THE FEASIBILITY OF INTERNAL COMBUSTION ENGINE BASED COGENERATION IN RESIDENTIAL APPLICATIONS

by

Christianne Diane Aussant

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I would like to dedicate this work to my parents, Mama and Papa.

Everything I am and ever will be, I owe to you.

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Abbreviations

A/C	Air Conditioning
AB	Alberta
ACH	Air Change per Hour
AIM-2	Alberta Infiltration Model
ALC	Appliance, Lighting and Cooling
ASCII	American Standard Code for Information Interchange
BC	British Columbia
CCHT	Canadian Centre for Housing Technology
CDA	Conditional Demand Analysis
CHP	Combined Heat and Power
CSA	Canadian Standards Association
DHW	Domestic Hot Water
EGH	EnerGuide for Houses
ESP-r	Environmental Systems Performance – research
ESRU	Energy Simulation Research Unit
FCHU	Fuel Cell Heating Unit
GHG	Greenhouse Gas
GWP	Global Warming Potential
HDD	Heating Degree Day
HHV	Higher Heating Value
HVAC	Heating, Ventilation and Air Conditioning
ICE	Internal Combustion Engine
IEA	International Energy Agency
LHV	Lower Heating Value
LPG	Liquefied Petroleum Gas
MB	Manitoba

MLC	Multi-Layer Construction
NB	New Brunswick
NF	Newfoundland
NG	Natural Gas
NHS	New Housing Survey
NN	Neural Network
NRCan	Natural Resources Canada
NS	Nova Scotia
ON	Ontario
PEI	Prince Edward Island
PEM	Proton Exchange Membrane
PQ	Quebec
RSI	R-value Système International
SFC	Specific Fuel Consumption
SHEU	Survey of Household Energy Use
SI	Spark Ignition
SK	Saskatchewan
SOFC	Solid Oxide Fuel Cell
TOU	Time of Use
WCH	Wet Central Heating

Symbols

$\bar{\eta}$	average efficiency
$\bar{A}$	Average house area (ft^2)
$\%surface_i$	percentage of heat loss through surface i
$(S:L)_1$	sensible to latent ratio for first occupant
$(S:L)_r$	sensible to latent ratio for remaining occupants
A	area of house as defined by SHEU (ft^2)
BB_{output}	annual back-up burner output (MJ/yr)

$capacity_{ss}$	steady-state furnace capacity (W)
$cost_{BC}$	total fuel cost in base case simulation (CAD/yr)
$Cost_{el,flat}$	annual cost of electricity using a flat rate electricity price (CAD/yr)
$Cost_{el,TOU}$	annual cost of electricity using TOU pricing (CAD/yr)
$Cost_{i,C1}$	fuel cost for test case house i simulated in city 1 (CAD/yr)
$Cost_{i,C1,BC}$	base case fuel cost for test case house i simulated in city 1 (CAD/yr)
$Cost_{i,C2}$	fuel cost for test case house i simulated in city 2 (CAD/yr)
$Cost_{i,C2,BC}$	base case fuel cost for test case house i simulated in city 2 (CAD/yr)
$Cost_{i,MIN}$	minimum increase in fuel cost for test case house i (CAD/yr)
$cost_{ICE}$	total fuel cost in ICE based cogeneration simulation (CAD/yr)
$Cost_{NG}$	annual cost of natural gas (CAD/yr)
$Demand_{DHW}$	DHW demand ((GJ/yr)
$Demand_{el}$	annual electricity demand of test case house (kWh/yr)
$Demand_{el,grid}$	grid-imported electricity in ICE based cogeneration simulations (kWh/yr)
$Demand_{SH}$	estimated space heating demand (GJ/yr)
$Energy_{th}$	annual thermal energy requirement of test case house (GJ/yr)
E	electricity demand
$EF_{el,avg}$	Average GHG emissions factor for electricity (gCO_2eq/kWh)
$EF_{el,hi}$	high intensity electricity emissions factor (gCO_2eq/kWh)
EF_F	GHG emissions factor for fuel (gCO_2eq/m^3)
EG_{ff}	total electricity generation from fossil fuel fired power plants (kWh)
fan_i	fan power at time step i
$fuel_{DHW}$	annual DHW energy requirement (GJ/yr)
$fuel_{SH}$	annual space heating fuel requirement (GJ/yr)
GHG_{BC}	total GHG emissions in base case simulation (tonnes/yr)
$GHG_{el,avg}$	annual GHG emissions due to electricity using average emissions factor (tonnes/yr)
$GHG_{el,hi}$	annual GHG emissions due to electricity using the high intensity

	electricity emissions factor (tonnes/yr)
GHG_{ff}	total GHG emissions from fossil fuel fired power plants (gCO_2eq)
$GHG_{i,C1}$	GHG emissions for test case house i simulated in city 1 (tonnes/yr)
$GHG_{i,C1,BC}$	base case GHG emissions for test case house i simulated in city 1 (tonnes /yr)
$GHG_{i,C2}$	GHG emissions for test case house i simulated in city 2 (tonnes/yr)
$GHG_{i,C2,BC}$	base case GHG emissions for test case house i simulated in city 2 (tonnes /yr)
$GHG_{i,MAX}$	maximum GHG reduction for test case house i (tonnes/yr)
GHG_{ICE}	total GHG emissions in ICE based cogeneration simulation (tonnes/yr)
GHG_{th}	annual fuel GHG emissions (tonnes/yr)
$GHG_{tot,avg}$	total annual GHG emissions using average electricity emissions factor (tonnes/yr)
$GHG_{tot,hi}$	total annual GHG emissions using high intensity electricity emissions factor (tonnes/yr)
H_{Attic}	attic height (m)
H_{eave}	height of building eaves (m)
HHV_v	higher heating value of fuel per unit volume (MJ/m^3)
h_I	number of kWh in first price tier
h_{II}	number of kWh in second price tier
h_{TOTAL}	total number of kWh
i	time-step, test case house number
ICE_F	annual ICE fuel consumption (kg/yr)
$ICE_{Output,el}$	ICE electrical output (kWh/yr)
$ICE_{Output,th}$	ICE thermal output (GJ/yr)
L	length of house (ft or m)
Lf_i	furnace part load ratio at time step i
LHV_m	lower heating value of fuel per unit mass (MJ/kg)

LHV_v	lower heating value of fuel per unit volume (MJ/m^3)
Losses	transmission and distribution losses (kWh)
MET_1	metabolic rate of first occupant (W/m^2)
MET_r	metabolic rate of remaining occupants (W/m^2)
n	number of occupants
NG_{tot}	annual total natural gas consumption (m^3/yr)
NN	neural network estimate of annual electricity consumption
O_F	Ontario flat rate electricity price (¢/kWh)
O_{TOU}	Ontario time-of-use electricity price (¢/kWh)
P_1	population of simulation city 1
P_2	population of simulation city 2
$P_{el,flat}$	flat rate price of electricity (¢/kWh)
$P_{el,TOU}$	cost of electricity according to TOU pricing at time-step i (¢/kWh)
P_F	flat rate electricity price (¢/kWh)
P_F	provincial flat rate electricity price (¢/kWh)
P_I	flat rate electricity price for first tier (¢/kWh)
P_{II}	flat rate electricity price for second tier (¢/kWh)
P_{NG}	price of natural gas (¢/m^3)
P_{TOU}	Provincial time-of-use electricity price (¢/kWh)
Q	thermal demand
SA_i	surface area of surface i (m^2)
SA_{Total}	total surface area of basement (m^2)
Storeys	the number of storeys excluding the basement
W	width of house (ft or m)
W_{daily}	daily water draw (litres)
WF_1	weighing factor for simulation city 1
WF_2	weighing factor for simulation city 2
$WF_{i,C1}$	weighing factor for simulation city 1, test case house i
$WF_{i,C2}$	$WF_{i,C2}$ = weighing factor for simulation city 2, test case house i

WF_{SHEU}	SHEU weighing factor
X_i	data
X_{iAB}	absolute data point
X_{iN}	normalized data point
X_W	weighted average
α_E	part of the energy transformed into electricity in a cogeneration unit (%)
α_Q	part of the energy transformed into usable heat in a cogeneration unit (%)
Δcost	change in fuel cost relative to base case cost (%)
ΔGHG	change in GHG emissions relative to base case GHG emissions (%)
η_{CHP}	ICE based cogeneration CHP efficiency (%)
η_E	electrical yield of an electrical power plant (production of electricity only)
η_{el}	ICE electriclal efficiency (%)
η_Q	yield of a boiler (production of heat only)

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Abstract

The objectives of this work are to model a group of test case houses using a high-resolution building simulation program, to evaluate the efficiency of internal combustion engine (ICE) based cogeneration and to determine the economical (in terms of fuel cost) and environmental impacts of using ICE based cogeneration systems for residential use.

Fifty-seven independent houses models were created using the high-resolution building simulation software, ESP-r and were simulated using conventional space and domestic hot water heating equipment. The results of these base case simulations were used as the basis of comparison for the ICE based cogeneration simulations. A sensitivity analysis was performed on the ICE based cogeneration model, simulating a 1.0 kW and 2.0 kW ICE system with a 300 litre and 450 litre tank in all of the test case house models.

The performance in terms of electrical and CHP efficiencies of the ICE based cogeneration systems in Canada were investigated and it was determined that the performance of the ICE based cogeneration system is dependent on the thermal and electrical loads of the house, on climate, especially the severity and duration of the heating season, and on the constructional characteristics of the house.

The economic viability in terms of fuel costs of the ICE based cogeneration system was investigated using both flat rate and time-of-use electricity pricing. It was determined that the economic viability of the ICE based residential cogeneration is dependent on the provincial fuel and electricity prices. In provinces with relatively low fuel prices and relatively high electricity prices (e.g. Saskatchewan) using the 1.0 kW ICE based cogeneration system resulted in an increase (< 15%) in fuel costs in all of the test case houses. In provinces with relatively high fuel prices and low electricity prices (e.g. Quebec), the fuel cost using the ICE based cogeneration system was considerably higher (>90%) compared to the base case.

The potential reduction of GHG emissions using the ICE based cogeneration system was investigated. A GHG emissions analysis was performed on each of the test case house models for the base case scenario and the cogeneration cases. The total GHG emissions for each of the cogeneration system configurations were calculated and compared the emissions profile for the base case scenario. It was determined that the GHG reduction potential was dependent on the provincial electricity emissions factor. In provinces where the electricity generation mix is such that the emissions factor is high, (>750 gCO_2eq/kWh), using the ICE based cogeneration system resulted in a reduction of GHGs.

The annual simulation results were extrapolated to comment on the GHG reductions and associated increase in fuel costs at a regional and national level using ICE based cogeneration. At a national level, there is a potential for between 1900 kt – 5200 kt of GHG reductions using ICE based cogeneration in residential applications costing between 420 CAD to 515 CAD in increased fuel costs per tonne of GHG reductions.

Chapter 1

Introduction

Due to rising fuel costs, decreasing fossil fuel stocks, increasing atmospheric carbon dioxide levels and Canada's commitment under the Kyoto Protocol, there is a need for measures to be taken to increase energy efficiency and decrease emissions production. Cogeneration, or the simultaneous production of electricity and useful heat using one fuel stream, offers a way of increasing fuel efficiency while decreasing emissions when compared to conventional electrical and thermal energy generation.

Residential cogeneration is an attractive option for increasing energy efficiency and decreasing greenhouse gas (GHG) emissions as residential cogeneration systems can achieve energy conversion efficiencies of up to 80% (based on HHV) as compared to 30-35% (HHV) efficiency obtained through conventional fossil fuel based electricity production and up to 55% (HHV) for combined cycle plants, such as combined cycle gas turbine. Higher efficiency translates into reduced GHG emissions and reduced fuel costs. Moreover, there are several technologies suitable for residential cogeneration currently available or under development including reciprocating internal combustion engine, micro-turbine, fuel cell, and reciprocating external Stirling engine based cogeneration systems.

1.1 Problems Associated with Conventional Energy Generation and Utilization, and Canada's Response

According to the International Energy Outlook 2006 published by the US Department of Energy, world energy demand is expected to increase by 71% between 2003 and 2030 (Energy Information Administration, 2006). In addition, all forecasts of future world energy supply (POLES, IEA, World Bank, etc.) anticipate an almost doubling of world primary energy supply between 2000 and 2020 (Pilavachi, 2002). Carbon dioxide (CO_2) emissions are expected to increase by at least the same amount as the reduced emissions achieved by using advanced technologies in developed countries will be offset by an increase in fossil fuel use for transportation and by the use of low efficiency technologies in developing countries (Pilavachi, 2002). Current world energy demand is met primarily by fossil fuels – oil with 39% of the total share, natural gas at 23%, coal at 24%, nuclear at 7% and others including renewable sources at 8% (Doman, 2004). Fossil fuel dependence is expected to be 90% by 2020 (Pilavachi, 2002).

In Canada, between 1990 and 2003, secondary energy use – the energy used to heat and cool homes and workplaces, to operate appliances, vehicles and factories – increased 22%, from 6950 to 8460 petajoules (PJ) (NRCan, 2005). Consequently, secondary energy-related GHG emissions increased 23% from 410 to 500 megatonnes (Mt) (NRCan, 2005). As Figure 1.1 indicates, over 17% of this energy use was in the residential sector contributing 16% of the total secondary energy-related GHG emissions (NRCan, 2005).

