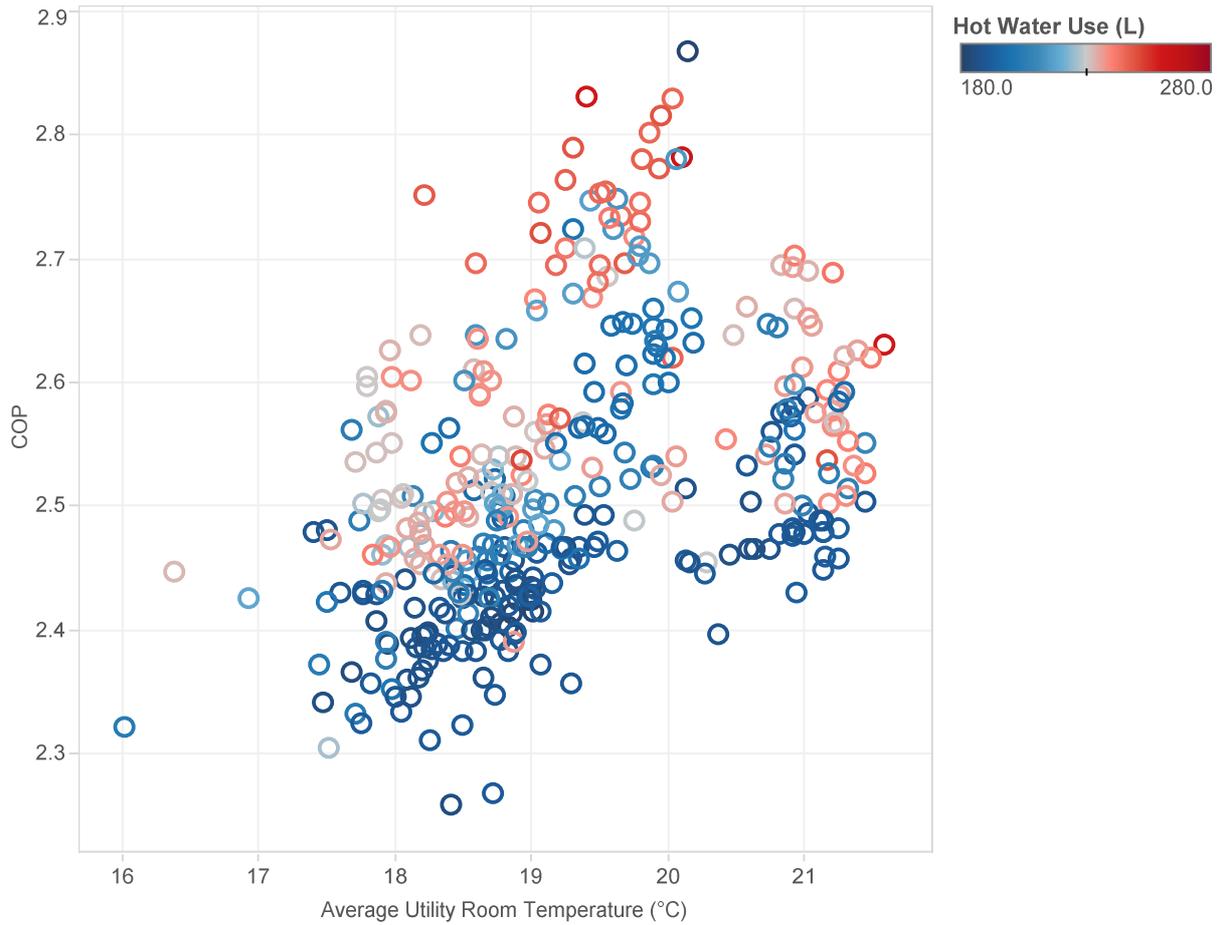


Figure 3: WC4 HPWH Daily Performance

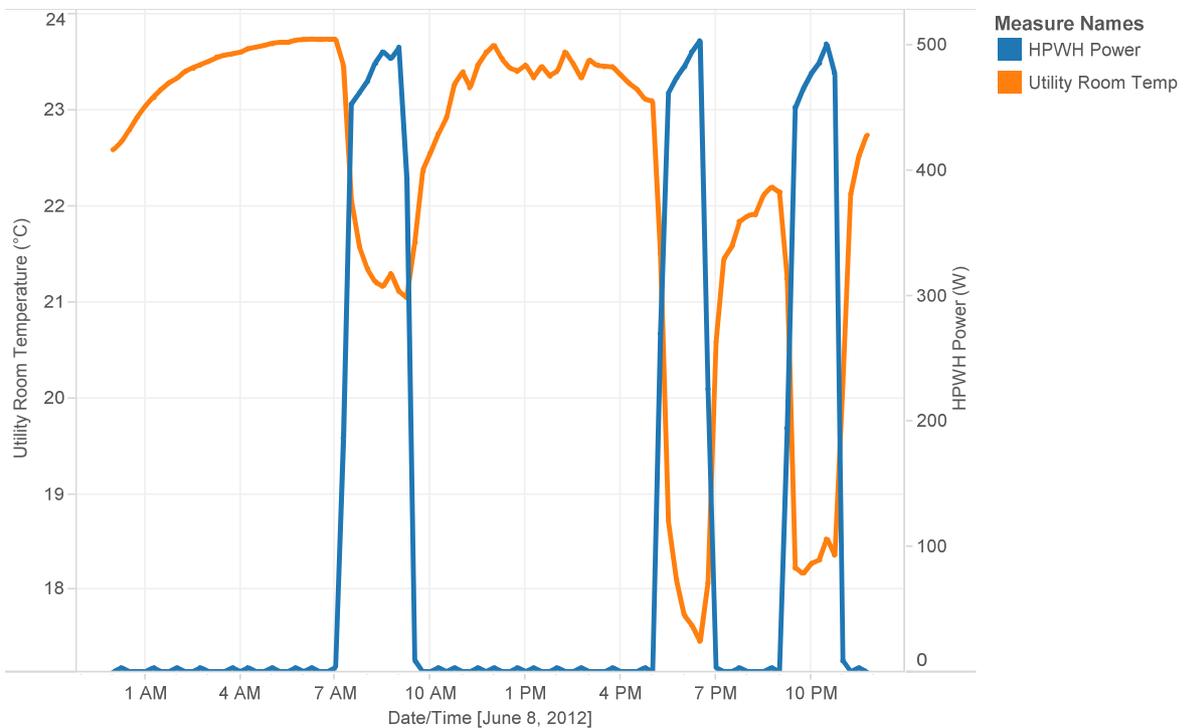


Figure 4: WC4 Impact of HPWH on Ambient Temperature

7 COMPARISON TO REAL HOUSES

Figure 5, Figure 6, and Figure 7 show similar plots as those for CC2 and WC4, but in three occupied houses also located in East Tennessee. All three HPWHs were the same model as those used in CC2 and WC4, and all were operated with a set point of 48.9°C (120°F). Due to the large variation in water draws each day, the performance of the HPWHs varies significantly. Some days show no or very little hot water use and therefore have very low COPs since the HPWH only runs to offset tank jacket heat losses with little or no useful hot water output. This is not unique to HPWHs and would occur with any storage type water heater. There are also some days with very large hot water use, particularly in the first occupied house, requiring a lot of resistance heat to keep up with the hot water demand.

