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Research paper

Performance of two domestic solar water heaters with drain water heat recovery units: Simulation and experimental investigation

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HIGHLIGHTS

- Performance evaluation of two solar domestic water heaters with DWHR units.
- The results show that the DWHR is capable of an annual heat recovery of 789 kWh.
- SDWH of House A with flat collector produces an annual energy of 2038 kWh.
- SDWH of House B with evacuated collector produces an annual energy of 1383 kWh.

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ABSTRACT

This paper presents an investigation on the performances of drain water heat recovery (DWHR) system and two solar domestic water heaters (SDWH). The DWHR units and water heater systems were recently installed side-by-side at the Archetype Sustainable Twin Houses at Kortright Center, Vaughan, Ontario. The first SDWH system in House A consists of a flat plate solar thermal collector in conjunction with a gas boiler and a DWHR unit. The second SDHW system in House B consists of an evacuated tube solar collector, an electric tank, and a DWHR unit. The extrapolated results based on the experimental study showed that the DWHR unit is capable of an annual heat recovery of 789 kWh and an overall effectiveness of about 50%. The flat plate and evacuated tubes collectors based SDWH systems produce an annual thermal energy output of 2038 kWh and 1383 kWh, respectively.

1. Introduction

The residential sector consumes about 16% of the total energy consumption and contributes to about 15% of the greenhouse gas (GHG) emissions in Canada [1]. Decreasing energy consumptions and conserving energy, beside integrating renewable systems is becoming important as the concerns are growing for rapidly depleting fossil fuels and environmental degradation. Domestic water heating (DWH) is estimated to be the second largest energy end-use for Canadian households, exceeded only by space heating, accounts for about 18% of total household energy consumption [2]. Several strategies were suggested for reducing the amount of energy required in residential DWH, including energy efficient water heaters, methods of heat recovery, and systems that use renewable energy like solar water heaters [3–6].

To reduce the energy consumption in water heating, drain water heat recovery (DWHR) systems are fairly simple in design and are used to extract part of the heat contained in drain water that would otherwise be lost [7,8]. DWHR units usually consist of a main pipe around which a spiral coil is wrapped. Both main pipe and coil are made of copper to enhance heat transfer. These units are usually inserted vertically into the regular plumbing system as a replacement of a section of drain pipes. The drain water flows inside the main pipe and adheres to the inner wall and the inlet cold water from the city mains circulates in the spiral coil in a close and indirect contact with the drain water pipe and feeds water to the water storage tank. The nature of this system implies that there must be simultaneous water flow in the drain pipe and in the coil in order to maximize heat recovery and this occurs mostly during showers [9]. A case study described the significance of DWHR units

Abbreviations: ASH, Archetype Sustainable House; COP, Coefficient of Performance; DHW, Domestic Hot Water; DWH, Domestic Water Heating; DWHR, Drain Water Heat Recovery; GHG, Greenhouse Gas; GSHP, Ground Source Heat Pump; NREL, National Renewable Energy Laboratory; SDHW, Solar Domestic Hot Water; TRCA, Toronto and Region Conservation Authority.

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being installed horizontally into the plumbing system of high rise buildings [10]. Gill and Fung has simulated different DHW systems using TRNSYS to study their fuel consumptions, GHG emissions and 30-year lifecycle costs [11]. They concluded that the SDHW system with DWHR and 225 L daily hot water demand at 60 °C could achieve up to 80% reductions in electricity cost and GHG emissions, when compared with conventional electrical tank without DWHR.

Solar collectors are being increasingly used for the purpose of producing domestic hot water (DHW). Usually, there are two types of collectors used in domestic solar water heater systems: flat plate and evacuated tube collectors. There are several advantages for the flat plate collectors; these collectors use both beam and diffuse solar radiation, do not require tracking of the sun and are low-maintenance, inexpensive and mechanically simple [12]. However, thermal losses in these collectors rapidly increase with higher operating temperatures and low ambient temperature that make them relatively ineffective. On the other hand, the evacuated tube solar collectors can be classified into two main categories: direct flow tubes and heat pipe tubes. All evacuated tube solar collectors consist of a row of parallel evacuated glass tubes to reduce conduction losses and eliminate convection losses [13]. It was suggested that the performance of evacuated tube collectors are generally better than the flat plate collector around or below zero degree air temperature.