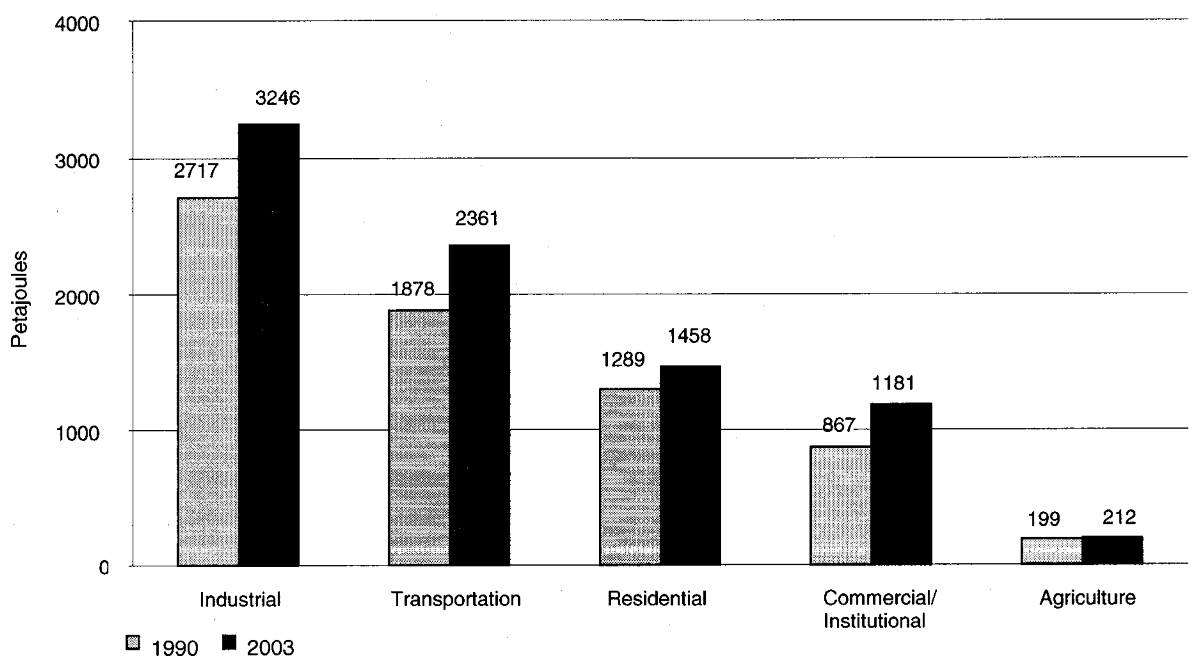

Figure 1.1 Energy Use by Sector, 1990 and 2003 (Petajoules) (NRCan, 2005)

In response to increasing GHG emissions resulting from increasing energy demand and consequent fossil fuel use, Canada has agreed, under the Kyoto Protocol, to reduce its annual GHG emissions to levels 6% below that of 1990 by 2012. Published by the Government of Canada, the Action Plan 2000 outlines Canada's commitment to reduce GHG emissions by approximately 65 Mt per year during the commitment period of 2008-2012 with 10% of the reductions expected to come from the residential sector (Government of Canada, 2000).

1.2 Cogeneration

Cogeneration, also known as combined heat and power (CHP), is defined as the simultaneous production of electrical or mechanical energy and useful thermal energy from a single energy stream such as oil, coal, natural or liquefied gas, biomass or solar (ASHRAE, 2000). Cogeneration is a well-proven technology that has been used for over 125 years. Its first appearance was in industrial plants in the 1880s when steam was the primary source of energy in industry and electricity was just surfacing as a product for both power and lighting (Knight and Ugursal, 2005). Figure 1.2 shows the difference between cogeneration and conventional generation.

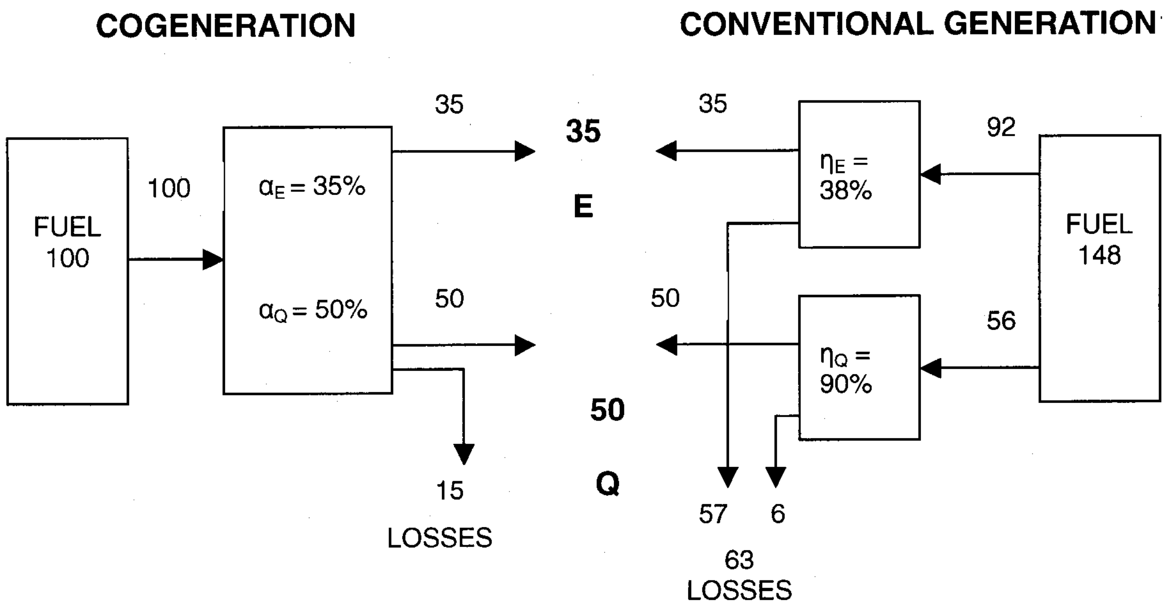

Figure 1.2: Cogeneration vs. Conventional Generation (Knight and Ugursal, 2005)

Where:

α_E = part of the energy transformed into electricity in a cogeneration unit

α_Q = part of the energy transformed into usable heat in a cogeneration unit

η_E = electrical yield of an electrical power plant (production of electricity only)

η_Q = yield of a boiler (production of heat only)

E = electricity demand

Q = thermal demand

The efficiency of a cogeneration system is defined as the ratio of energy output to fuel input as shown in Equations 1.1 and 1.2. Many manufacturers base engine power ratings on the lower heating value (LHV) (ASHRAE, 2000). Thus when defining efficiency, the LHV of the fuel is used, where LHV is defined as the higher heating value of the fuel (HHV) less the energy required to vaporize the water produced during the combustion process (Onovwiona and Ugursal, 2006).

$$\text{Electrical Efficiency} = \frac{\text{electrical output (kW)}}{\text{fuel input (kW)}} \quad [1.1]$$

$$\text{Overall Efficiency} = \frac{\text{useful thermal (kW)} + \text{electrical output (kW)}}{\text{fuel input (kW)}} \quad [1.2]$$

While cogeneration can provide thermal and electrical energy at higher efficiencies than conventional methods, many applications still involve the burning of fossil fuels resulting in combustion products that are harmful to the environment. The combustion products obtained from the burning of fossil fuels include carbon dioxide (CO_2), oxides of nitrogen (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO), unburned hydrocarbons and particulates. However, due to the increased efficiency of cogeneration systems, less fuel has to be used in order to produce the same amount of useful energy, resulting in lower GHG emissions using cogeneration when compared to conventional generation methods.

Currently, there are a number of types of cogeneration systems available commercially with others at various stages of research and development. With respect to single-family dwellings, there are several systems that could be applicable including reciprocating internal combustion engine (ICE) (spark ignition – gasoline, natural gas, propane, or compression ignition – diesel), micro gas turbine based systems, fuel cell based systems and Stirling engine based systems. Any of these systems could be used in place of a boiler or furnace and used to produce the required thermal and electrical energy while surplus energy could be sold to the local utility grid or stored in an energy storage device (Onovwiona and Ugursal, 2006).

1.3 Techno-Economic and Environmental Analyses

To aid in the implementation of residential cogeneration systems, computer modeling and simulation techniques can be used to determine information regarding the technical, economic and environmental aspects of cogeneration. Assessing the techno-economic feasibility and environmental impacts of cogeneration and providing conclusions about the feasibility of using cogeneration on a residential level are critical in the development of the residential cogeneration industry.

While the energetic performance of a cogeneration system for residential use is key, factors such as the economic cost, environmental benefits and the impact of electricity rate structure are important aspects to be considered in determining the feasibility of residential cogeneration. In order to ensure that the use of a residential cogeneration system is economically viable, a feasibility analysis must be undertaken, and is one of the main objectives of this research project.

1.4 Objectives

This research project has the following objectives:

- Using a high-resolution building energy simulation program, to conduct building energy simulations to predict and compare the annual energy requirements and energy consumption of single detached houses in Canada using conventional and cogeneration energy systems.
- To evaluate the feasibility of residential cogeneration in Canada. The performance of the cogeneration system in terms of efficiency and ability to meet the electrical and thermal demands will be analyzed.
- To determine the economic feasibility of residential cogeneration in Canada. The economic performance under both flat rate and time-of-use electricity pricing scenarios will be examined.
- To determine the environmental impacts of residential cogeneration versus conventional technologies. Analyses on the GHG emissions will be done and conclusions drawn about the environmental impacts of using cogeneration.

Chapter 2
Review of Cogeneration Technologies

2.1 Conventional Methods Used to Heat and Power Residential Spaces

Typically, Canadian homes receive electricity from the electrical grid and have onsite equipment for thermal energy generation as illustrated in Figure 1.2. Under this scheme, up to 1.5 times the amount of fuel is required to meet the electrical and thermal demands when compared to cogeneration, depending on the way in which the electricity was generated. While conventional thermal energy generation equipment (i.e. boilers, furnaces) may have high efficiencies (~90% based on HHV), the efficiency by which electrical energy is produced by the conventional power plant is less than 35% (based on HHV) and is reduced even further by distribution and transmission losses. In addition, two sources of fuel are needed – one at the offsite power plant and one at the onsite thermal plant, compared to one fuel source for onsite cogeneration systems, yielding lower overall efficiencies and increased GHG emissions.

2.2 Residential Cogeneration

Currently, there are several cogeneration systems available for use in residential buildings including reciprocating internal combustion engine (ICE) (spark ignition – gasoline, natural gas, propane, or compression ignition – diesel) based systems, micro gas turbine based systems, fuel cell based systems and Stirling engine based systems (Onovwiona and Ugursal, 2006). A brief description of each system and its advantages and disadvantages are presented here while a more detailed description of ICE based cogeneration is given in Section 2.3. Both sections are based on two recent review papers (Onovwiona and Ugursal, 2006) and (Knight and Ugursal, 2005) which provide a comprehensive review of the available technologies.

Reciprocating internal combustion engines are well suited to residential cogeneration due to their robust and well-proven technology. They are commercially available over a wide range of sizes, can utilize a wide variety of fuels and operate with high (>80%) availability making them well suited to numerous cogeneration applications including residential cogeneration. The reciprocating internal combustion engine based cogeneration system has several key advantages over competing technologies (i.e. fuel cell, micro-turbine and Stirling engine based cogeneration systems) including low capital cost, reliable onsite energy, low operating cost, ease of maintenance and wide service infrastructure. In addition, with proper maintenance, modern internal combustion engine based cogeneration systems operate at high levels of availability.

Micro-turbine based cogeneration systems are a scaled down version of conventional combustion turbines that can achieve electrical efficiencies of approximately 30% and overall efficiencies of approximately 80% (based on LHV). Currently, micro-turbine based cogeneration systems are commercially available in sizes ranging from 20-80 kW - sizes suitable for multi-family dwellings, commercial or institutional buildings. Specifically, Capstone Turbine Corporation (30 kW), Honeywell Power Systems (75 kW), Elliot/Bowman Company (45 kW and 80 kW), Kohler Power Systems (80 kW), and Turbec (105 kW) manufacture commercially available cogeneration systems. Installed costs of micro-turbine cogeneration systems vary depending on project and site specific factors, however, the capital costs of micro-turbine based cogeneration systems have been estimated to be between US$ 1560 – US$ 2520 kW_e^{-1}. In addition, presentations from the Third Annual Workshop on Microturbine Applications held in 2003 summarize the operational experience of a multitude of installed micro-turbine based CHP projects concluding that installed costs are less than US$ 3000 kW_e^{-1} (CANMET, 2003). Research is ongoing for systems suitable for single-family dwellings with capacities ranging from 1-10 kW.

Micro-turbine based cogeneration systems have several advantages over reciprocating internal combustion engine based cogeneration systems. These advantages include compact size, low weight, small number of moving parts, lower noise, multi-fuel capability (including fuels such as natural gas, diesel, landfill gas, ethanol, industrial off-gases and other bio-based liquids), low emission levels, higher heat recovery potential due to high grade waste heat, low maintenance requirements, and low vibration. However, internal combustion based systems are able to achieve higher efficiencies at lower power ranges than micro-turbine based cogeneration systems.

Fuel cell technology, while still considered an emerging technology, has potential to be used successfully in cogeneration applications while offering many environmental benefits when compared to conventional generation or reciprocating internal combustion based cogeneration systems. Advantages offered by fuel cell based cogeneration include low noise levels, potential for low maintenance, excellent part load management, low emissions and high overall efficiencies – up to 85-90% (based on HHV).

