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ORIGINAL ARTICLE

Inclusive analysis and performance evaluation of solar domestic hot water system (a case study)

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Abstract In recent years Solar Domestic Hot Water systems have increased significantly their market share. In order to better understand the real-life performance of SDHW systems, a single detached house was selected for extensive monitoring. Two solar panels were installed on the house roof to provide thermal energy to the Domestic Hot Water (DHW) system. The house was equipped with data logging system and remotely monitored with performance data collected and analyzed over one year. The paper presents the inclusive analysis and performance evaluation of SDHW system, including DHW recirculation loop, under Canadian weather conditions for average family occupancy (two adults and two kids) with daily average DHW, draws of 246 L. Moreover, the study is carried out a significant recommendation to improve the SDHW performance, decrease the gas energy consumption and reduce greenhouse gas (GHG) emissions. The SDHW performance depends mainly on DHW flow rate, draw time and duration, city water temperature, DHW recirculation loop control strategy and system layout. The performance analysis results show that 91.5% of the collected solar energy is transferred to the DHW heating load through the solar tank. The contribution to DHW heating load is about 69.4% from natural gas and 30.6% from solar. The recirculation loop is responsible for close to 34.9%, of DHW total energy.

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1. Introduction

In Canada, domestic hot water (DHW) heating in an average house contributes to about 18–20% of the total energy use and 15% of greenhouse gas (GHG) emissions [1]. By integrating renewables with conventional fossil fuel fired system a modest reduction in energy use and GHG emissions can be achieved. In residential applications utilized, solar energy for DHW heating can lead to significant energy saving while complimenting the operation of the conventional water heater and energy heat recovery system [1–4]. The solar domestic hot water system performance is mainly dependent on the amount of solar energy received by solar collector and is then transferred to solar storage tank [5–7]. Based on the preliminary estimate data provided by renewable energy network (REN21), about 27 GW_{th} was added to solar collectors for water heating during 2015 and total of 435 GW_{th} existed at the end of 2015

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Nomenclature

Acronyms
DHW domestic hot water
E_{DHW} domestic hot water heating load
E_{gas} input gas energy
$E_{Recir.}$ recirculation heat loss
E_{SD} solar delivery energy
GHG greenhouse gas
SDHW solar domestic hot water system
SF solar fraction

Symbols
Cp_w specific heat capacity of water (kJ/kg °C)
E_{pump} pump energy (kJ)
LHV_{gas} natural gas low heating value (kJ/L)
T_{cold} city cold water temperature (°C)
$T_{glcol\ cold}$ return glycol temperature to the solar collector (°C)
$T_{glcol\ hot}$ outlet glycol temperature from the solar collector (°C)
$T_{hx\ outlet}$ DHW outlet temperature to solar heat exchanger (°C)
T_{return} return recirculation temperature (°C)
T_{solar} DHW outlet temperature from solar storage tank (°C)
$T_{storage}$ DHW inlet temperature to solar heat exchanger (°C)
$T_{storage\ bottom}$ bottom temperature inside the solar storage tank (°C)
$T_{storage\ top}$ top temperature inside the solar storage tank (°C)
T_{supply} supply water temperature from gas fired tank (°C)
V_{DHW} DHW draw volume ($m^{3)}$
V_{gas} natural gas volume (ft^3)
ρ_w density of water (kg/m^3)

[8]. On the other hand, many studies focused on DHW energy saving and stated the difference between expected and real measurement data [9–11].

The average domestic hot water consumption for a single family according to ASHRAE standard (90.1) is about 255 L/day for a typical family with two adults and two children. Various DHW consumption studies have been conducted in Canada and USA to determine the real DHW usage. Perlman and Mills [12] conducted a field trial where DHW flow measurements from 59 homes at 15 min time steps for short period were collected to investigate the household DHW consumption according to various occupancies. They have analyzed the DHW usage based on daily, monthly, and seasonal profiles and presented the DHW flow pattern for a typical family with different occupancies. In addition, the study showed that at high outdoor temperature, the DHW consumption significantly reduces. The DHW consumption depends on technology use, human behavior and demographics. Becker and Stogshill [13] have created a database study from millions of 15 min DHW data records collected from homes and apartments located in Canada and USA.

Thomas et al. [14] monitored 74 households in Ontario and analyzed the frequency and volume of daily DHW draws. Usage data have been collected from each house for about a month with high 2–4 s resolution. Their study concluded that the average daily DHW consumption and frequency of the draws were lower than recommended by the ASHRAE standard. Moreover, Edwards et al. [15] measured DHW profiles from 73 households in Quebec with 5 min resolution. The data were clustered to present four aggregate DHW consumption levels and 12 houses were selected for developing representative DHW annual profiles. The DHW profiles were used to investigate numerically the performance of typical solar DHW system equipped with auxiliary DHW tank. They concluded that for large DHW draws, the auxiliary gas-fired tank should be provided the DHW energy load when there was no solar radiation (during the morning, evening and overnight).

The Halifax Regional Municipality established solar city pilot program and contents 35 data fields from each participating homeowner. The data featured occupancy, water source, method of DHW heating, energy use and energy costs for each house. Evarts and Swan [16] used these data to calculate the daily average DHW energy consumptions.

Several researchers use available statistic data to generate DHW consumption profiles. Jordan and Vajen [17] used synthetic profiles based on data provided by [18] to generate DHW draw profiles with various time steps and loads. On the other hand, Hendron and Burch [19] estimated DHW profiles based on collected data provided by American Water Works Association. In order to obtain real and accurate DHW draw profiles have cost associated with installation and instrumentation. In recent years, few researchers have been completed measuring DHW draw profiles for short period by assigning a probability to particular DHW events and then estimating the DHW usage for every time of interval of interest [20–23].

Canadian demographics have changed since 2011 where the average number of people per household is 2.5 in Canada and 2.6 in Alberta [24]. At the same time, the numbers of household appliances such as clothes washing machines and dishwashers have increased and the installations of low flow faucet and showerhead have considerably decreased the household water consumption. Currently, a number of federal and provincial government programs have encouraged actions to improve the efficiency of the DHW system and reduce DHW consumption.

Hourly DHW profiles are presented by [25] for selected weekday and weekend days over the entire year featuring five different groups and a number of occupants based on a limited noncontinuous monitoring data. The averaged DHW consumption per day based on collected data can be used in relative simulations and system sizing software. An excellent technical, economic achievability and different world scenario review for solar water heating system (SWHS) are presented by [26]. Many researchers have also integrated SDHW with heat

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