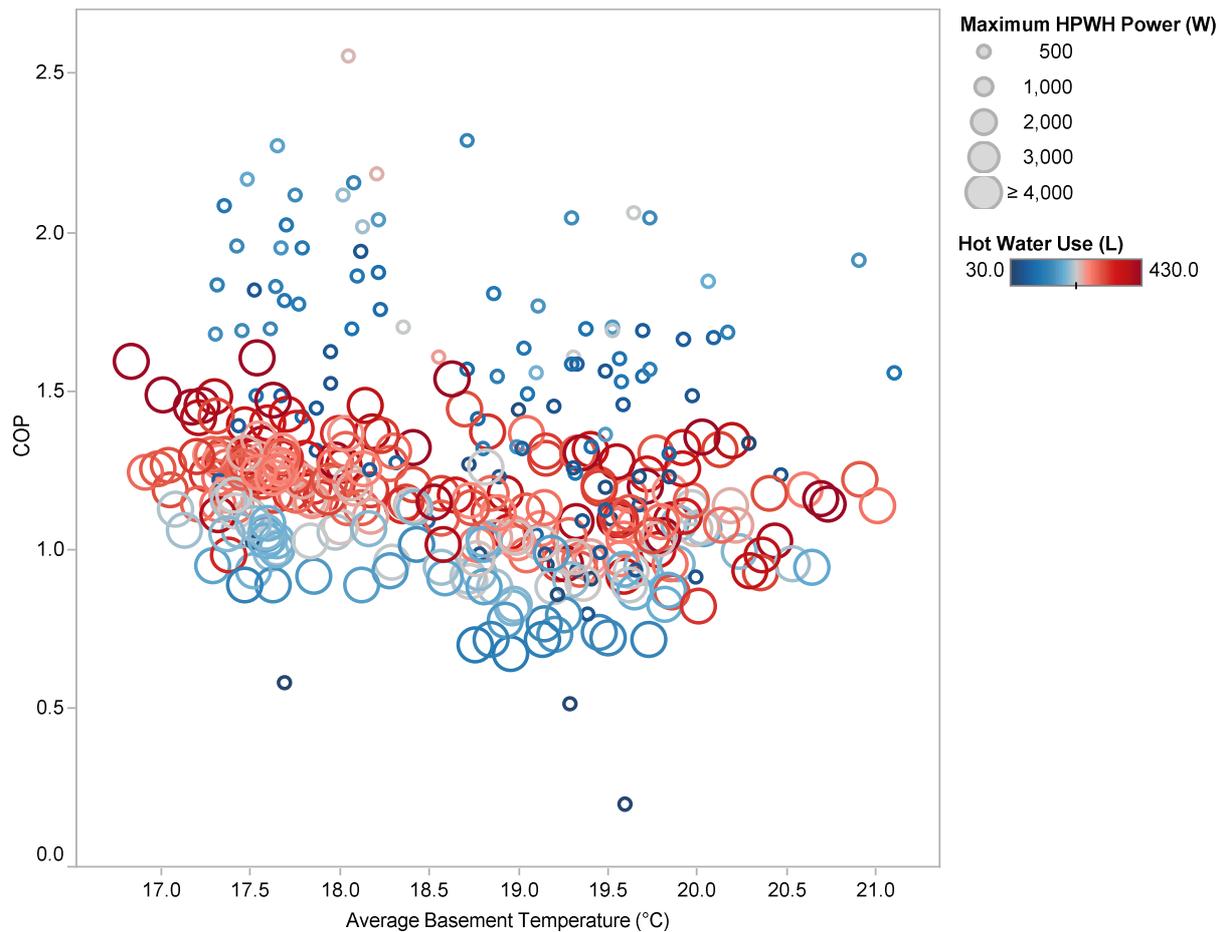


Figure 5: Occupied House 1 Daily HPWH Performance

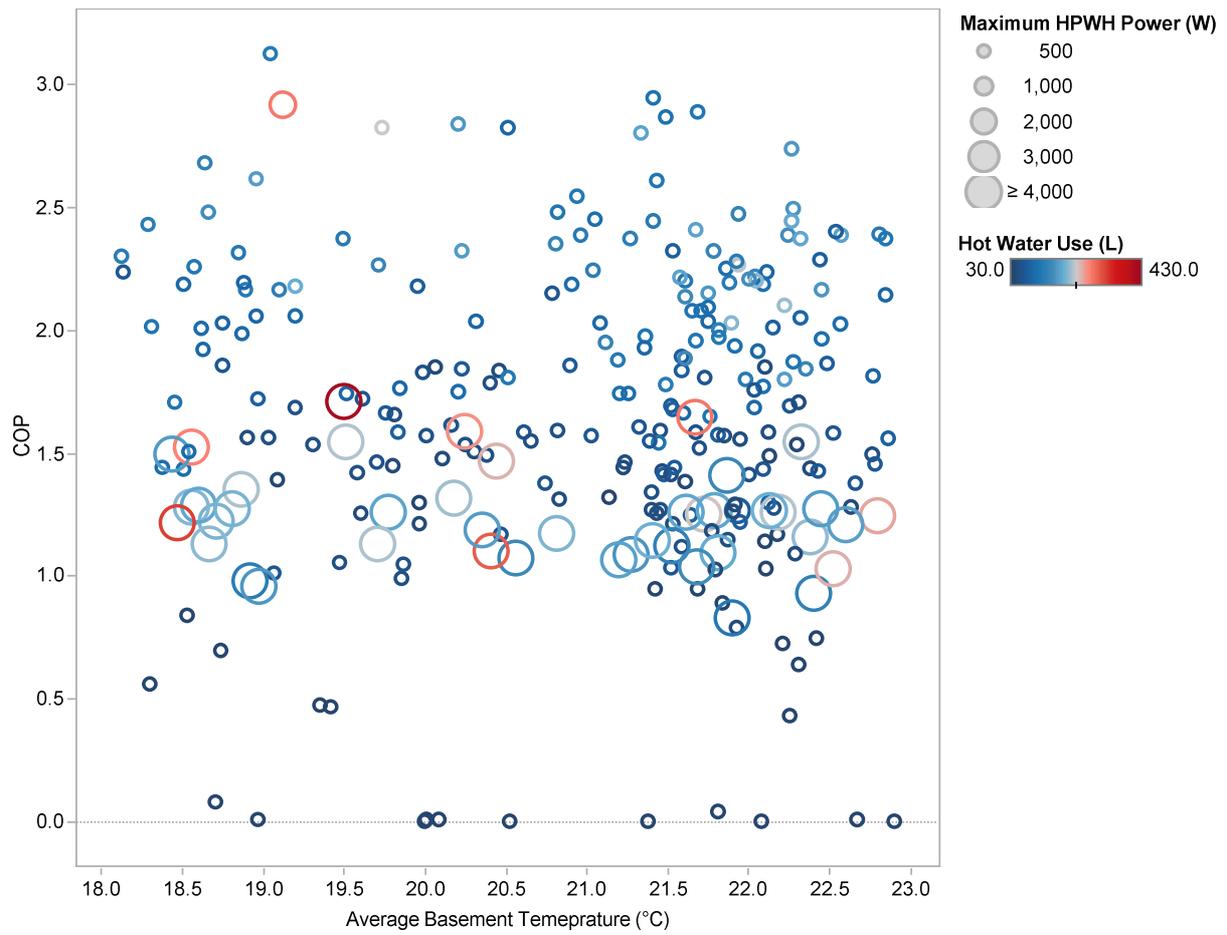


Figure 6: Occupied House 2 Daily HPWH Performance

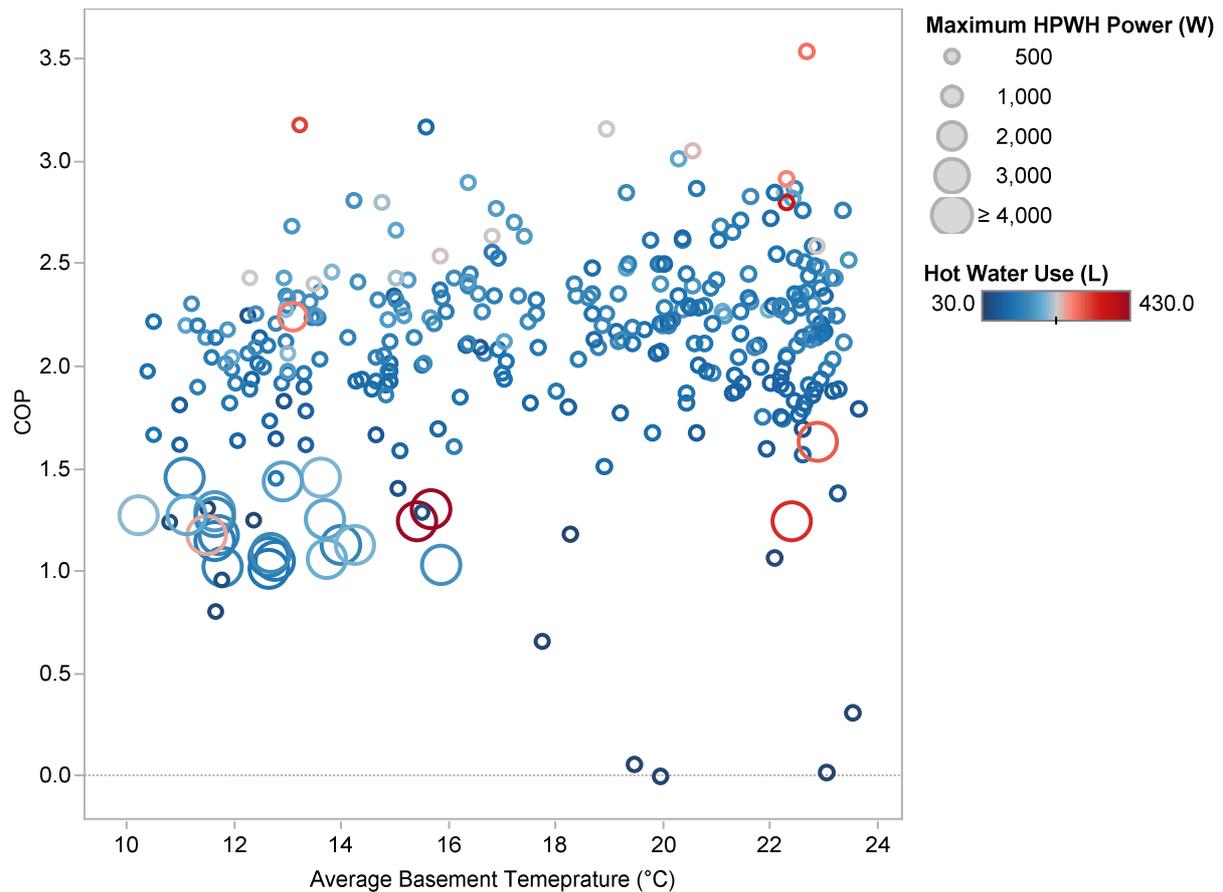


Figure 7: Occupied House 3 Daily HPWH Performance

8 CONCLUSION

The ambient temperature has a relatively small impact of 10% change in COP per 8°C change in ambient temperature on the HPWH performance when operating within its temperature limits. However, when the ambient temperature falls outside of the HPWH operating limits, resistance heat is used and the COP is severely impacted. It is important for installers and homeowners to understand the operating limits of their prospective HPWH and ensure that the installed location will experience temperatures that are within these limits. If installed inside the conditioned space, the HPWH should be installed in an area of the home that it is not frequently occupied in order to minimize the impact of reduced space temperatures on the comfort of occupants.

Of equal importance to the installation location is the homeowner's hot water use pattern. For this particular unit, using more than 76-95 L of hot water during a single event is enough to activate the resistance heating elements. If this is a common occurrence for a household, then either a larger HPWH or a HPWH installed with a mixing valve and elevated set point temperature could be options to ensure enough hot water is available without the use of resistance heat.

HPWHs are capable of delivering hot water at over twice the efficiency of a standard electric water heater. However, selecting a HPWH based on an occupant's hot water use and the ambient temperature of the desired installation location is critical to realizing the full efficiency potential of any HPWH.

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