With respect to emissions, stationary fuel cells powered by natural gas produce less GHG emissions compared to combustion based cogeneration systems. Specifically, carbon dioxide (CO_2) emissions may be reduced by up to 49%, nitrogen oxide (NO_x) emissions by 91%, carbon monoxide by 68% and volatile organic compounds by 93% making fuel cell based cogeneration attractive from an environmental perspective. As fuel cell based cogeneration is still an emerging technology, high cost and short lifetime are the major disadvantages of this system. However, research into developing less costly materials and mass production processes is ongoing and it is expected that the cost of fuel cell based cogeneration will decrease in the future. A survey conducted by Fuel Cell Today in December 2006 lists companies that are actively involved in the development of residential fuel cell based cogeneration system including (Adamson, 2006):

- Acumentrics (USA): developing a number of products for CHP systems using its tubular SOFC.
- Ebara Ballard (Canada): released its next generation residential cogeneration fuel cell, the Mark 1030 V3 1 kW stack.
- Centrica (UK): developing CHP fuel cell units specifically for the UK market.
- European Fuel Cells (Germany): developing a 'Fuel Cell Heating Unit (FCHU)' which will cover 75% of the heating demand of a typical European single family home. The PEM, natural gas fuelled unit is anticipated to remain a 1.5 kW electrical output.
- Idemitsu Kosan (Japan): testing a number of different cogeneration units, in terms of fuel and size.
- Japan Energy (Japan): in conjunction with Toshiba Fuel Cell Power Systems has installed a number of LPG fuelled 700W fuel cells into homes that it serves with a reported electrical efficiency of 33% (HHV) and thermal efficiency of 45% (HHV).
- Koa Gas Development Corporation (Japan): introduced an LPG fuelled home-use cogeneration system of 750W output.
- Kyushu Oil (Japan): in conjunction with Toshiba Fuel Cell Power Systems, are testing and marketing LPG PEM CHP units.
- Matsushita Electric Industrial (Japan): Currently installing PEM based CHP units with 33% (HHV) electrical efficiency and 45% (HHV) thermal efficiency and marketing houses with these units pre-installed.
- Nuvera (Italy): currently producing its 3rd generation Avanti CHP (5 kW_e and 7 kW_{th}) unit
- Sanyo Electric (Japan): developing a 1 kW PEM unit for the domestic CHP market.
- Saibu Gas (Japan): started demonstration tests of cogeneration system of home-use PEM systems.

- Toshiba Fuel Cell Power Systems (Japan): is the new subsidiary formed by Toshiba for the sole purpose of commercialisation of its 1 kW residential PEM fuel cells by 2008. The technical targets for the system include overall efficiency of > 77% (HHV) and 80 °C waste heat.

As can be seen from the above list, many of the residential fuel cell based cogeneration systems are still in the pre-commercialisation phase.

Currently, proton exchange membrane (PEM) fuel cells have been identified as the preferred technology among residential CHP projects as this type of fuel cell runs at temperatures of approximately 90°C, thus avoiding the need for special expensive materials (d' Accadia et al., 2003). Conversely, solid oxide fuel cells (SOFC) operate at temperatures around 800°C, requiring the use of expensive materials (d' Accadia et al., 2003). With electrical efficiencies up to 40% (based on HHV), SOFC's perform better than PEMFC technology, but start-up and cooling phases last longer which affects time and costs required for installation, maintenance and repair (d' Accadia et al., 2003).

Fuel cell based residential cogeneration is still in the development and demonstration phases thus little information on installation and maintenance costs is available. D'Paepe et al. (2006) determined the installation and maintenance costs of a natural gas fuelled 4 kWe Idatech fuel cell, with 9kWth output to be 140,000 € and 35 €/year respectively.

Stirling engine based cogeneration, while not widely used, has good potential because of several advantages including its ability to attain high efficiency, fuel flexibility, low emissions, low noise/vibration levels and good performance at partial load. In addition, the heat supply in a Stirling engine is from an outside source thus allowing for a wide variety of fuels to be used including conventional fuels such as fossil fuels and renewable energies such as solar and biomass. Due to the continuous combustion process taking place outside of the engine and having fewer moving parts than a reciprocating internal combustion engine, Stirling engines have low wear and longer maintenance free operating periods, operate more quietly and are smoother than reciprocating internal combustion engines.

Stirling engine based cogeneration systems are being developed by several companies, including:

- Infinia Corporation (USA) (Infinia Corporation, 2005): Infinia has worked with several technology development partners to create CHP systems based on its Stirling generators, for residential applications. In the next two years, these products are expected to enter into volume production and facilitate large-scale deployment of clean, efficient CHP systems. The ENATEC consortium in the Netherlands and Rinnai in Japan both use Infinia Stirling generator technology in their residential CHP systems achieving CHP efficiencies as high as 95%.
- SOLO Stirling Engine (Germany) (SOLO Stirling Engine, 2006): currently manufactures Stirling-engine based CHP systems ranging from 2 - 9.5 kW_e, 8 - 26 kW_{th} with CHP efficiencies between 92% - 96% (based on HHV).
- WhisperGen Limited (New Zealand) (WhisperGen, 2004): currently manufactures 1 kW_e (7.5 - 12 kW_{th}) Stirling engine based cogeneration systems.
- Sunpower Inc. (USA) (Sunpower, 2006): developed and delivered a variety of free-piston Stirling power generators at power levels between 35 W_e - 7.5 kW_e. Applications to residential cogeneration are expected to enter the market in 2007.
- Sigma Elektroteknisk (Norway) (Sier, 2002): currently working on industrialising the PCP (Personal Combustion Powerplant), a micro energy converter utilizing a Stirling engine as the prime mover. The PCP 1-130 is an energy converter based on a Stirling engine designed in Sweden to be used in micro CHP applications with 1.5 kW_e generator and 9kW_{th} of available heat.

Still considered an emerging technology, there is little information available on the cost of Stirling engine based cogeneration, however, De Paepe et al. (2006) have summarized the installation and maintenance costs for two Stirling engine based cogeneration systems, namely the Stirling 161 microKWK module manufactured by SOLO and the WhisperGen manufactured by WhisperGen Limited. These costs are summarized in Table 2.1.

Table 2.1: Stirling Engine Based Cogeneration Costs

System	System Capacity (kW)	Installation Cost (€)	Maintenance Costs (€/yr)
Solo	2 – 9.5 kW_e	25000	75
	8 –26 kW_{th}		
WhisperGen	1 kW_e	9000	75
	4.9 – 8 kW_{th}		

2.3 Internal Combustion Engine (ICE) Based Cogeneration

Reciprocating internal combustion engines are classified based on the internal combustion engine cycle: Otto cycle and Diesel cycle (EDUCOGEN, 2001). In an Otto cycle, a mixture of air and fuel is compressed in each cylinder and an externally supplied spark causes ignition. In a Diesel cycle, only the air is compressed in the cylinder, and fuel is injected into the cylinder when the cylinder is near the end of its compression stroke. Ignition is spontaneous due to the high temperature of the compressed air. Otto engines can operate on a wide range of fuels including gasoline, natural gas, propane, sewage plant gas and, landfill methane while diesel engines operate on higher pressure and temperature levels, thus utilize heavier fuels namely, Diesel oil, fuel oil and residual fuel oil (EDUCOGEN, 2001).

While diesel engines are used mainly for large-scale cogeneration, they can also be used in small-scale applications. Comparatively, spark ignition (SI) engines are better suited to small-scale cogeneration applications as they can produce hot water up to 160°C or a 20 bar steam output, whereas the heat recovery potential is lower in diesel engine based systems, usually achieving maximum temperatures of 85°C. Diesel engines operate with shaft efficiencies from 35% - 45% (based on LHV) while SI engines operate with shaft efficiencies in the range of 27% - 35% (based on LHV) (EDUCOGEN, 2001a). The characteristics that make reciprocating engines the most widely used prime mover in CHP installations under 1 MW_e include good part-load operation, proven technology, wide range of sizes and fuels and ease of maintenance (Hinojosa et al., 2005). In addition, the typical availability of reciprocating internal combustion engines is in the range of 90% - 96%, and according to the North American Electric Reliability Council 1999, average availabilities are above 94% - 96% (EDUCOGEN, 2001a).

The primary emissions related to reciprocating internal combustion engines are oxides of nitrogen (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs – unburned, non-methane hydrocarbons). Specifically, NO_x emissions are a result of burning fossil fuel in the presence of oxygen. The level of NO_x emissions is dependent on several factors that can be optimized to reduce NO_x production including temperature, pressure, and combustion chamber geometry and air-fuel mixture. NO_x emissions can be reduced markedly by operating with a large excess of combustion air (lean burn) (EDUCOGEN, 2001a). In addition, low NO_x emissions are achieved using engines fitted with air/fuel ratio controllers and stoichiometric engines fitted with three-way catalytic converters, where a three-way catalytic converter treats the exhaust gases with catalysts to convert NO_x back to nitrogen and oxygen. Through better design and control of combustion as well as the use of exhaust catalysts, the emissions profile of modern natural gas fired SI engines has improved drastically making lean burn natural gas fired engines the lowest emitter of NO_x while diesel engines produce the most.

The electrical efficiencies of reciprocating internal combustion engine-coupled generators are in the range of 28-39% (based on LHV) and tend to increase as the engine size increases, while the overall efficiency of a reciprocating internal combustion based cogeneration system is in the range of 85-90% (based on LHV) with little variation due to size. Figure 2.1 shows a reciprocating internal combustion engine based cogeneration system.

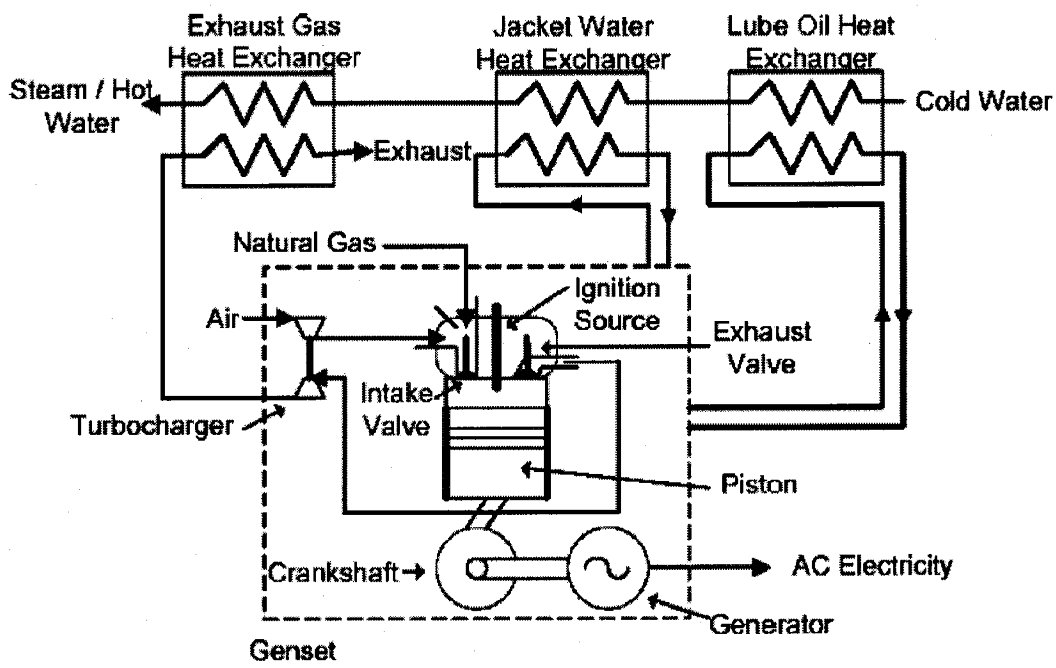

Figure 2.1: Typical Packaged Internal Combustion Engine Based (spark ignited) Cogeneration System (Onovwiona, 2005)

There are four sources from which heat can be recovered in a reciprocating internal combustion based cogeneration system as illustrated above. The four sources are the exhaust gas, engine jacket cooling water, lube oil cooling water and turbocharger cooling. The majority of the heat that is recovered comes from the exhaust stream, accounting for between 30-50%, while the engine-cooling jacket represents up to 30% of the heat recovery. The heat recovery potential from lube oil cooling is generally low grade and not always usable (EDUCOGEN, 2001a), therefore by recovering the heat from the exhaust stream and the engine jacket cooling, between 70-80% of the fuel used is converted into electricity and useful heat.

Currently, there are several manufacturers that offer reciprocating internal combustion based cogeneration systems suitable for residential use. Specifically, Honda Motor Co. has developed a cogeneration system for single-family residential applications with a 1 kW electrical output and a 3 kW thermal output with an overall efficiency of 85% (based on LHV), while a German company Senertec, manufacturers a 5.5 kW electrical, 10 kW thermal cogeneration system. There are several companies that offer larger systems better suited to multi-family, commercial and institutional applications including Tokyo Gas (6 kW), The Yanmar Diesel Engine Co. in collaboration with Osaka Gas Co. (8.2-9.8 kW), Cummins, Inc. (7.5 – 1750 kW), Lister-Petter, Inc. (5-400 kW), Alturdyne Power Systems, Inc. (25kW-2MW), Tecogen, Inc. (60-75 kW) and DTE Energy (10-1000 kW).

Capital costs for reciprocating internal combustion engine based cogeneration systems are low compared to other technologies (i.e. fuel cell, micro-turbine and Stirling engine based cogeneration systems). In general, systems less than 500 kW in size cost between 800 and 1300 $/kW, with the cost for smaller systems higher. Maintenance costs vary depending on the type, speed, size, and number of cylinders of an engine. Maintenance costs include maintenance labour, engine components and materials such as oil filters, air filters, spark plugs, gaskets, valves, piston rings, and oil. In addition, maintenance costs include minor and major overhauls where minor overhauls involve changing of engine oil, coolant and spark plugs, are often carried out for every 500-2000 hours of operation. Major overhauls include a top-end overhaul at 12000-15000 hours of operation including a cylinder head and turbo-charger rebuild and for a major overhaul at 24000-30000 hours of operation including piston/ring replacement and replacement of crankshaft bearings and seals.

