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Research paper

An investigation of the techno-economic impact of internal combustion engine based cogeneration systems on the energy requirements and greenhouse gas emissions of the Canadian housing stock

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HIGHLIGHTS

- Techno-economic evaluation ICE cogeneration systems for Canadian housing is reported.
- ICE cogeneration retrofit could yield 13% annual energy savings in Canadian housing.
- Annual GHG emissions of Canadian housing could decrease by 35% with ICE cogeneration.
- But, in some provinces, GHG emissions would increase as a result of ICE cogeneration.

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ABSTRACT

This study provides a techno-economic evaluation of retrofitting internal combustion engine (ICE) based cogeneration systems in the Canadian housing stock (CHS). The study was conducted using the Canadian Hybrid Residential End-Use Energy and GHG Emissions Model (CHREM). CHREM includes close to 17,000 unique house files that are statistically representative of the Canadian housing stock. The cogeneration system performance was evaluated using a high resolution integrated building performance simulation software. It is assumed that the ICE cogeneration system is retrofitted into all houses that currently use a central space heating system and have a suitable basement or crawl space. The GHG emission intensity factor associated with marginal electricity generation in each province is used to estimate the annual GHG emissions reduction due to the cogeneration system retrofit. The results show that cogeneration retrofit yields 13% energy savings in the CHS. While the annual GHG emissions would increase in some provinces due to cogeneration retrofits, the total GHG emissions of the CHS would be reduced by 35%. The economic analysis indicates that ICE cogeneration system retrofits may provide an economically feasible opportunity to approach net/nearly zero energy status for existing Canadian houses.

1. Introduction

Energy use in Canada increased by 22.3 percent between 1990 and 2010. According to the Office of Energy Efficiency (OEE), in 2010 Canadian households were responsible for 16 percent of the total national energy use and 14 percent of the greenhouse gas (GHG) emissions, and spent $26.3 billion on their energy needs [1]. Of the total energy use in the Canadian residential sector, 80 percent is associated with space and domestic hot water (DHW) heating and 18 percent is for appliances and lighting [1]. Thus, there is increasing interest to reduce the energy consumption and associated GHG emissions of the Canadian housing stock by retrofitting individual houses and communities with advanced and renewable energy options to approach or achieve net-zero energy (NZE) status. To facilitate a national scale research effort in identifying feasible technologies and paths to approach or achieve NZE status, the Smart Net-zero Energy Buildings Strategic Research Network (SNEBRN) initiative was recently established [2].

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Nomenclature

ACSH	annual cost savings for the house due to energy savings in a uniform series (C$)
ATCCH	average tolerable capital cost per house (C$)
e	fuel cost escalation rate (decimal)
E	energy saving per period for each fuel type (unit depends on fuel type; kg, litre, kWh, etc.)
EIF	emission intensity factor (g CO_{2eq}/kWh)
F	fuel price per unit of each fuel type (C$/unit)
GER	GHG emission reduction (decimal)
GHG_{CHP}	GHG emissions from combined heat and electricity generation in houses eligible for ICE cogeneration retrofit
GHG_{CHS}	GHG emissions from separate heat and electricity generation in CHS
GHG_{N-E}	GHG emissions from separate heat and electricity generation in houses not eligible for ICE cogeneration retrofit
i	interest rate (decimal)
m	number of different fuels used in a house
n	acceptable payback period (year)
NH	number of houses that received the upgrade
PE_{CHP}	primary energy consumption for cogeneration
$PE_{CHS,EE}$	primary energy consumption for separate electricity production for the CHS
$PE_{CHS,th}$	primary energy consumption for separate heat production for the CHS
PE_{conv}	primary energy consumption of separate heat and electricity generation
PE_{ICE}	primary energy consumption for ICE cogeneration in houses that receive ICE cogeneration retrofit
$PE_{N-E,EE}$	primary energy consumption for separate electricity production in houses not eligible for ICE cogeneration retrofit
$PE_{N-E,th}$	primary energy consumption for separate heat production in houses not eligible for ICE cogeneration retrofit
PES	primary energy saving (decimal)
SE_{EE}	electricity use
SE_{th}	secondary energy used for heating
TCC	tolerable capital cost (C$)
TCCH	tolerable capital cost of the retrofit for the house (C$)
TTCC	total tolerable capital cost (C$)

Greek symbols

$\eta_{EE,CHP}$	electrical efficiency of the cogeneration production
$\eta_{EE,conv}$	efficiency reference value for separate electricity production
$\eta_{th,CHP}$	thermal efficiency of the cogeneration system
$\eta_{th,conv}$	efficiency reference value for separate heat production

Abbreviations

AB	Alberta
AL	appliance and lighting
BC	British Columbia
CHP	combined heat and power
CHREM	Canadian hybrid residential end-use energy and GHG emissions model
CHS	Canadian housing stock
CSDDRD	Canadian single-detached double/row database
C$	Canadian dollar
DHW	domestic hot water
GHG	greenhouse gas
HHV	higher heating value
IC	internal combustion
ICE	internal combustion engine
LHV	lower heating value
MB	Manitoba
NB	New Brunswick
NG	natural gas
NF	Newfoundland
NS	Nova Scotia
NZE	net zero energy
OEE	Office of Energy Efficiency
ON	Ontario
PCM	phase change material
PE	Prince Edward Island
QC	Quebec
SK	Saskatchewan
SNEBRN	smart net-zero energy buildings strategic research network

Cogeneration (i.e. combined heat and power – CHP) systems that generate electrical and thermal energy simultaneously from a single source of fuel are of interest because of their higher efficiency compared to conventional systems that generate electricity and thermal energy in two separate processes. Onovwiona & Ugursal [3] classified micro cogeneration units into four major categories: reciprocating internal combustion (IC) engine based, micro turbine based, fuel cell (FC) based and reciprocating external heat source Stirling engine (SE) based. As part of a comprehensive effort to evaluate the feasibility of different cogeneration systems for the Canadian housing sector to achieve or approach net-zero rating, the IC engine based system is considered in this work due to the mature technology, fuel adaptability and ubiquitous presence of IC engines in the market. Several authors used experimental and numerical approaches to study residential scale ICE cogeneration systems. For example, Aussant et al. [4] developed a series of test case house models using a building performance simulation program to assess the economic feasibility and efficiency of residential scale ICE cogeneration system in Canada. It was concluded that electrical and thermal loads as well as climatic conditions and construction characteristics of the house may have strong influence on the overall performance of the micro cogeneration system. It was also found that the increase in the fuel cost of household due to the cogeneration system could be justified by the electricity trade with the grid. Aliabadi et al. [5] conducted a study to compare three natural gas powered micro cogeneration systems (i.e. ICE, SE and FC) from energy, exergy and marginal efficiency perspectives. The analysis showed that for all three systems, the ICE cogeneration system energy and exergy efficiencies increase with heat use. Caresana et al. [6] modelled a 28 kW_e natural gas fired ICE cogeneration system to investigate the constant and variable speed operation modes. Techno-economic analysis showed that good energy and economic performances compared with a conventional heat and electricity generation system can be achieved in a 10-flat apartment building. Beausoleil-Morrison [7] and Ferguson et al. [8] developed a model for residential scale ICE cogeneration system as part of IEA/ECBCS Annex 42. The model was implemented into a series of whole building simulation programs including EnergyPlus,