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Comparative assessment of residential energy options in Ontario, Canada

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ABSTRACT

In this paper, the electricity, heating and cooling demands of a Southern Ontario residence are assessed and compared. Five specific systems are analyzed: ground and air source heat pumps, stand-alone PV, PV/fuel cell hybrid and a wind turbine/fuel cell hybrid system. Actual monitored data from a residence using a ground source heat pump is taken as a reference and compared with the others. Average weather conditions, electricity prices and average electricity loads in Toronto, Ontario, are used as reference data. Thermodynamic, economic and environmental comparisons are performed. It is found that heat pump systems offer significant advantages over the other systems.

1. Introduction

Sustainability in the building sector requires major effort to reduce energy demand, improve energy efficiency and increase the share of renewable energy sources. The improvement of fenestration, heat insulation and air tightness in the building envelope has importance. Various options exist on the supply side for the combined provision of home electricity, heating and the integration of renewable energies [1]. Renewable energy sources (solar, wind, etc.) are gaining more attention as alternatives to conventional fossil fuel sources, due to diminishing fuel sources, as well as environmental pollution and global warming problems [2]. In this paper, three renewable energy technologies are considered for buildings; solar, wind and fuel cells.

The solar photovoltaic (PV) cell is one of the most significant and rapidly growing renewable energy technologies. During the last decade, PV applications have increased and extended to industrial use in some countries. The clean, renewable and reliable PV systems have attracted growing attention from political and business decision makers [3]. Wind energy is also among the world's most significant and rapidly growing renewable energy sources. Recent technological developments have significantly reduced wind energy costs to economically attractive levels in many locations. Wind energy farms, consequently, are considered as a key alternative energy source in many jurisdictions [4]. Though still in early stages of adoption, fuel cell systems are becoming a focus of interest due to their potential for high efficiency, low emissions and low noise. Fuel cells normally operate on hydrogen, but can also be used with natural gas or other fuels by external or internal reforming.

In this paper, a comparison of different residential energy sources for electricity and heat demand is performed. Except for the reference cases, they are stand-alone systems which imply an off-the-grid electricity system for locations that are not supplied with an electricity distribution system. The comparison between grid dependent and independent systems is made to distinguish the thermodynamic, environmental and cost elements of the systems.

Dorer et al. [1] have presented a performance assessment of fuel cell micro-generation systems for residential buildings in Switzerland. Gencoglu and Ural [5] developed a stand-alone fuel cell system activated by PV panels. Onovwiona and Ugursal [6] presented a review of residential cogeneration systems. Nexus [7] presented a comparison and data for several systems. Cetin et al. [8,9] examined a residential system supplied with DC power using a fuel cell system in Turkey. Hamada et al. [10–12] investigated a polymer electrolyte fuel cell for a residential energy system. Islam and Belmans [13] presented results of an optimal design of an independent photovoltaic fuel-cell hybrid system. Eroglu et al. [14] designed and operated a "renewable house" using a PV/wind/fuel cell hybrid power system. Also, Nelson et al. [15] performed a unit sizing and cost analysis of stand-alone hybrid wind/PV/fuel cell power generation systems.

Although there have been many past studies of renewable sources of energy for buildings, stand-alone power generation systems and comparisons therein, to the best of our knowledge, there have been no comprehensive comparative studies of heat pumps,

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Nomenclature

A	cell area (m^2), swept area of rotor (m^2)
A_c	area of collector (m^2)
b	Tafel slope
CC	cooling capacity (W)
C_p	power coefficient of wind turbine
$COP_{act,h}$	actual heating coefficient of performance
$COP_{C,h}$	maximum heating coefficient of performance
COP_{Carnot}	coefficient of performance of Carnot cycle
E_o	standard reversible cell potential (V)
$E^{SW}_{S/Y}$	incident radiation flux (W/m^2)
$EEER_{Carnot}$	energy efficiency ratio of Carnot cycle
EFF_{ad}	efficiency of AC/DC converter
FPC	fan power correction (W)
HR	heating rate (W)
i	current density (A)
I_e	current between electrodes (A)
ICC	ISO Cooling Capacity (W)
ICE	ISO COP Efficiency (W/W)
IEE	ISO EER Efficiency (W/W)
IHC	ISO Heating Capacity (W)
P_{max}	maximum power output (W)
P_{wind}	wind power (W)
PI	power Input (W)
PPC	pump power correction (W)
Q'_{sh}	space heating load rate
R	ohmic resistance (ohms)
T_c	indoor temperature (K)
T_H	temperature of high temperature reservoir/outdoor temperature (K)
T_L	temperature of low temperature reservoir (K)
V	cell voltage under load (V)
V_o	open circuit reversible cell potential (V)
X_{H_Z}	hydrogen production rate
X_i	mole fractions of species (g mole)
Greek	
v	wind speed (m/s)
η_{II}	second law efficiency
η_{max}	maximum efficiency
ρ	air density (kg/m^3)

PVs, fuel cells and wind turbines in Ontario, Canada. This paper performs a case study for Ontario that can be adapted to other jurisdictions for potential renewable energy systems.