Chapter 3
Review of Analysis Tools Used

3.1 Building Simulation and ESP-r

Building simulation is a powerful tool used to aid in the assessment of renewable energy technologies in buildings. With respect to both environmental impacts and economics, it is important that critical design decisions can be tested and analyzed using building simulation (Hensen et al., 1993). Due to the progression of computing power, as well as the increasing demand for detailed thermal performance assessments, users regularly employ comprehensive, dynamic thermal appraisal tools which are able to handle the complexity of design (Hensen et al., 1993). Currently, there is a plethora of building simulation software available. For information on the abilities of some of the available software, refer to Crawly et al. (2005).

ESP-r is a transient building energy simulation program developed and maintained by Energy Systems Research Unit (ESRU) at the University of Strathclyde (ESRU, 2002). It is an integrated modeling tool for the simulation of the performance of buildings in terms of thermal, visual and acoustic performance as well as the assessment of the energy use and gaseous emissions associated with the environmental control system and constructional materials (ESP-r, 2000). ESP-r's capabilities have expanded to include thermal behaviour as well as electrical, fluid, acoustic and visual performance (ESP-r, 2000)

Using ESP-r, buildings are modelled as five separate domains. Below is a brief description of each domain (Ferguson, 2003).

Thermal Domain: the thermal domain includes all of the thermal masses contained within the building envelope, as well as the heat transfer (conduction, convection and radiation) occurring between thermal masses and between the building and its environment The thermal domain is modelled using a heat balance method and the resulting equation set is solved to determine the temperature of each thermal mass in the building envelope.

Plant Domain: the plant domain includes mechanical equipment used to produce electricity and heat for use in the building. ESP-r allows for plants to be modelled at two different levels of complexity:

- Implicit plant models treat mechanical plants as a single control volume exchanging energy with the space and operating at a specified efficiency.

- Explicit plant models are constructed from one or more smaller models that represent separate elements within the plant. This approach allows for the individual plant components to be analysed as well as the plant's interaction with the building to be studied.

Flow Domain: the flow domain considers the flow or movement of air and moisture within the building. ESP-r also includes an optional computational fluid dynamics (CFD) model that can determine airflow patterns inside zones within a building.

Power Domain: ESP-r has the ability to simulate complete electrical systems, including lighting equipment and equipment energy use, on site generation devices, and electrical distribution networks.

Control Domain: ESP-r allows a number of control schemes, including ideal, proportional-integral-derivative and adaptive strategies, to be imposed in the building mechanical equipment.

Each of ESP-r's five modeling domains is interdependent and at any one time, the state of each domain is dependent on the states of the other four domains. Each of the five domains is treated using a separate module, and due to the interdependence of the domains, ESP-r determines the solutions of all five domains simultaneously.

Modeling in ESP-r can be achieved using the Project Manager. ESP-r's Project Manager allows for the specification of the model in terms of (Clarke, 1994):

- 3D building geometry with attribution in relation to opaque and transparent material, surface finishes, occupancy, lighting schemes, small power and leakage distribution, with superimposed events to represent phenomena such as window opening, shading device positioning and electric light switching.

- Plant specifications in terms of networks of connected components representing the thermodynamic process occurring yielding pressure and temperature differences that drive heat transfer between, and the flow of, the working fluid.

- Control system specification in terms of a list of control loops.

While the Project Manager is useful in defining a building and plants that are available in the ESP-r database, extending modeling functionality or adding a plant to the database requires the source code to be revised. ESP-r has achieved this by compartmentalizing the source code into technical domains. This allows for changes to be made to one area of the model's code without affecting other areas. Figure 2.2 illustrates the difference between using the project manager and dealing with the source code.

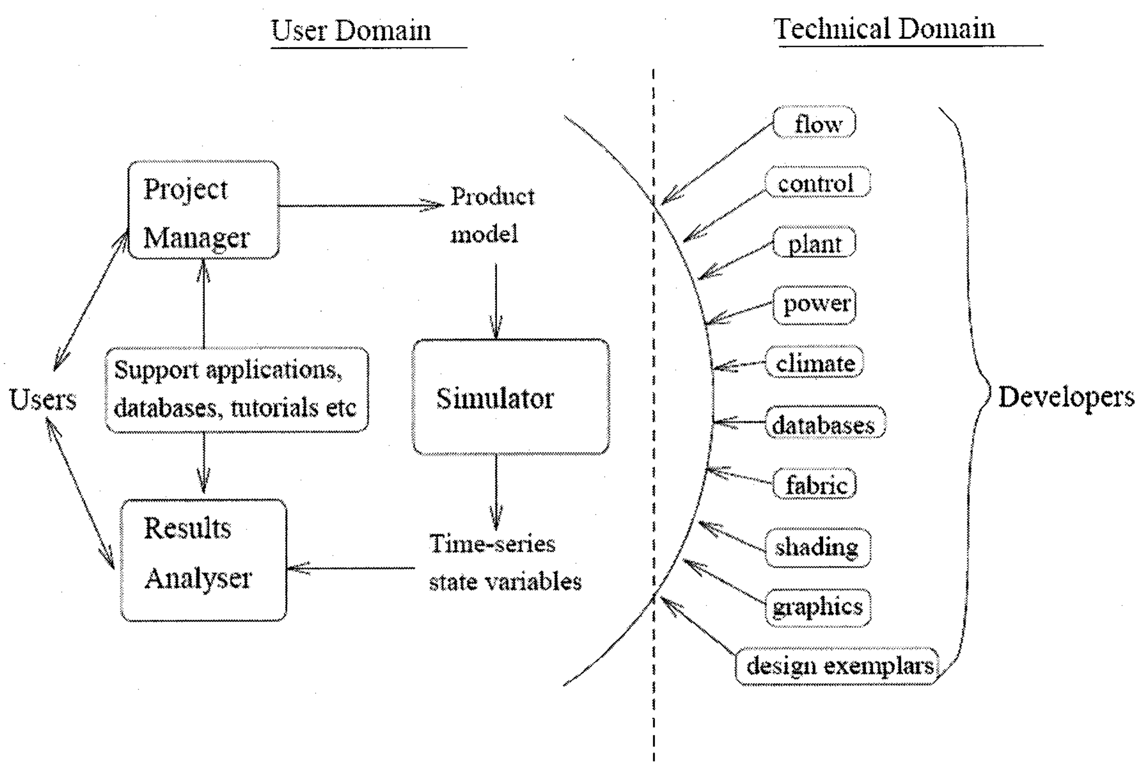

Figure 2.2: ESP-r: Project Manger versus Technical Domains (ESRU, 2002)

ESP-r is a comprehensive modeling and simulation tool. It aims to represent all relevant phenomena, and to process these phenomena simultaneously so that the inter-relationships are preserved (Clarke, 1994). This is achieved by establishing sets of conservation equations for different spatial regions and arranging for the integration of these equations over time (Clarke, 1994). Finally, the theories upon which heat transfer and fluid flow within ESP-r are based and the numerical techniques used are detailed in (Hensen, 1991).

3.2 Feasibility and Sensitivity Analyses

There have been several studies published in recent years investigating the feasibility of residential cogeneration. Peacock and Newborough (2005) investigated the potential economic and CO_2 emissions savings using Stirling engine and fuel cell based cogeneration in the UK while Hawkes et al. (2007) concentrated on SOFC based cogeneration in the UK. De Paepe et al. (2006) investigated the potential cost and CO_2 emissions reductions using ICE, fuel cell, and Stirling engine based cogeneration in Belgium in both single detached and terraced houses. Several Italian studies (Santangelo and Tartarini, 2007), (Possidente et al., 2006), and (d'Accadia et al., 2003) have investigated the reduction in cost and CO_2 emissions using ICE, fuel cell (PEMFC and SOFC), and Stirling engine based cogeneration systems and Dorer et al. (2005) investigated the potential economic savings and CO_2 reduction in single and multi-family dwellings in Switzerland using PEMFC and SOFC based cogeneration. In Canada, Entchev et al. (2004) investigated the performance of Stirling engine based cogeneration and Alanne et al. (2006) investigated the financial viability of SOFC based cogeneration in single-family dwellings.

While ICE based cogeneration is a well-proven technology (Knight and Ugursal, 2005), the feasibility of such systems is not well understood, especially in the Canadian context (Onovwiona, 2005). The current work seeks to improve the understanding of the feasibility of ICE based cogeneration in Canada with emphasis on the economic viability and potential GHG reductions. The ICE based cogeneration system model developed by Onovwiona (2005) for the ESP-r platform will be used as the simulation tool for the analysis. Moreover, a thorough sensitivity analysis will improve understanding of the performance of ICE based cogeneration systems and will allow for conclusions to be drawn regarding the sizing of ICE based cogeneration systems in residential applications.

Chapter 4
Methodology

The purpose of this study is to investigate the economic and environmental impacts of using ICE based cogeneration in single detached houses in Canada. To provide an indication of the potential economic savings and reductions in GHG emissions using ICE based cogeneration in single detached Canadian homes, information from three publicly available Canadian databases was used to model test case houses in ESP-r to be used in building energy simulations. The Survey of Household Energy Use (SHEU) database (Statistics Canada, 1993) was the main database used, however was lacking vital information, therefore two other databases were also used namely, the EnerGuide for Houses (EGH) database (NRCan, 2005) and the New Housing Survey (NHS) database (NRCan, 1997). Note that only houses heated by natural gas or oil were considered in this project as houses heated by either electricity or wood do not have the necessary infrastructure needed to install an ICE based cogeneration system. Moreover, the SHEU database does not include data from Yukon, the Northwest Territories and Nunavut and these territories were therefore not included in this project.

The SHUE and EGH databases were classified into categories according to province, vintage, namely, before 1941, 1941-1960, 1961-1977, 1978 and later, and lastly by space heating fuel type, either natural gas or oil, yielding 8 category groups per province. The NHS database was classified on the basis of province only, as there were not enough entries to allow for further classification. The SHEU database contains weighting factors for each of the houses in the database. The weighting factors indicate the number of houses that a particular house in SHEU represents in the Canadian housing stock. The selection of test case houses was based on the weighting factors in SHEU. The SHEU weighting factors were summed for each category group, and the three highest ranking groups per province, based on the SHEU weighting factors, were chosen as the test case houses yielding 30 test case houses overall.

The test case house dwelling characteristics and space and domestic hot water heating equipment characteristics were determined by conducting a simple statistical analysis of the data provided in SHEU, EGH, and NHS databases. To account for the effect of appliance and lighting usage, electricity load profiles detailing the electricity demand in fifteen-minute intervals were identified for each test case house based on data from BC Hydro (Good et al., 2004).

The test case houses were simulated using the building simulation program ESP-r. Two sets of simulations were conducted to estimate the thermal and electrical demands of the test cases houses. The first set of simulations was conducted using conventional methods, for example, natural gas or oil fuelled furnace and domestic hot water tank, and electricity from the grid, and the second set of simulations was conducted using ICE based cogeneration.

A sensitivity analysis was performed on the ICE based cogeneration model to study the impact on cost and GHG emissions of varying the ICE and thermal storage tank capacities. Two ICE capacities (1 kW and 2 kW) and two hot water storage tank sizes (300 litres and 450 litres) were simulated in each of the test case houses. The simulation results from all simulations, using conventional methods and ICE based cogeneration, were analyzed on the basis of cost, using a flat rate and time-of-use electricity pricing scheme, and potential GHG emission reductions. Conclusions were drawn regarding the economic and environmental impacts of using ICE based cogeneration in single detached Canadian homes.

Figure 4.1 illustrates the methodology followed in this project.

