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An investigation of the technoeconomic feasibility of solar domestic hot water heating for the Canadian housing stock

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Abstract

This study evaluates the impact on energy consumption and GHG emissions as well as the technoeconomic feasibility of retrofitting solar domestic hot water (DHW) heating systems to all houses in the Canadian housing stock (CHS). The study was conducted using the Canadian Hybrid Residential End-Use Energy and GHG Emissions Model (CHREM). It was assumed that all houses that have a DHW system with a tank, and a roof facing south, south–west or south–east could be retrofitted with a solar DHW system. As to be expected, the energy and GHG emissions impact of retrofitting SDHW systems into the CHS is substantial. If all eligible existing DHW systems (30% of those existing in the CHS) were to be retrofitted with SDHW systems, the energy consumption and GHG emissions of the Canadian residential sector would be reduced by about 2%. This is equivalent to 22.7 PJ of end-use energy savings and 1 Mt of GHG emissions reduction, or 11.8% and 11.9%, respectively, of the current amounts associated with domestic hot water heating. The energy savings potential with SDHW systems in all provinces are similar, while the GHG emission reductions vary significantly due to the substantially different fuel mix used in different provinces. The economic feasibility results demonstrate the impact of installation and fuel costs, as well as interest and energy price escalation rates on payback period.

Keywords: Solar domestic hot water heating; Residential energy consumption; Residential greenhouse gas emissions; Canadian housing stock

1. Introduction

As one of the countries with the highest per capita energy consumption, there is pressure on Canada to reduce its energy consumption and associated GHG emissions. The Canadian residential sector, responsible for about 16% of the total national end-use energy consumption and 15% of the total GHG emissions (OEE, 2007), offers a large potential to reduce energy consumption and the associated GHG emissions.

A variety of strategies are available to reduce energy consumption and GHG emissions in the residential sector through energy retrofits (Nikoofard, 2012; Nikoofard et al., 2013a). Solar domestic hot water heating, which is a proven and cost-effective technology, is one of the most obvious retrofit choices that can replace or substantially reduce the consumption of conventional energy sources. While an increasing number of households in Canada install solar domestic hot water (SDHW) heating systems to take advantage of solar energy, the number of such installations is still negligibly small within the Canadian housing stock (CHS).

Taking into consideration the cold Canadian winters with temperatures well below the freezing point for extended periods, and the attractive unit price of flat plate

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collectors, the most suitable SDHW heating technology for the CHS is the forced circulation (active) type systems utilizing an anti-freeze solution (commonly propylene glycol–water) with external or internal heat exchangers and flat plate collectors shown in Fig. 1 (Nikoofard, 2012).

While there have been numerous studies evaluating the feasibility of SDHW heating systems for Canadian houses (for example Biaou and Bernier, 2005; Fung and Gill, 2011; Tanha et al., 2011), and many others for the USA and elsewhere, including the seminal works by Klein, Beckman and their colleagues at the University of Wisconsin–Madison Solar Energy Laboratory (Grater et al., 1993; Cragan et al., 1995a,1995; Trzesniewski et al., 1996; Lenius et al., 2002), no comprehensive study was conducted to evaluate the energy saving and GHG emission reduction potential of SDHW systems for the entire CHS. Since it is critical to accurately determine the energy and GHG emission implications of large scale implementation of SDHW retrofits into the CHS, this work was conducted within the Solar Buildings Research Network initiative (SBRN, 2010).

2. Methodology

Due to the substantial regional differences in climate, primary fuel availability, fuels used in electrical generation, as well as the construction, heating/cooling equipment and appliance characteristics, the suitability and feasibility of policy tools and strategies that involve solar technologies differs dramatically in Canada from region to region. Therefore, this study was conducted using the Canadian Hybrid Residential End-use Energy and Emission model (CHREM) (Swan et al., 2008, 2011a; Swan, 2010). CHREM is statistically representative of the Canadian housing stock (CHS). It is based on the Canadian Single-Detached and Double/Row Database (CSDDRD) (Swan et al., 2009; Swan, 2010), and utilizes the high resolution building energy simulation program ESP-r (ESRU, 2013) as its simulation engine. ESP-r is a widely used open-source integrated energy modeling tool for the simulation of the thermal, visual and acoustic performance of buildings (ESRU, 2013; Clarke, 2001; USDOE, 2013). It is capable to model heat, air, moisture and electrical power flows at user-determined resolution (allowing minute level time-steps required to model active and passive solar technologies), and supports simultaneous building fabric/network mass flow and CFD domains. ESP-r has a strong research heritage (e.g.) (Crawley et al., 2008) and has been extensively validated (Strachan et al., 2008). CSDDRD was developed using the latest data available from the EnerGuide for Houses database, Statistics Canada housing surveys and other available housing databases, and consists of close to 17,000 houses representative of the CHS. CHREM consists of six components that work together to provide predictions of the end-use energy consumption and GHG emission of the CHS. These components are (Swan et al., 2008, 2011a; Swan, 2010; Farhat and Ugursal, 2010):

- The Canadian Single-Detached and Double/Row Housing Database (CSDDRD).
- A neural network model of the appliances and lighting (AL) and domestic hot water (DHW) energy consumption of Canadian households.
- A set of AL and DHW load profiles representing the usage profiles in Canadian households.

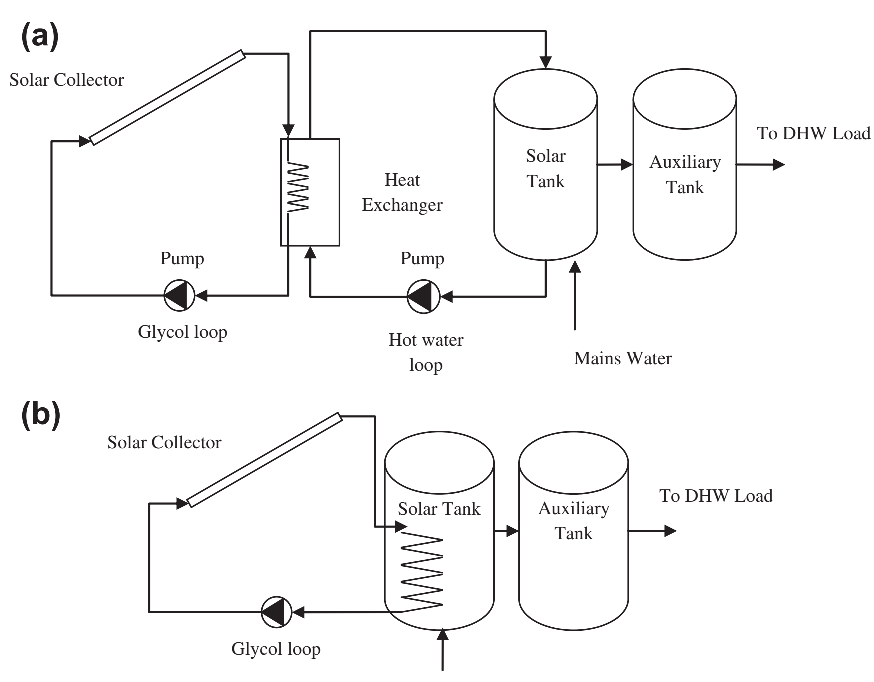

Fig. 1. Solar domestic hot water systems suitable for CHS: (a) system 1 and (b) system 2.