A research performed by the National Renewable Energy Laboratory (NREL) on the design, simulation and performance of a solar water heating system installed at the top of a federal building in Philadelphia [14]. The solar heating system consisted of 360 evacuated heat-pipe collector tubes with gross area of 54 m^2 and net absorbing area of 36 m^2. It was found that the annual average collector efficiency based on the net and gross area of the collector was 61.5% and 41% respectively. In a series of comparison tests on solar thermal collectors, twelve systems with flat plate collectors and four systems with evacuated tube collectors were investigated [15]. These systems were tested for thermal performance, durability, reliability, environmental and safety aspects. Their results showed that the system with an evacuated tube collector of 3.2 m^2 had the shortest payback period of 1.3 years. A study was performed on the performance of the vacuum tube and flat plate solar collectors with solar assisted heating systems of two houses [16]. The heating system of one of the houses consisted of a flat plate solar collector, oil furnace and in-floor heating, while the other house was equipped with evacuated tube solar collectors and a stratified water storage tank. The results showed that although the energy yield per aperture area of the vacuum solar collector was higher during the periods with higher ambient temperatures, but it was almost equal to the energy yield of flat plate collector for low ambient temperature. Kim and Seo investigated the thermal performance of a glass evacuated tube solar collector with different absorber tube shapes through numerical and experimental analysis [17]. The studied solar collector consisted of two-layered glass tube and a copper absorber tube. Four different models according to the shape of the absorber were used and studied. The results showed that as the incidence angle for different cases increased, the efficiency was decreased. It was concluded as the center distance of the tubes becomes shorter, the performance of the evacuated tube collector increases even though there was an increase in the shadow effect. Zambolin and Col has presented comparative tests on flat-plate and evacuated-tube solar collectors [18]. The flat-plate solar collector was a standard glazed collector and the evacuated-tube collector was a direct flow type with external compound parabolic concentrator reflectors. The two collectors were installed in parallel and tested under the same operating conditions. From the tests results, it was concluded that the evacuated-tube collector displayed a higher efficiency for a larger range of operating conditions in comparison to the flat-plate collector. The better performance was due to the geometry of evacuated tube collector which exposed the absorbing area to the normal incident solar radiation for longer duration. Several other studies were carried out on the comparative performance of flat plate and evacuated tube solar collectors [19,20]. This research paper presents the performances of two SDWH systems, recently installed in two semi-detached Archetype Sustainable Houses (ASH) at the Living City Campus, located at Kortright Center in Vaughan, Ontario. The main objective of this research was to compare the performances of two SDWH systems for year round application and to evaluate the significance of drain water heat recovery system (DWHR) in the annual energy savings.

2. Descriptions of sustainable houses and systems

2.1. Archetype Sustainable Houses

The Archetype Sustainable House project is composed of two almost similar semi-detached twin houses, named House A and House B. Fig. 1 shows the south-west view of the two houses with House A on the left hand side and House B on the right hand side. These houses are equipped with different mechanical equipments and a comprehensive monitoring systems for evaluating real-time outputs of system and house parameters. House A demonstrates energy efficiency technologies and practices that are current and practical today, while the House B is a showcase of advanced technologies that can be used in residential housing in the near future. Both houses are R2000 and LEED Platinum certified [21]. Although both houses are built based on the R-2000 standard, there are a few differences in the insulation, windows and mechanical systems.

2.2. Domestic water heater of House A

The domestic water heater (DWH) of House-A consists of a solar system for water heating in conjunction with an auxiliary heating system with natural gas and a drain water heat recovery (DWHR) unit. A schematic of DWH system of House A is given Fig. 2. The piping setup of the house is such that the cold water from the main supply is passed through the DWHR unit to get preheated. The solar water heater (SWH) utilizes a flat plate thermal collector and a hot water tank for DHW heating. A wall-mounted gas boiler is used for auxiliary heating when the heat provided by the solar collector is not sufficient. The hot water system of the house is only a one-tank system which serves as heat exchanger for gas boiler and DHW tank. A mixture of water and propylene glycol (60:40) is used as heat transfer fluid in the collector loop and is circulated between

Fig. 1. South-west side of twin houses at Toronto and Region Conservation Authority (TRCA).