RESEARCH HIGHLIGHT

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The Impact of Heat Pump Water Heaters on Whole-House Energy Consumption

INTRODUCTION

Heat pump water heaters are one of the most energy-efficient water heating options currently available in the Canadian market. Heat pump water heaters operate by using electricity to circulate refrigerant in a loop to move heat from the surrounding air into the tank's water. Since a heat pump water heater (HPWH) can deliver more heating energy to the water than it consumes, the water heating efficiency, or coefficient of performance (COP) exceeds that of conventional storage hot water tanks. However, as HPWHs draw energy from the indoor air, during the winter months, they add to the space heating load and in the summer months, reduce the air-conditioning loads.

The purpose of this set of experiments was to examine the whole-house impact of operating a heat pump water heater in the basement of an R-2000 house at the Canadian Centre for Housing Technology[1] (CCHT), including any resulting changes in basement air temperature, and any impacts on energy consumption for heating and cooling. Researchers hypothesized that because the heat pump operation depends on moving heat from one space to another, heat pump water heaters could potentially impact their surrounding environment, affecting room temperatures and the house space cooling and heating loads. For example, the heat that is removed from the basement in order to heat water could cool the basement air temperature and require additional heating from the furnace. In summer, the additional cooling of air by the heat pump water heater may contribute to the overall cooling of the house—and offset air-conditioning system operation.

RESEARCH PROGRAM

The evaluation of the heat pump water heaters was carried out at the Canadian Centre for Housing Technology (CCHT) in Ottawa, Canada. The unique nature of the CCHT twin house facility allows not only the examination of energy savings but also provides a complete picture of house performance.

METHODOLOGY

Two different heat pump water heater systems were installed in the basement of the experimental house (see figure 1). The first system was a 303-L (80-U.S. gal.) heat pump water heater—referred to as Heat Pump Water Heater A, the second system was a smaller 189-L (50-U.S. gal. system—referred to as heat pump water heater B.

To determine the impact of heat pump water heater operation, the CCHT houses were first benchmarked during each season (heating and cooling) under identical conditions with electric resistance water heating (270 L, 60 imperial gal.). Subsequently, water heating in the experimental house was provided by heat pump water heater A or B (each for a period of two weeks), while the control house water heating continued to be provided by the standard electric resistance water heater.

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1 The Canadian Centre for Housing Technology is jointly operated by the National Research Council, Natural Resources Canada, and Canada Mortgage and Housing Corporation. This research and demonstration facility features two highly instrumented, identical R-2000 homes with simulated occupancy to evaluate the whole-house performance of new technologies in side-by-side testing. For more information about the CCHT facilities please visit http://www.ccht-cctr.gc.ca.

Figure 1 Heat pump water heaters installed in the basement of the CCHT experimental house. (Left: heat pump water heater A – 80 U.S. gal./303 L, Right: Heat pump water heater B – 50 U.S. gal./189 L)

Throughout the benchmark and the experiment in winter, the central thermostats were set to 22°C (72°F) and a high-efficiency condensing gas furnace (94% measured steady state efficiency) provided the space heat. In summer, in each house, the central thermostats were set to 24°C (75°F), and a two-ton SEER 13 air conditioner provided the cooling. The furnace fan circulated air at continuous low speed when not in high speed heating or cooling mode.

Water draws were simulated by the twin house simulated occupancy systems. Realistically scheduled dishwasher, washer, shower, bath and tap events consumed approximately 230 L/day (51 imperial gal.) of hot water.

Furnace gas and electrical consumption, water heater electrical consumption, and room air temperatures were collected throughout the experiments and benchmarking.

FINDINGS

Ability to meet water draws

Both heat pump water heaters were able to meet the water draw demands of the CCHT schedule, supplying 53°C (127°F) water (after a mixing valve) to all taps and appliances in the house. While both heat pump water heaters were equipped with backup resistance heating, the backup heater was not required to meet the house's loads, and did not come on during the experiment.

Localized change in basement air temperature

The heat pump water heaters were located in the Northeast corner of the unfinished basement. When operating, the heat pump water heaters produced cool air. The output air temperature of heat pump A was ~16°C (~61°F) and heat pump B was ~12°C (~54°F). This cold air output affected the basement air temperature in the immediate vicinity of the heat pump water heaters, reducing the temperature by approximately 2°C (3.6°F), to 17°C (63°F) in winter, and 18°C (64°C) in summer. Basement air temperatures elsewhere in the basement dropped by ~1°C (~1.8°F). Once each heat pump cycle was complete, the air temperatures did return to comparable temperatures to the control house basement. There was also no detectable lasting impact on foundation surface temperatures. In general the temperature changes were transient and other areas of the house were unaffected.

Electrical draw

Compared to the standard electric resistance water heater, the heat pump water heaters operated at lower power for longer cycles. Heat pump water heater A had a power draw of ~1000 W, heat pump water heater B had a power draw of ~500 W, whereas the electric resistance water heater had a power draw of ~4000 W.