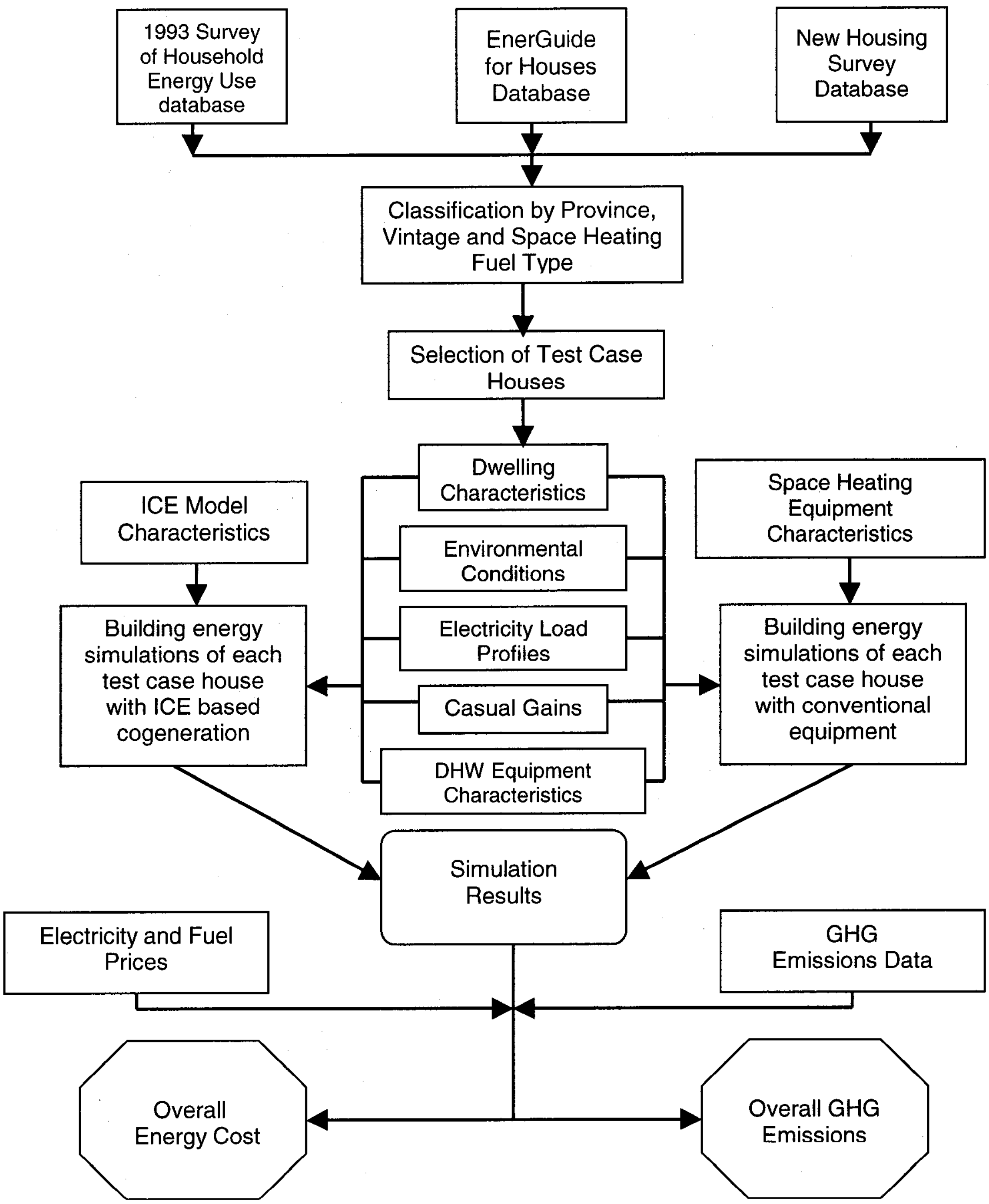

Figure 4.1: Methodology Flow Chart

Chapter 5
Database Classification and Test Case House Selection

5.1 Database Description

To determine a group of test case houses and to have sufficient data from which ESP-r house models could be developed, three databases were used. Below is a description of each database. Appendix A lists the data available in each database.

5.1.1 Survey of Household Energy Use Database

The Survey of Household Energy Use (SHEU) 1993 database (Statistics Canada, 1993) contains detailed information on 8767 houses, representing more than seven million low-rise, single-family dwellings in Canada and is the most comprehensive and statistically representative survey on household energy use in Canada. This survey was conducted by Statistics Canada for Natural Resources Canada in 1993 using both mail-in and telephone interview techniques. The 1993 SHEU database contains detailed information regarding dwelling characteristics, socio-demographical characteristics, as well as information on appliance usage. The database contains weighting factors for each house which quantify the number of houses each entry in the SHEU database represents in Canada. Information regarding the house size, occupancy, number of storeys, number of doors and windows, space heating equipment and fuel type and temperature set points are available in SHEU and this information was used to model the test case houses in ESP-r. However, the information available in SHEU was not sufficient to develop ESP-r models, thus to augment the information in SHEU, data from the EnerGuide for Houses database and the New Housing Survey database was used.

5.1.2 EnerGuide for Houses Database

The EnerGuide for Houses Initiative, a large-scale home energy audit program, was launched in April 1998 and was subsidized by Natural Resources Canada (Fung, 2003). Participation in the EGH program was voluntary and interested homeowners contacted the EGH representative in their area to arrange an audit. The EGH program calculated a measure of energy efficiency, called the "EnerGuide Rating" for each house audited, as well as collected information on the dwelling and space and domestic hot water heating equipment characteristics. The EnerGuide for Houses (EGH) database is a management information tool and central depository for tracking residential energy evaluations and measuring benefits from the energy evaluations delivered across Canada (Blais et al., 2005). The database contains more than 165,000 houses rated across Canada, containing more than 162 information fields per house detailing information on its physical characteristics and energy use (Blais et al., 2005). Equipment type and efficiency levels for space heating and domestic hot water equipment, air change rates and insulation values for the main walls, ceiling and foundation were taken from this database and used to develop the ESP-r test case house models, as this information was not available in SHEU.

5.1.3 New Housing Survey Database

The 1994 New housing survey (NHS) was conducted by Criterion Research Corp. between September 1995 and February 1996 for Natural Resources Canada surveying 2300 participants from all provinces except Prince Edward Island via a mailed out survey (NRCan, 1997). The NHS database contains detailed information on dwelling characteristics, specifically detailed information on window types and window location. Information on house orientation and the relative window distribution (i.e. percentage of windows on each side of the house) were taken from this database, as this information is not available in SHEU or EGH databases.

5.2 Housing Classification

The scope of the project is limited to simulating single detached dwellings, since there is not sufficient data available to develop building energy simulation model input files for low and high-rise apartments, and mobile homes (Fung, 2003). In addition, single-detached houses account for 70% of the SHEU database thus all attached houses, including semi-detached, row, duplex, mobile homes, and low and high-rise apartments are excluded. In addition, only houses heated by either natural gas or oil were considered, as they would have the infrastructure needed to implement a cogeneration system, thus houses heated by electricity were not considered in this analysis. Houses heated by fuels other than natural gas or oil are also excluded as houses using these fuels are not widespread enough (less than 15%) to be considered a test case house. Also, because the SHEU database does not contain any houses from the Yukon Territories, the Northwest Territories and Nunavut, they are not included in the analysis. The NHS database does not contain information on house type (e.g. detached or attached), therefore all entries were utilized.

To determine the test case houses, the databases had to be classified. The classification categories used to classify both SHEU and EGH are illustrated in Figure 5.1.

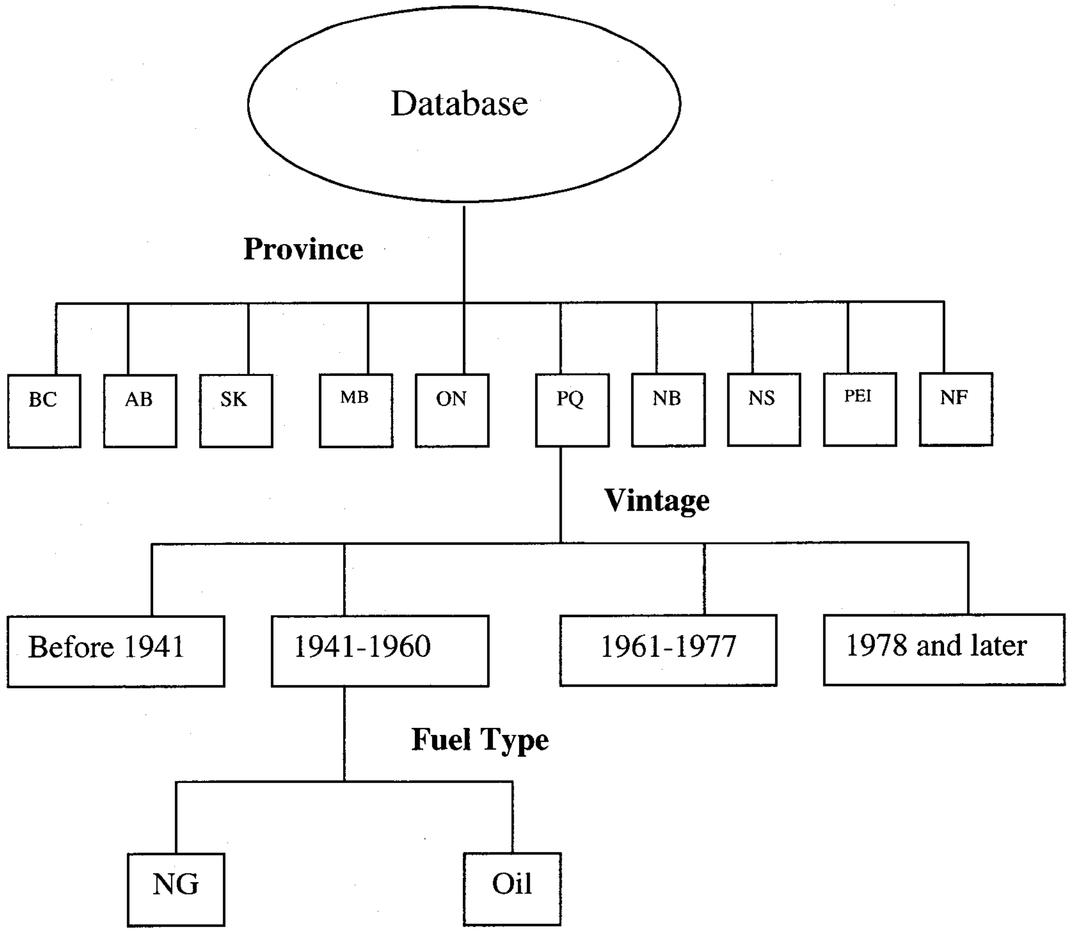

Figure 5.1: Classification Scheme

As illustrated in Figure 5.1, the first step in classification process was to categorize the SHEU and EGH databases by province as listed below:

Province:

- British Columbia
- Alberta
- Saskatchewan
- Manitoba
- Ontario

- Quebec
- New Brunswick
- Nova Scotia
- Prince Edward Island
- Newfoundland

Once classified by province, the data in SHEU and EGH was classified by vintage, namely before 1941, 1941-1960, 1961-1977 and 1978 and later and further classified by space heating fuel type, namely natural gas and oil.

Tables 5.1 – 5.10 present the results of the classification process for the SHEU (weighted values) and EGH databases based on province, vintage and space heating fuel type.

Table 5.1: Classification Results – British Columbia

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	50510	before 1941	NG	2231
before 1941	OIL	11009	before 1941	OIL	411
1941-1960	NG	71086	1941-1960	NG	4377
1941-1960	OIL	23339	1941-1960	OIL	580
1961-1977	NG	186858	1961-1977	NG	10912
1961-1977	OIL	29225	1960-1977	OIL	641
1978 and later	NG	139032	1978 and later	NG	8367
1978 and later	OIL	5733	1978 and later	OIL	127

Table 5.2: Classification Results – Alberta

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	47305	before 1941	NG	1951
before 1941	OIL	0	before 1941	OIL	3
1941-1960	NG	102455	1941-1960	NG	6523
1941-1960	OIL	870	1941-1960	OIL	5
1961-1977	NG	195889	1961-1977	NG	11706
1961-1977	OIL	4363	1960-1977	OIL	4
1978 and later	NG	152023	1978 and later	NG	9743
1978 and later	OIL	0	1978 and later	OIL	1

Table 5.3: Classification Results – Saskatchewan

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	39770	before 1941	NG	1645
before 1941	OIL	5268	before 1941	OIL	84
1941-1960	NG	52328	1941-1960	NG	2695
1941-1960	OIL	4259	1941-1960	OIL	92
1961-1977	NG	73206	1961-1977	NG	4787
1961-1977	OIL	4805	1960-1977	OIL	127
1978 and later	NG	53821	1978 and later	NG	3360
1978 and later	OIL	1077	1978 and later	OIL	38

Table 5.4: Classification Results – Manitoba

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	38044	before 1941	NG	2545
before 1941	OIL	2840	before 1941	OIL	64
1941-1960	NG	48801	1941-1960	NG	2944
1941-1960	OIL	4732	1941-1960	OIL	66
1961-1977	NG	50603	1961-1977	NG	2902
1961-1977	OIL	3939	1960-1977	OIL	47
1978 and later	NG	24936	1978 and later	NG	1369
1978 and later	OIL	985	1978 and later	OIL	14

Table 5.5: Classification Results – Ontario

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	287837	before 1941	NG	10191
before 1941	OIL	124939	before 1941	OIL	2692
1941-1960	NG	276848	1941-1960	NG	9580
1941-1960	OIL	109347	1941-1960	OIL	2077
1961-1977	NG	257750	1961-1977	NG	9968
1961-1977	OIL	59866	1960-1977	OIL	1511
1978 and later	NG	444964	1978 and later	NG	9617
1978 and later	OIL	10574	1978 and later	OIL	484

Table 5.6: Classification Results – Quebec

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	0	before 1941	NG	289
before 1941	OIL	64932	before 1941	OIL	944
1941-1960	NG	13720	1941-1960	NG	409
1941-1960	OIL	50048	1941-1960	OIL	1603
1961-1977	NG	17587	1961-1977	NG	872
1961-1977	OIL	111517	1960-1977	OIL	1441
1978 and later	NG	0	1978 and later	NG	206
1978 and later	OIL	2278	1978 and later	OIL	144

Table 5.7: Classification Results – New Brunswick

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	0	before 1941	NG	4
before 1941	OIL	15438	before 1941	OIL	260
1941-1960	NG	0	1941-1960	NG	7
1941-1960	OIL	13858	1941-1960	OIL	166
1961-1977	NG	0	1961-1977	NG	2
1961-1977	OIL	14416	1960-1977	OIL	149
1978 and later	NG	161	1978 and later	NG	1
1978 and later	OIL	2631	1978 and later	OIL	41

Table 5.8: Classification Results – Nova Scotia

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	531	before 1941	NG	0
before 1941	OIL	40453	before 1941	OIL	1349
1941-1960	NG	529	1941-1960	NG	0
1941-1960	OIL	27521	1941-1960	OIL	875
1961-1977	NG	451	1961-1977	NG	0
1961-1977	OIL	42123	1960-1977	OIL	674
1978 and later	NG	0	1978 and later	NG	3
1978 and later	OIL	17625	1978 and later	OIL	434

Table 5.9: Classification Results – Prince Edward Island

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	0	before 1941	NG	0
before 1941	OIL	6873	before 1941	OIL	125
1941-1960	NG	121	1941-1960	NG	0
1941-1960	OIL	2903	1941-1960	OIL	44
1961-1977	NG	0	1961-1977	NG	0
1961-1977	OIL	7371	1960-1977	OIL	130
1978 and later	NG	0	1978 and later	NG	0
1978 and later	OIL	7537	1978 and later	OIL	99

Table 5.10: Classification Results – Newfoundland

SHEU			EGH		
Vintage	Fuel Type	# of Entries	Vintage	Fuel Type	# of Entries
before 1941	NG	0	before 1941	NG	0
before 1941	OIL	7950	before 1941	OIL	170
1941-1960	NG	0	1941-1960	NG	0
1941-1960	OIL	13568	1941-1960	OIL	270
1961-1977	NG	0	1961-1977	NG	0
1961-1977	OIL	16340	1960-1977	OIL	256
1978 and later	NG	176	1978 and later	NG	2
1978 and later	OIL	10056	1978 and later	OIL	181

The NHS database was classified on the basis of province only as there were not enough entries to allow for further classification. The results of the classification are detailed in Table 5.11.

