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Affordable photovoltaic and heat pump water heating for cold climates

Summary

Domestic water heating contributes significantly to residential energy use in cold climates. Photovoltaic water heaters (PVWHs) and heat pump water heaters (HPWHs) can decarbonize water heating in the residential sector while avoiding increased strain on the electrical grid. TRNSYS models were developed of representative PVWHs and HPWHs and these systems were simulated in 14 major population centers across Canada. Techno-economic results found that the required subsidies for PVWHs and HPWHs to achieve breakeven cost with electric resistance water heaters range from \$118 to \$3221. The affordability depends greatly on local solar resource, electricity costs, and space heating requirements.

Keywords: Water heating, photovoltaic heating, techno-economic analysis, solar water heating

Field of application for the findings: Residential water heating

Addressed audience: Researchers, Policymakers, Government

Introduction

In Canada, nearly 70% of hot water heating is supplied by natural gas, and national estimates show that significant increases in the electrical grid will be needed to meet the country's NetZero by 2050 goal. Low-carbon water heating including solar photovoltaic water heats (PVWHs) and heat pump water heaters (HPWHs) can decarbonize water heating in the residential sector while avoiding increased strain on the electrical grid. Though HPWH's are the most popular of the three options, potential barriers to their uptake in the Canadian market include system costs, tank temperature recovery rate, and size (Andrushuk et al., 2016; Kegel et al., 2017).

PV water heaters are commercially available, with many variations in design and controls, including both DC and AC-based systems, custom tanks integrated with solar controllers and elements screw-in elements that can be retrofit with a standard electric tank. A recent IEA SHC Task 69 surveyed 44 market actors and experts and found the two largest perceived barriers to uptake of PVWH worldwide to be lack of knowledge and training, and high upfront installation costs (Taylor et al., 2025). In Canada, Hachchadi et al. (2023) conducted a techno economic comparison between PV and solar thermal water heating systems for two Quebec locations. Their study found that although the thermal performance of a PVWH system is low compared to conventional solar thermal water heating, the economics were favourable due to the low cost of PV panels.

The present work will share the results of a techno-economic analysis of PV and HPWH systems in 14 locations throughout Canada. The overall goal of this work is to identify the opportunity for implementing these technologies and determine what level of support would be needed to achieve cost parity with conventional electric water heating.

1. Approach

To conduct an energy analysis and comparison of a suite of low-carbon hot water heaters, TRNSYS models were developed of four representative DHW systems: PV water heaters, heat pump water heaters, and a conventional electric resistance water heater for baseline comparison. The HPWH model includes a housing component to account for the impact on space conditioning that the HPWH has on the total house load, while the PVWH and EWH systems are standalone and assume constant ambient indoor air temperature in relation to the tank. The models were simulated in 14 major population centers across Canada using CWEC weather files, with simulations run for a period of 1 year, providing ambient temperature and solar radiation inputs to the models including the solar collectors and the housing archetype. The 14 locations were selected to represent a wide range of climactic and economic conditions across the country (e.g. electricity costs, variations in construction costs). The daily average temperature ranges from 10.3 °C in Victoria, British Columbia, to -8.6 °C in Iqaluit, Nunavut, and electricity costs range from a low of 6.08 ¢/kWh in Quebec City, Quebec to a maximum of 58.56 ¢/kWh in Iqaluit.

The low-carbon systems were sized generally to achieve a 50%-70% reduction in the amount of electricity required to meet the load. They each use a 170 L tank and a draw profile of 170 L per day. The systems are all standalone and do not interact directly with the other house loads (space heating, electrical), or bidirectionally with the grid. The PVWH considered in this study consists of a single tank and an inverter-connected PV array that uses MPPT. The PV array consists of 300 W panels with an area of 1.8 m^2 each and the panel tilt set to the location latitude. Simulations were performed with array sizes varying from 5 to 10 panels, equivalent to 1.5 kW to 3 kW systems.

2. Results

A parametric study was performed to size the PVWH considering array size and tank size. The main metric used to compare the energy performance of all the scenarios is the annual Seasonal Performance Factor (SPF), defined in Equation 1 as the ratio between the overall heat delivered ($Q_{delivered}$) and the energy consumed by the system ($E_{consumed}$).

$$SPF = \frac{Q_{delivered}}{E_{consumed}} \text{ (eq. 1)}$$

Figure 1 shows the results for array sizes of 1.5 kW to 3 kW, plus the HPWH and EWH for all the considered locations. The net SPF was also calculated for the HPWH which takes into account the annual increase in space heating required when this technology is used.