Water heating savings

Results for the two heat pump water heater systems were comparable. In winter, the heat pump water heaters consumed on average 5.0 kWh/day, a 61% energy savings compared to the conventional electric water heater. In summer, the heat pump water heaters consumed on average 4.3 kWh/day, a 60% energy savings compared to the conventional electric water heater.

Impact on heating loads and operating cost

In winter, the results were similar for both heat pump water heaters. As expected, the savings in energy use for water heating was offset by an increase in furnace energy consumption for heating. During the experiment, furnace energy consumption increased an average of 23.7 MJ/day (6.6%, or equivalent to 6.6 kWh/day) due to operation of the heat pump water heaters (see figure 2).

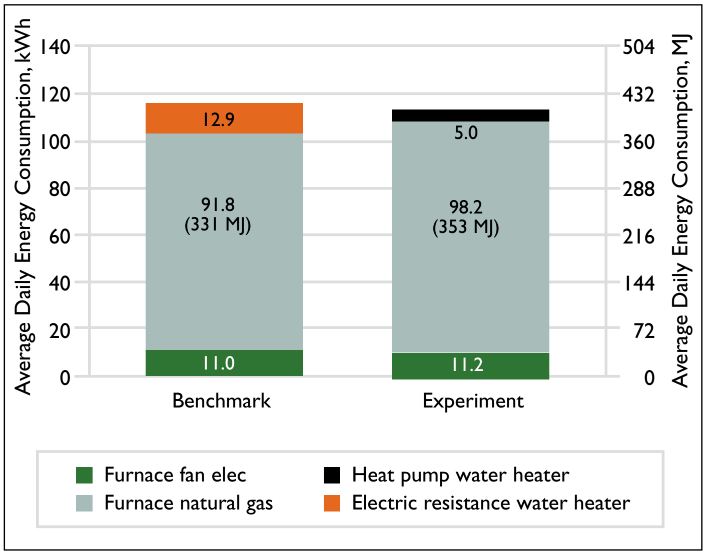

Figure 2 Average daily consumption during heating season experiment

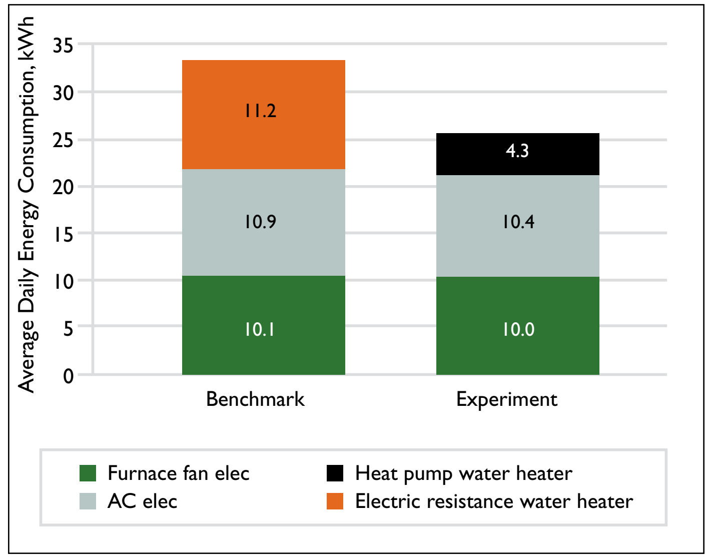

Figure 3 Average daily consumption during cooling season experiment

When energy savings for water heating are combined with the increase in heating load, the impact of the heat pump water heater on whole-house energy balance is considered insignificant. This means that if the space heating were provided by electrical resistance means, there would be no energy or cost savings. However, because the space heating is provided by natural gas, the water heating is provided by electricity, and the energy pricing in Ontario at the time of the research was favourable to heating by natural gas, then the reduction in electrical energy for water heating and increase in natural gas for space heating results in significant cost savings of about $0.78/day (see table 1 for January 2012 energy rates used for these calculations).

Impact on cooling loads and operating costs

In summer, a small secondary impact on energy for operating the air conditioning system was seen. Heat pump water heater A produced a savings in cooling energy of 1.3 kWh/day (8.9%) and heat pump water heater B produced a cooling energy savings of 0.8 kWh/day (2.8%). These energy savings are both above the error margins for the CCHT test facility and thus are significant.

Total summer energy savings for water heating and space cooling was ~7.6 kWh/day (25%) (see figure 3), for an average cost savings of about $0.89/day (at 2012 rates in Ottawa, including time-of-use pricing. See table 1).

LIMITATIONS OF THIS STUDY

The impact of heat pump water heater operation will be different for all different houses and mechanical set-ups. Care should be taken in applying these results to other homes due to certain attributes of the CCHT facility.