Table 5.11: NHS Classification Results

Province	Number of Entries
British Columbia	309
Alberta	282
Saskatchewan	147
Manitoba	334
Ontario	446
Quebec	432
New Brunswick	257
Nova Scotia	7
Prince Edward Island	
Newfoundland	82

There were no entries in the NHS for Prince Edward Island, so for the purpose of this study, the data taken from this database for Nova Scotia was used for Prince Edward Island.

5.3 Test Case House Selection

To provide an indication of the potential energy savings and reductions in GHG emissions using ICE based cogeneration in single detached Canadian homes, three representative house archetypes were selected for each province as test case houses. While it is understood that test case houses in the less populated provinces (e.g. Prince Edward Island) will not represent as many homes as test case houses in more populated provinces (e.g. Ontario), it is still advantageous to be able to comment on the economic and environmental impacts of residential cogeneration across all of Canada. In addition, the local climates across Canada vary dramatically and this variation must be taken into account.

The selection of test case houses was based on the weighting factors in the SHEU database. The weighting factors for each classification category were summed, and the three groups per province with the highest sum of weighting factors were chosen as the test case houses for the province. Tables 5.12 and 5.13 present the summed weighting factors for each classification group. The boldface entries are the three highest ranking (according to the sum of weighting factors) categories per province.

Table 5.12: Classification Results for West and Prairie Regions

Classification Category	Province			
	BC	AB	SK	MB
before1941_NG	50510	47305	39770	**38044**
before1941_Oil	11009	0	5268	2840
1941-1960_NG	**71986**	**102455**	**52328**	**48801**
1941-1960_Oil	23339	870	4259	4732
1961-1977_NG	**186858**	**195889**	**73206**	**50603**
1961-1977_Oil	29225	4363	4805	3939
1978_NG	**139032**	**152023**	**53821**	24936
1978_Oil	5733	0	1077	985

Table 5.13: Classification Results for Central and Atlantic Regions

Classification Category	Province					
	ON	PQ	NB	NS	PEI	NF
before1941_NG	**287837**	0	0	531	0	0
before1941_Oil	124939	**64932**	**15438**	**40453**	**6873**	7950
1941-1960_NG	**276848**	13720	0	529	121	0
1941-1960_Oil	109347	**50048**	**13858**	**27521**	2903	**13568**
1961-1977_NG	257750	17587	0	451	0	0
1961-1977_Oil	59866	**111517**	**14416**	**42123**	**7371**	**16340**
1978_NG	**444964**	0	161	0	0	176
1978_Oil	10574	2278	2631	17625	**7537**	**10056**

The highest ranking groups per province – the bolded values in Tables 5.12 and 5.13 - were chosen as the test case houses and are listed in Table 5.14

Table 5.14: Test Case House List

Test Case House	Province	Vintage	Fuel Type
1	BC	1961-1977	Natural Gas
2	BC	1978 and later	Natural Gas
3	BC	1941-1960	Natural Gas
4	AB	1961-1977	Natural Gas
5	AB	1978 and later	Natural Gas
6	AB	1941-1960	Natural Gas
7	SK	1961-1977	Natural Gas
8	SK	1978 and later	Natural Gas
9	SK	1941-1960	Natural Gas
10	MB	1961-1977	Natural Gas
11	MB	1941-1960	Natural Gas
12	MB	before 1941	Natural Gas
13	ON	1978 and later	Natural Gas
14	ON	before 1941	Natural Gas
15	ON	1941-1960	Natural Gas
16	PQ	1961-1977	Oil
17	PQ	before 1941	Oil
18	PQ	1941-1960	Oil
19	NB	before 1941	Oil
20	NB	1961-1977	Oil
21	NB	1941-1960	Oil
22	NS	1961-1977	Oil
23	NS	before 1941	Oil
24	NS	1941-1960	Oil
25	PEI	1978 and later	Oil
26	PEI	1961-1977	Oil
27	PEI	before 1941	Oil
28	NF	1961-1977	Oil
29	NF	1941-1960	Oil
30	NF	1978 and later	Oil

5.4 Test Case House Characteristics

To model the test case houses in ESP-r, the average characteristics for each test case house were determined. The information from the three databases had to be handled separately as the methods required in determining averages of each characteristic (i.e.

house size, insulation levels, etc) varied. The details of the methods used can be found in Appendix B, and a brief discussion is given below.

5.4.1 Survey of Household Energy Use Database

The SHEU database contains weights for each entry in the database. To determine the average of each characteristic taken from SHEU used to model the test case house in ESP-r, a weighted average approach according to Equation 4.1 was used.

$$X_{Wi} = \frac{\sum X_i W_{SHEU}}{\sum W_{SHEU}} \qquad [4.1]$$

Where: X_{Wi} = weighted average

X_i = data

W_{SHEU} = SHEU weighting factor corresponding to each entry

In the case where data was invalid or missing, the weight corresponding to the missing or invalid data was removed and a new sum of weights was calculated. See Appendix B for details. In addition, many of the variables in the SHEU database are qualitative variables represented by an indicator variable. The details of averaging indicator variables can also be found in Appendix B.

Table 5.15 lists the characteristics taken from the SHEU database as well as the averaging technique used.

Table 5.15: Characteristics from SHEU Database

Parameter Number	Parameter Name	SHEU Inquiry Field	Statistical Technique
1	Serial Number	1	-
2	Weight	5	-
3	Occupancy	8	Weighted Average
4	Space Heating Fuel Type	140	Indicator Variable
5	Set-point temperatures (6AM-6PM)	178	Weighted Average
6	Set-point temperatures (6PM-10PM)	179	Weighted Average
7	Set-point temperatures (10PM-6AM)	180	Weighted Average
8	Number of Storeys	181	Indicator Variable
9	Exterior Wall Material	182	Indicator Variable
10	House Size (ft^2)	189	Weighted Average
11	Basement Type	191	Indicator Variable
12	Basement Size	192	Weighted Average
13	Basemetn Heating	201	Weighted Average
14	how much of the basement is area is heated	202	Indicator Variable
15	Attic type	207	Indicator Variable
16	Numer of wood doors with storm door	210	Weighted Average
17	Numer of wood doors	211	Weighted Average
18	Numer of metal doors with storm door	213	Weighted Average
19	Number of metal doors	214	Weighted Average
20	Numer of other doors	218	Weighted Average
21	Numer of 3 pane oversized window	231	Weighted Average
22	Numer of 3 pane other sized windows	232	Weighted Average
23	Numer of 2 pane oversized window	234	Weighted Average
24	Numer of 2 pane other sized windows	235	Weighted Average
25	Numer of 1 pane oversized window with storm wndowes	237	Weighted Average
26	Numer of 1 pane other sized windows witjh storm window	238	Weighted Average
27	Any 1 pane window without storm wndowes	239	Indicator Variable

Table 5.15 Continued: Characteristics from SHEU Database

Parameter Number	Parameter Name	SHEU Inquiry Field	Statistical Technique
28	Numer of 1 pane over sized windows without storm window	240	Weighted Average
29	Numer of 1 pane other sized windows without storm window	241	Weighted Average
30	Air conditionuing usagfe	296	Indicator Variable
31	DHW Fuel	317	Indicator Variable
32	DHW Tank Size	323	Weighted Average
33	DHW add-on insulation blanket	324	Indicator Variable

5.4.2 EnerGuide for Houses Database

The EGH database does not have weighting factors, thus simple averaging was used. The method used to average indicator variables is discussed in Appendix B.

Table 5.16 lists the characteristics taken from the EGH database as well as the averaging techniques used.

Table 5.16: Characteristics from EGH Database

Parameter Number	Parameter Name	EGH Inquiry Field	Statistical Technique
1	Space Heating Equipment Type	7	Indicator Variable
2	Space Heating Equipment Efficiency	8	Simple Average
3	DHW Equipment Type	12	Indicator Variable
4	DHW Efficiency	13	Simple Average
5	Ceiling RSI	19	Simple Average
6	Foundation RSI	20	Simple Average
7	Main Wall RSI	21	Simple Average
8	ACH @ 50 PA	28	Simple Average

5.4.3 New Housing Survey Database

Like the EGH database, the NHS database does not contain weighting factors, allowing the simple averages to be used. As mentioned above, the NHS database was classified on the basis of province only, therefore both house orientation and average relative window distribution were averaged for a province and the results used in all three test case houses per province.

Table 5.17 lists the characteristics taken from the NHS database as well as the averaging techniques used.

Table 5.17: Characteristics from NHS Database

Parameter Number	Parameter Name	NHS Inquiry Field	Statistical Technique
1	House orientation	58	Indicator Variable
2	Number of front basement windows	61a	Simple Average
3	Number of front main windows	61b	Simple Average
4	Number of back basement windows	64a	Simple Average
5	Number of back main windows	64b	Simple Average
6	Number of left basement windows	67a	Simple Average
7	Number of left main windows	67b	Simple Average
8	Number of right basement windows	70a	Simple Average
9	Number of right main windows	70b	Simple Average

5.5 Test Case House Descriptions

Tables 5.18 and 5.19 present the data for test case house 1, which is located in British Columbia, built between 1961-1977, and uses natural gas as the space heating fuel. The test case house descriptions for all 30 test case houses are given in Appendix C.

Table 5.18: Test Case House 1 – Specifications

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	3 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.75
Foundation RSI (Km^2/W)	1.82
Ceiling RSI (Km^2/W)	3.91
Roof RSI (Km^2/W)	0.26
Attic	full attic
External Wall Material	wood
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	77.3
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	51.1
Basement Heating	whole basement heated
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	8.07

Table 5.19: Test Case House 1 – Window Data

Number of 3 Pane Large	0
Number of 3 Pane Regular	0
Number of 2 Pane Large	1
Number of 2 Pane Regular	7
Number of 1 Pane Large	3
Number of 1 Pane Regular	11
Number of Front Basement	0
Number of Back Basement	1
Number of Left Basement	1
Number of Right Basement	1
Number of Front Main	6
Number of Back Main	7
Number of Left Main	3
Number of Right Main	3
Number of Windows in Basement	3
Number of Windows in Main	19

Chapter 6
Load Profile Identification

Individual electricity load profiles were identified for each test case house detailing electricity consumption from appliance and lighting loads in fifteen-minute intervals for an entire year.

6.1 Introduction

Currently, there is no load profile data available in the Canadian public domain. Residential load profile data based on province or dwelling type is not available. It is well known that residential electricity demand varies with socio-economic factors such as household income, dwelling type and ownership, and number of children and adults (Aydinalp et al., 2002a). The availability at home of each household member and their associated home activities also affect the household electricity demand (Capasso et al., 1994). In addition, the shape and magnitude of load profiles also vary with factors such as time of day, time of year, geographical location, and climate (Paatero and Lund, 2006) and (de Dear and Hart, 2002). Due to the absence of load profile data, rather than using arbitrary load profiles, electricity load profiles based on data from B.C. Hydro were used in this study. The B.C. Hydro electricity load profiles are categorized according to geographical regions within British Columbia, namely the Northern, Southern Interior, Lower Mainland, and Vancouver Island regions. Since there is no load profile data available for the remaining provinces, the B.C. load profiles were assigned to the remaining provinces based on heating degree-days. While it is recognized that there are many other factors that affect the shape of the load profile other than the severity of the heating season, the approach detailed below was used in the absence of a more accurate approach due to lack of available data.

6.2 Methodology

Using electricity consumption data for 107 individual yearly accounts of households located in four different regions of British Columbia from B.C. Hydro, electrical load profiles detailing the annual electricity consumption in fifteen-minute intervals were published by Good et al. (2004). Good et al. (2004) selected the load profile that most closely represented the average load profile for the categories defined below. For more information on how the best-matches were determined, see Good et al. (2004). Houses with complete accounts of electrical consumption were classified into categories based on:

Region:

- Lower Mainland
- Northern
- Southern Interior
- Vancouver Island

Annual Electricity Consumption:

- 0 - 9,999 kWh
- 10,000 – 19,999kWh
- 20,000 – 30,000 kWh

House Size:

- 0 – 1499 ft^2
- 1500 – 2499 ft^2
- 2500 – 4500 ft^2

Occupancy:

- 1

- 2
- 3
- 4

Primary Space Heating Fuel Type:

- Natural gas
- Electricity
- Oil

For the categories defined above, the corresponding best-match accounts are listed in Table 6.1.