2. System description

Five residential energy systems will be compared in this section. The first two systems are widely used and grid dependent. The other three systems are innovative alternatives and grid independent. The comparison will be made between traditional and promising systems. These alternatives are chosen as the first two options and widely used while the last three are alternative and renewable options. In this way, the users may choose between different options. Also, the comparison of the grid versus stand-alone system has been made to characterize the current situation. Grid energy prices are increasing and alternative energy is becoming cheaper so there is a break-even point. The research objective is to determine whether or not we have come to that point or not.

A nearly 90 m^2 bungalow with a full basement in family residence in Southern Ontario is chosen for a case study. The house is supplied by grid electricity and uses a ground source heat pump.

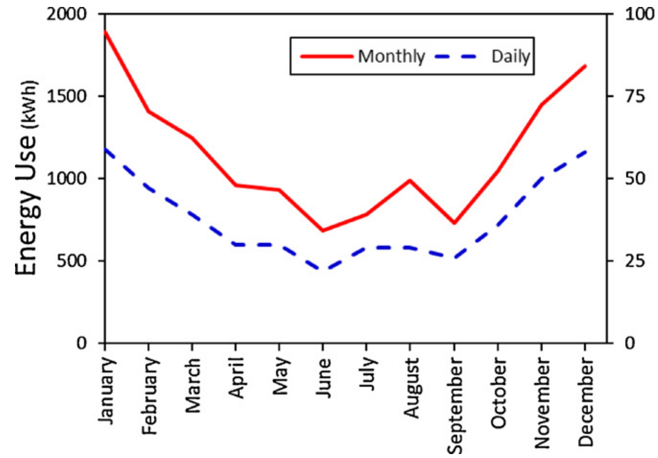

Fig. 1. Monthly and daily energy use of the ground source heat pump system.

Monthly electricity bills for the year 2010 are used. This house was selected because it is a common example of a Southern Ontario residence using the grid as the electricity source and a ground source heat pump as the heat source.

The geothermal heat pump unit is a Geosmart 049 with a horizontal loop (four 600 foot loops). The specifications of the unit are shown in Table 1 [16]. The monthly electricity bills are shown in Table 2. The data are shown in Fig. 1. Although an average Ontario household consumes around 1000 kWh each month, the selected house consumes around 600 kWh/month.

On an average, 60% of a yearly electricity bill goes toward heating and cooling the home in Ontario. In the USA, about 66% of the annual domestic energy consumption is heating and cooling. Home appliances use about 18% of household electricity consumption in Toronto. In the USA, this ratio is 25%.

In a typical home in Toronto, Ontario, about 20% of household energy costs are due to hot water. In the USA, this value is about 15%. This ratio will be used in the sample house in Southern Ontario. Another aspect is the hourly use of electricity as the cost of grid electricity changes depending on the day of the week and time of day. Renewable energy sources are intermittent, since solar PV electricity is effective only during daylight hours and the wind speed changes at different times.

Hourly electricity demand of Ontario is obtained for the years 2002–2011 [17]. For example, in January, 2011, 59 kWh energy was used per day on an average. This energy is distributed hourly according to the Ontario Average Load and used during the period. While considering the average Ontario power load, there are residences and industry. During working days and weekends, although the load changes, it will be assumed the same.

The Monthly Average Solar Radiation and Wind Speed Data of Toronto [18] are shown in Table 3. This data will be used to calculate the solar and wind power. To find the hourly span of solar radiation, the average radiation span will be used. The monthly average solar radiation values are distributed according to the data in Table 3. Wind speed monthly averages for Toronto are also used. Daily values are inconsistent, average values will be used.

Electricity prices in Ontario change with the time of day and week. The prices effective May 1, 2012 will be used [18]. Weekends and holidays are off-peak during both the winter and summer periods.

The selected house uses a ground source heat pump and electrical water heater. This will be a reference for comparisons with other systems. In the cooling cycle, as shown in Fig. 2, refrigerant vapor exits the compressor at a temperature in the range of 50–60 °C, which is warmer than the ground. As a result, it loses