Some of the issues that should be kept in mind include:

- The CCHT houses are built to R-2000 standards; therefore, they hold heat better than older houses. Heat pump water heater operation in a less efficient house could lead to a less significant secondary impact on overall house energy use and lower cost savings.
- The CCHT schedule features a particular set of hot water draws. A different quantity or frequency of water draws would affect the energy savings result. Higher hot water loads could require the backup resistance heating coil to operate, which would negatively impact water heating efficiency and cost savings.
- The CCHT houses feature an unfinished basement with insulated walls. The open nature of the basement allows air to mix and circulate freely. If the water heater were isolated in a smaller space, the cold air from the heat pump exhaust could potentially have a greater influence on local air and surface temperatures.
- The basement at the CCHT is considered as being part of the conditioned space.

Table 1 Utility rates for research period

Ottawa Hydro rates (January 2012)								
Time of Use (summer)		**Rates ($/kWh)**	**Transmission ($/kWh)**	**Hydro Ottawa Delivery ($/kWh)**	**Low Voltage Service Charge ($/kWh)**	**Regulatory ($/kWh)**	**Debt Retirement ($/kWh)**	**Total[1] ($/kWh)**
Off-Peak	7 p.m. - 7 a.m.	0.062	0.0108	0.0203	0.0002	0.0065	0.00694	0.10674
Mid-Peak	7 a.m. - 11 a.m. and 5 p.m. - 7 p.m.	0.092	0.0108	0.0203	0.0002	0.0065	0.00694	0.13674
On-Peak	11 a.m. - 5 p.m.	0.108	0.0108	0.0203	.0002	0.0065	0.00694	0.15274

[1] Total rates do not account for $10.14/monthly fixed charge

Enbridge Gas Distribution Inc. residential gas rates (January 2012)				
Amount of Gas Used per Month in Cubic Metres (m^3)	**Cost (¢/m^3)**	**Gas Supply Charge (¢/m^3)**	**Transportation to Enbridge (¢/m^3)**	**Total[1] (¢/m^3)**
First 30	8.2392	11.8492	6.1676	**26.256**
Next 55	7.7807	11.8492	6.1676	25.7975
Next 85	7.4215	11.8492	6.1676	25.4383
Over 170	7.154	11.8492	6.1676	25.1708

[1] Total rates do not account for $20/monthly fixed customer charge

- The air in the CCHT houses is circulated continuously. There is also one return and three supply ducts in the basement. This allows a rapid recovery of air temperatures after each heat pump water heater cycle.
- This study did not assess long-term life-cycle costs that would take into account costs of maintenance and repairs. This, combined with higher purchasing costs of HPWHs, should be factored into any purchase decision.
- The benchmark system included an electric water heater. Comparison to a gas water heater would potentially show higher energy savings results (due to the lower efficiency of the gas water heater), but also substantially lower cost savings (due to the comparably low cost of natural gas in the Ottawa region).

CONCLUSIONS

Through these experiments, heat pump water heater operation was shown to have no impact on overall house energy consumption in the winter and a significant reduction in overall house energy consumption in the summer. The impact of heat pump water heater operation will be different for all types of homes and mechanical set-ups. For this reason, it should be noted that while these findings are valid for the CCHT twin houses, an energy model should be used when projecting the results to other situations.

Heat pump water heaters provide an energy-efficient alternative to standard electric water heaters. However, regional fuel costs (natural gas and electricity), the daily hot water requirement and the home heating system should be taken into consideration in choosing a water heating system that produces both energy savings and cost savings for the homeowner.

The placement of heat pump water heaters should be chosen with care. Due to the cold exhaust from the heat pump, its location should have good air circulation and mixing with the rest of the house. This will help to minimize localized cold air temperatures and cool surfaces in the winter and maximize the cooling benefit in the summer.

Because of its long cycles at a comparatively low power draw, the heat pump water heater is a better match for power management systems than standard electric water heaters (with short duration high power draws). A low power draw is easier to meet with a photovoltaic system, and will also permit the use of smaller-sized batteries for electrical storage.

In areas where time-of-use rate structures for electricity are available, it maybe worthwhile investing in a larger volume heat pump water heater (for example, 302.8 L (80 U.S. gal.) or enough to last the family through the day) and only allowing water reheat during periods of low-cost electricity. This opportunity would have to be explored further to better quantify the potential energy and costs savings.

IMPLICATIONS FOR THE HOUSING INDUSTRY

The results of this research project show HPWHs can offer, depending on the application and utility costs, a cost-effective alternative to conventional hot water heating systems. This will provide consumers and builders with more choice with respect to water heating options. However, more information on equipment purchase and installation costs, operating and maintenance costs, and life-cycle costs would be needed to more fully understand the relative costs and benefits of HPWHs in comparison with more conventional forms of water heaters.

A full report on this project is available from the Canadian Centre for Housing Technology.

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Housing Research at CMHC

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