Table 6.1: Best Match Load Profiles (Good et al., 2004)

Category	Grouping	Best-Match Account
Region	Lower Mainland	2002529 (1997-98)
	Northern	3898678 (1999-00)
	Southern Interior	2004741 (2000-01)
	Vancouver Island	2005521 (1996-97)
Annual Electricity Consumption	0 to 9,999 kWh	3091971 (1996-97)
	10,000 to 19,999 kWh	2005201 (1997-98)
	20,000 to 30,000 kWh	2005521 (2000-01)
House Size	0 to 1,499 ft^2	3091971 (1996-97)
	1,500 to 2,499 ft^2	2005521 (2000-01)
	2,500 to 4,500 ft^2	2006040 (2000-01)
Number of Occupants	One	2005521 (2000-01)
	Two	2983460 (1996-97)
	Three	2004741 (1996-97)
	Four	2006040 (2000-01)
Primary Space Heating Fuel Type	Natural Gas	2004741 (2000-01)
	Electricity	2005521 (2000-01)
	Oil	3091971 (1996-97)

The details of each test case house, namely the region, annual electricity consumption, house size, number of occupants and the primary space heating fuel were used to determine which of the best-match files were to be used in generating the specific load profile. For example, test case house 1 is in British Columbia, has an annual electricity consumption of 10,000 to 19,999 kWh, is between 0 to 1,499 ft^2, has three occupants and uses natural gas as the space heating fuel. The 'best-match' accounts, as listed in Table 6.1, corresponding to the above categories were used to generate the load profile for test case house 1. Specifically, the data for each of the five categories was normalized and all five normalized profiles were averaged. The resulting normalized average load profile was used to generate the absolute load profile specific to test case house 1.

Each entry in each of the five data sets was normalized using Equation 6.1:

$$X_{iN} = X_i \times \frac{(4 \times 8760)}{\sum X_i} \qquad [6.1]$$

Where:

X_{iN} = normalized data point

X_i = data point

ΣXi = sum of data points

(4 x 8760) = the total number of data points - 4 data points per hour, 24 hours daily, 365 days per year.

Once all of the data sets were normalized, they were averaged to give the normalized average load profile for the test case house.

In order to generate an absolute load profile from the normalized load profile, an estimate of the annual electricity consumption for the test case house had to be determined. Aydinalp (2002) used Neural Networks (NN) as well as a Conditional Demand Analysis (CDA) model to estimate the end-use energy consumption of Canadian single-family households, specifically for the entries in the SHEU database. Neural Networks are simplified mathematical models of biological neural networks. They are highly suitable for determining casual relationships amongst a large number of parameters such as seen in the energy consumption patterns in the residential sector (Aydinalp, 2002). The NN model used to determine the electrical demand, specifically the Appliance, Lighting and Cooling (ALC) demand, achieved a high prediction performance ($R^2 = 0.909$) (Aydinalp, 2002). Moreover, the prediction performance of the NN Model was found to be higher than those of the CDA and Engineering Models (Aydinalp, 2002). In addition, the NN model was able to estimate the electricity consumption of individual appliances, to successfully evaluate the differences in end-use and total household electricity consumption based on various categories, and the capability to evaluate the effects of a large number of socio-economic factors (Aydinalp, 2002). Due to the high prediction performance, the estimates determined using the Neural Network model were used to determine the annual electricity consumption for the test case house group. Specifically, the weighted average of the annual electricity consumption for the test case house group using the NN estimates provided in Aydinalp (2002) was determined.

Once the NN estimate of the annual electricity consumption for the test case house was determined, an absolute load profile was generated using Equation 6.2:

$$X_{iAB} = X_{iN} \times \frac{(NN)}{\sum X_{iN}} \qquad [6.2]$$

Where:

X_{iAB} = absolute data point (kWh)

X_{iN} = normalized data point

NN = neural network estimate of annual electricity consumption (kWh)

ΣX_{iN} = sum of normalized data point

Good et al. (2004) reviewed each profile to assess the probability that the house described by the profile uses and air-conditioner in the summer months. The survey conducted by

B.C. Hydro specifically asks whether a central or room air-conditioner is in use, the number of units, and the months of operation. Three houses responded affirmatively to the use of A/C during the summer months, namely 2004357, 2004699, 2767818. None of these three accounts were determined to be 'best matches', thus it is safe to assume that the normalized average load profiles do not include the electricity demand due to cooling.

Statistics were done on the SHEU database to determine if any of the test case houses had cooling. It was found that none of the test case houses had air-conditioning; therefore the estimates for annual ALC electrical consumption for each of the SHEU database entries in the test case house group did not include cooling. Neither, the trends of the load profile, nor the overall annual value used to generate absolute load profiles from the normalized profiles include the effect of cooling.

6.3 Regional Mapping

Before specific load profiles could be generated for each test case house, the data from B.C. Hydro had to be extrapolated to the rest of the country. Specifically, it had to be determined which region in British Columbia could be used to represent the remaining regions in Canada. To facilitate this extrapolation, the heating degree-day (HDD) for each region was determined and compared to the HDD for each of the four regions in British Columbia. All degree-day data was taken from Environment Canada (2004). Tables 6.2 to 6.5 detail the average degree-day for the Atlantic region, Central region, Prairie region and Western region respectively. Table 6.6 details the HDD for the four regions of British Columbia while Table 6.7 details the comparison between the four regions of Canada and the four regions of British Columbia.

Table 6.2: Heating Degree-Day – Atlantic Region

Month	St. John's	Charlottetown	Halifax	Saint John
January	706	805	743	811
February	661	730	668	750
March	636	655	604	636
April	492	460	421	434
May	367	277	256	267
June	215	114	102	125
July	94	30	25	44
August	91	35	29	50
September	187	138	124	160
October	344	315	301	332
November	462	471	449	481
December	624	684	645	705
Total	4879	4714	4367	4795
Regional Average	4688.8			

Table 6.3: Heating Degree-Day – Central Region

Month	Montreal	Toronto
January	875	753
February	747	662
March	628	572
April	369	353
May	157	172
June	43	49
July	8	9
August	21	18
September	117	102
October	308	283
November	492	445
December	753	647
Total	4518	4065
Regional Average	4291.5	

Table 6.4: Heating Degree-Day – Prairie Region

Month	Winnipeg	Saskatoon	Calgary
January	1109	1086	835
February	894	876	680
March	746	738	618
April	422	409	401
May	200	208	252
June	68	82	131
July	21	36	74
August	41	61	90
September	179	207	218
October	395	420	392
November	698	726	631
December	1004	1002	787
Total	5777	5851	5109
Regional Average	5579		

Table 6.5: Heating Degree-Day – Western Region

Month	Vancouver	Victoria
January	455	440
February	374	372
March	353	358
April	264	277
May	171	192
June	27	112
July	34	59
August	31	59
September	104	123
October	246	255
November	358	359
December	449	435
Total	2866	3041
Regional Average	2953.5	

Table 6.6: Heating Degree-Day – British Columbia Regions

Month	Lower Mainland	Vancouver Island	Southern Interior	Northern
January	455	440	676	853
February	374	372	540	662
March	353	358	445	566
April	264	277	295	385
May	171	192	172	253
June	27	112	70	143
July	34	59	24	89
August	31	59	30	107
September	104	123	135	237
October	246	255	335	414
November	358	359	498	621
December	449	435	649	801
Total	2866	3041	3869	5131

Table 6.7: Heating Degree-Day – Comparison

Canadian Region	Regional Average HDD	B.C. Region	Regional Average HDD
Atlantic	4688.8	Northern	5131
Central	4291.5	Southern	3869
Prairies	5579.0	Northern	5131
West	2953.5	Lower	2866

The results of the regional mapping using HDD show that the Atlantic region can best be represented by the Northern region of British Columbia, the Central region by the Southern region of British Columbia, the Prairies by the Northern region of British Columbia, and the West by the Lower Mainland region of British Columbia.

6.4 Load Profile Results

Figure 6.1 shows an average daily electricity load profile for test case house 1 where winter is December to February, spring is March to May, summer is June to August and fall is September to November. The load data for each day in each season was averaged to illustrate the average daily electricity load profile for each season.

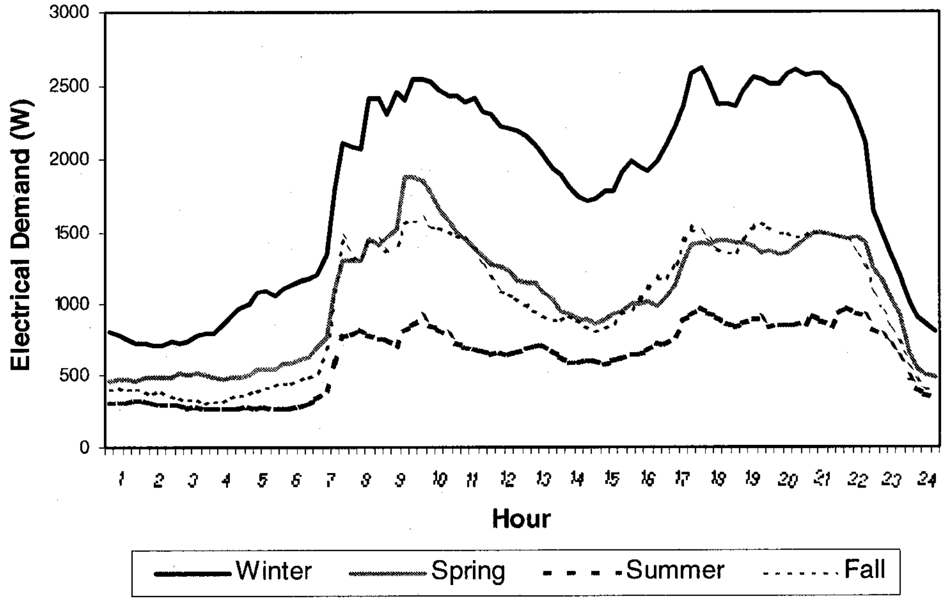

Figure 6.1: Average Daily Electricity Load Profile

Table 6.8 list the annual average electricity consumption for each of the test case houses.

Table 6.8: Test Case House Average Annual Appliance and Lighting Electricity Consumption

Test Case House	Province	Vintage	Fuel Type	Average Annual Electricity Consumption (kWh)
1	BC	1961-1977	Natural Gas	17301
2	BC	1978 and later	Natural Gas	17355
3	BC	1941-1960	Natural Gas	15149
4	AB	1961-1977	Natural Gas	10510
5	AB	1978 and later	Natural Gas	10654
6	AB	1941-1960	Natural Gas	9534
7	SK	1961-1977	Natural Gas	8517
8	SK	1978 and later	Natural Gas	9569
9	SK	1941-1960	Natural Gas	7903
10	MB	1961-1977	Natural Gas	9697
11	MB	1941-1960	Natural Gas	8276
12	MB	before 1941	Natural Gas	7344
13	ON	1978 and later	Natural Gas	9613
14	ON	before 1941	Natural Gas	7433
15	ON	1941-1960	Natural Gas	8429
16	PQ	1961-1977	Oil	8537
17	PQ	before 1941	Oil	7625
18	PQ	1941-1960	Oil	6078
19	NB	before 1941	Oil	7439
20	NB	1961-1977	Oil	9013
21	NB	1941-1960	Oil	7450
22	NS	1961-1977	Oil	9818
23	NS	before 1941	Oil	7418
24	NS	1941-1960	Oil	8198
25	PEI	1978 and later	Oil	7143
26	PEI	1961-1977	Oil	7527
27	PEI	before 1941	Oil	6774
28	NF	1961-1977	Oil	9390
29	NF	1941-1960	Oil	8382
30	NF	1978 and later	Oil	9109

Once the normalized load profiles and the average annual consumption for each test case house were determined, the absolute load profiles were generated and converted into the format required by ESP-r and use in all subsequent simulations.

Chapter 7
Modeling in ESP-r

7.1 Test Case House Site and Year of Assessment

Simulations in ESP-r were run for each test case house using weather from two different cities. The simulation cities were chosen based on the following criteria:

- **Weather Data Availability:** The availability of the weather file in ESP-r governed the selection of simulation cities.

- **Selection of Representative city:** The two largest cities for which weather files were available in ESP-r were chosen as the simulation cities. There are several large cities for which weather files are not available and in this case, the next largest city with an available weather file was chosen. Table 7.1 lists the most populous cities per province and the associated ESP-r weather file availability.

- **Location of the Representative city:** While Vancouver and Abbotsford are the most populous cities in British Columbia for which ESP-r weather files are available; they are very near in terms of geographical location. To be able to better represent the entire province, Prince George was selected as the second simulation city after Vancouver. In the same way, North Battleford was chosen over Swift Current as the second simulation city after Regina for the simulation cities in Saskatchewan.

- **Exceptions:** The only ESP-r weather file available for Prince Edward Island is for the city of Charlottetown, thus the Prince Edward Island test case houses were simulated using this weather file only.