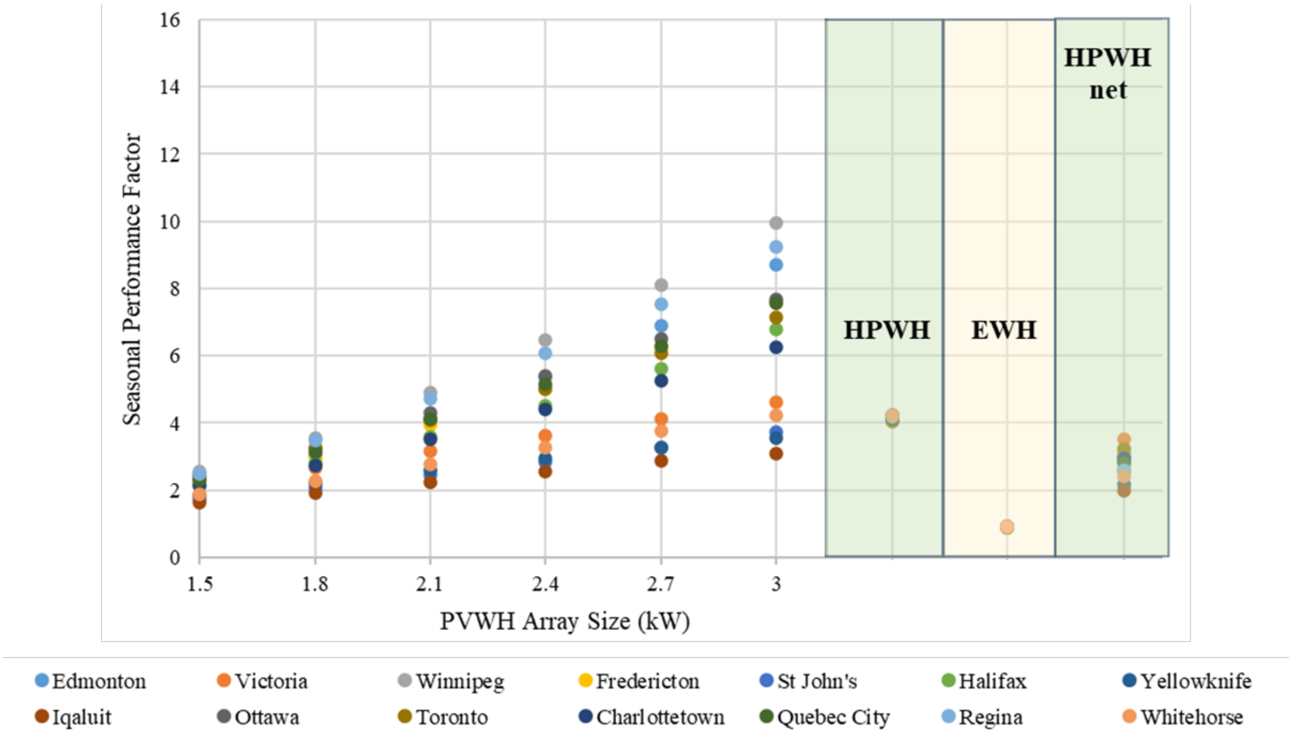

Figure 1: Annual Seasonal Performance Factors of each water heating scenario for 14 locations

The SPF of the EWH is of course under 1, as the energy conversion when taking losses into account is below 100%. The PVWH performance ranges from 1.8 to 2.2 for the smallest array size considered, and from 2.5 to 10 for the largest 3 kW system. The HPWH achieves an SPF of approximately 4 for each city before considering space heating effects, while the PVWH is more dependent on location due to varying temperature and solar availability. The net SPF of the HPWH systems demonstrates the influence of climate and location on the system performance, as the net increase to the annual space heating load results in lower SPF that varies from city to city. When considering the net SPF, the HPWH achieves performance comparable to the 1.8 kW PVWH. The impact on HPWH performance from environmental conditions is dominated by outdoor air temperature, while the PVWH is more impacted by solar availability, so the performance of each system varies according to location. That is to say, the PVWH performs better in a sunny but cold location like Winnipeg than the HPWH which performs better in a mild but low solar resource location like Victoria.

To determine the economic feasibility of PVWH systems across Canada for the full life of the equipment, a lifecycle cost analysis was conducted to determine the level of subsidy required for each system to achieve cost parity with the conventional EWH option. Additionally, a comparison was performed to determine how the different low-carbon systems relate to one another. Figure 2 below shows the cost differences between the PVWH and the HPWH systems assuming a 15-year lifetime, demonstrating that in locations with high solar resource in Canada, PVWH can already be more cost-effective than equivalent HPWH systems. Overall, this study seeks to demonstrate the opportunity for decarbonizing residential water heating using commercially available low-carbon systems, and the results generated can be used to inform policymaking and program design.

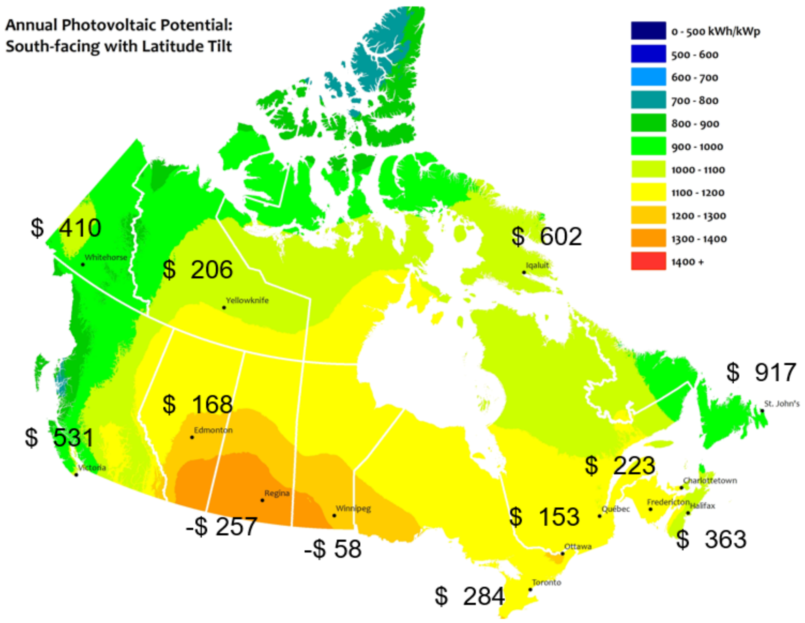

Figure 2: Cost comparison between PVWH and HPWH systems. Annual photovoltaic potential © His Majesty the King in Right of Canada (Natural Resources Canada, 2024)

3. References

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