Table 7.1: ESP-r Weather File Availability

Province	Simulation Cities	Population	ESP-r Availability
BC	Vancouver	545,671	Y
	Surrey	347,825	N
	Burnaby	193,954	N
	Richmond	164,345	N
	Abbotsford	115,469	Y
	Prince George	72,406	Y
AB	Calgary	878,866	Y
	Edmonton	666,104	Y
SK	Saskatoon	196,811	N
	Regina	178,225	Y
	Swift Current	14,821	Y
	North Battleford	13,692	Y
	Estevan	10,242	Y
MB	Winnipeg	619,544	Y
	Brandon	39,716	N
	Le Pas	6,030	Y
	Churchill	963	Y
ON	Toronto	2,481,494	Y
	Ottawa	774,610	Y
QB	Montreal	1,039,534	Y
	Laval	343,005	N
	Quebec City	169,076	Y
NB	Saint John	69,661	Y
	Moncton	61,046	N
	Fredrection	47,560	Y
NS	Halifax	359,111	Y
	Sydney	26,000	Y
PEI	Charlottetown	32,245	Y
NF	St. John's	99,192	Y
	Goose Bay	7,969	Y
	Stephenville	7,109	Y

The simulation cities chosen for this study according to the criteria outlined above are presented in Table 7.2 along with the latitude and longitude of each city as required by ESP-r.

Table 7.2: Simulation Cities

Province	Simulation Cities	Latitude	Longitude
British Columbia	Vancouver	49°13'	123°06'
	Prince George	53°55'	122°47'
Alberta	Calgary	51°05'	114°05'
	Edmonton	53°34'	113°25'
Saskatchewan	Regina	50°30'	104°38'
	North Battleford	52°46'	108°15'
Manitoba	Winnipeg	49°53'	97°10'
	Le Pas	53°48'	101°15'
Ontario	Toronto	43°40'	79°22'
	Ottawa	45°25'	75°43'
Quebec	Montreal	45°30'	73°35'
	Quebec	46°50'	71°15'
New Brunswick	Saint John	45°16'	66°03'
	Fredericton	45°57'	66°40'
Nova Scotia	Halifax	44°38'	65°35'
	Sydney	46°10'	60°03'
Prince Edward Island	Charlottetown	46°14'	63°09'
Newfoundland	St. John's	47°34'	52°41'
	Goose Bay	53°19'	60°25'

ESP-r requires a year of assessment to be defined when creating a house model and generates a calendar specifying the weekdays and weekends. The year defined in the weather file was used as the year of assessment to ensure that weekdays and weekends matched as both control strategies and casual gains schedules differ depending on the type of day (i.e.: weekday or weekend).

7.2 Test Case House Database Description

The ESP-r databases used in the current study can be classified into two categories. For more information on the databases available in ESP-r refer to Haugaard (2003).

7.2.1 ESP-r Default Databases

ESP-r default databases are the standard database files distributed with ESP-r containing all the relevant information required to define a house model. The ESP-r default databases used in this study are listed below (Haugaard, 2003):

- **Climate database** – defines diffuse horizontal radiation, dry bulb temperature, direct normal solar irradiance, wind speed, wind direction, and relative humidity. The climate files were obtained from NRCan and converted from ASCII to binary using ESP-r's Project Manager facility.

- **Pressure distributions database**– used to represent the connection between free stream wind velocities and the pressure generated on the outside face of surfaces of the building. The default pressure distributions database is based on a publication from the IEA's Air and Ventilation Centre (Air Infiltration Calculation Techniques – An Application Guide) and can be used for buildings of up to three storeys.

- **Plant components database**– contains plant components (e.g.: pumps, fans, ducts, etc.) used to model a wide range of systems such as ventilation, heating, and cooling systems. Each plant component requires a general component description, the connected volume discretisation scheme and the required thermo-physical data.

- **Materials database** – contains a description of the different classes of materials (e.g.: brick, concrete, wood, etc.) and the materials thermal conductivity, density, specific heat, absorption coefficient, emission value and diffusion resistance factor.

7.2.2 Test Case House Specific Databases

Three of the databases used were specific to the test case house and had to be modified to suit the test case house attributes. The test case house specific databases are listed below (Haugaard, 2003):

- **Construction database** – contains information on the composition of different building units such as walls, windows and floor systems. The database describes the thickness, positions and optical properties of each material. There are two different types of constructions, symmetrical and asymmetrical building units. If an asymmetrical construction is to be used as an internal partition (i.e.: the surface between two adjacent zones), it is necessary to make an inverted version of the construction and link it with the original construction. A constructions database was defined for each test case house, as the external wall, foundation and ceiling insulation levels were different for each house.

- **Event profiles database** – the test case house specific event profile database was generated using ESP-r's PRO facility in which the event start and end times and associated sensible and latent casual gains are defined. The determination of occupant casual gains is discussed in detail in Section 7.8.

- **Optical properties database** – contains the optical properties of transparent constructions. The angle dependent data for the direct solar transmission, absorption and reflectance is defined in the optical properties database. A test case house specific optical properties database was defined for houses that required triple pane windows. Defining and importing the optical properties for triple pane windows is discussed in detail in Sections 7.5.1. The default optical properties database was used for test case houses using single and double pane windows as the optical properties for these windows were available in the default database.

7.3 Zone Geometry, Construction and Attribution Modeling

The first step to creating a house model in ESP-r is to define the zone geometry and associated construction. Each zone, namely the basement, main floor, any additional storeys, and the attic were modeled as separate zones.

7.3.1 Above Grade Zones

The SHEU database defined the size of the house (excluding the basement) in square feet. This was used to determine the dimensions of the house. It was assumed that all of the test case houses were square[1]. The total square footage of the house was divided by the number of storeys (excluding the basement) as defined by Equation 7.1.

$$W = \sqrt{\frac{A}{storeys}} = L \qquad [7.1]$$

Where:

A = area of house as defined by SHEU (ft^2)

W = width of house (ft)

L = length of house (ft)

storeys = the number of storeys excluding the basement

[1] All houses except for one storey, 1750ft houses (test case houses numbers 5 and 8) as there is a limitation in BASESIMP, the algorithm used to model basements. This limitation is discussed in Section 7.3.2.

Table 7.3 details the dimensions used for houses of different sizes and different numbers of storeys.

Table 7.3: Test Case House Dimensions[2]

Number of Storeys	1250 ft^2 (116m^2)			1750 ft^2 (163m^2)		
	Width (m)	Depth (m)	Main Wall Height (m)	Width (m)	Depth (m)	Main Wall Height (m)
1	10.78	10.78	2.50	13.55	12.00	2.50
1.5	10.78	10.78	3.75	13.55	12.00	3.75
2	7.62	7.62	2.50	9.02	9.02	2.50

All wall heights were 2.5 metres, with the exception of 1.5 storey test case houses. In this case, the basement was modeled with a 2.5 metre wall height, and the main floor with a wall height of 3.75 metres.

Figure 7.1 shows a typical one-storey house model in ESP-r.

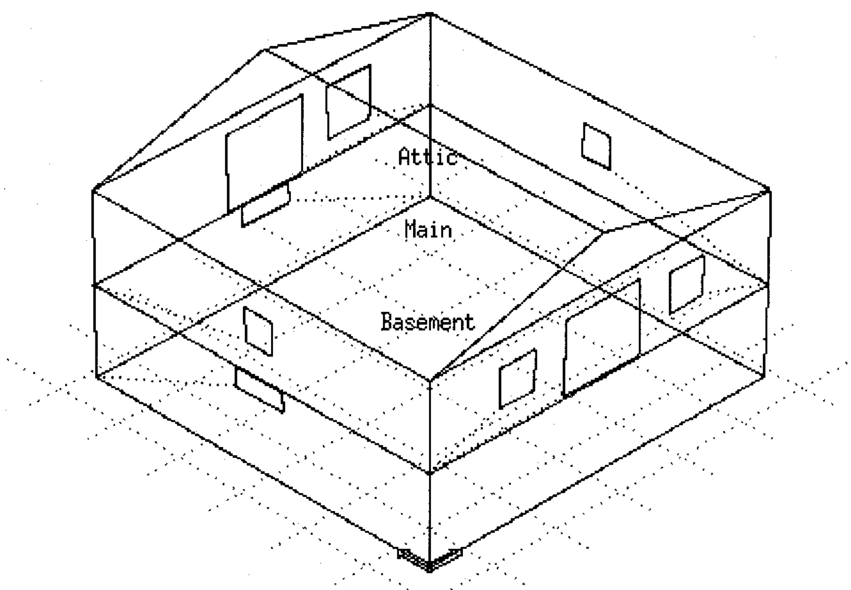

Figure 7.1: Typical ESP-r House Model

[2] All dimensions are interior dimensions

Once the geometry of the zones was defined, all surface had to be attributed by assigning the construction and boundary conditions. Specifically, the construction of each wall, floor, ceiling and roof had to be defined and the associated boundary conditions defined. The details of each of theses constructions can be found in the Multi-Layer Construction (MLC) database found in Appendix D. The same attributions were used for each test case house model, while the insulation thickness was varied to achieve the desired overall RSI value for the component. Figure 7.2 illustrates the attribution (construction and boundary conditions) scheme used for each scheme. The details on window and door construction and attribution are discussed in Sections 7.5 and 7.6 respectively.

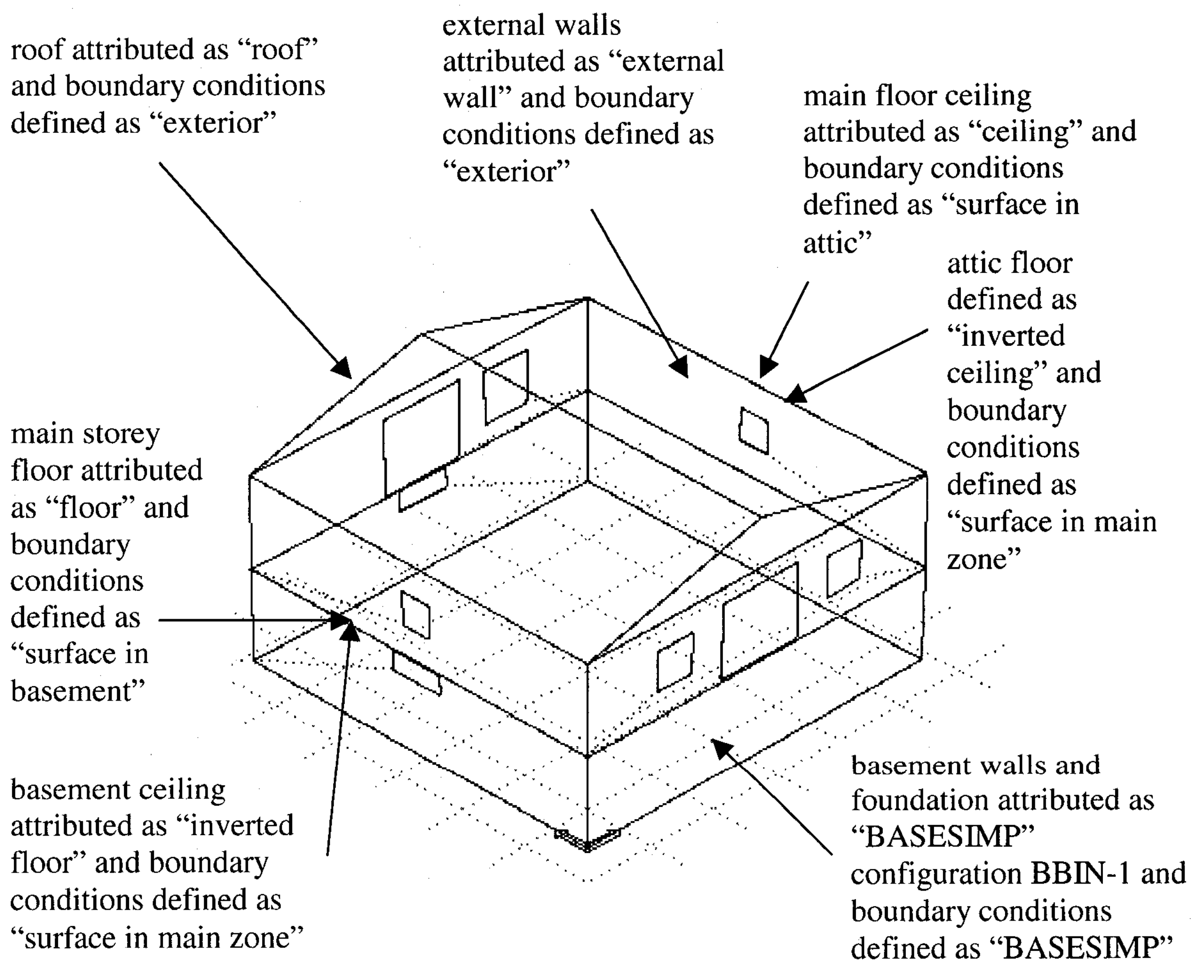

Figure 7.2: Test Case House Attribution

7.3.2 Basement Modeling

Heat losses from foundations are poorly considered in many whole-building energy programs commonly used to model houses (Beausoleil-Morrison and Mitalas, 1997). Foundation heat losses contribute considerably to residential heating loads, as high as 24% in energy efficient homes, and even higher in homes with conventional construction (Beausoleil-Morrison and Mitalas, 1997). Modeling foundations in ESP-r is improved by the use of BASESIMP. BASESIMP is a regression-based algorithm which expresses both above-grade and below-grade time-dependent heat losses (Beausoleil-Morrison and Mitalas, 1997). It calculates heat loss as a function of the foundation's thermal and geometrical properties such as insulation resistance, height, depth, width, length and site conditions, namely soil conductivity, water-table depth, and weather (Beausoleil-Morrison and Mitalas, 1997).

The test case houses were modeled using the BASESIMP configuration BBIN-1 as illustrated in Figure 7.3

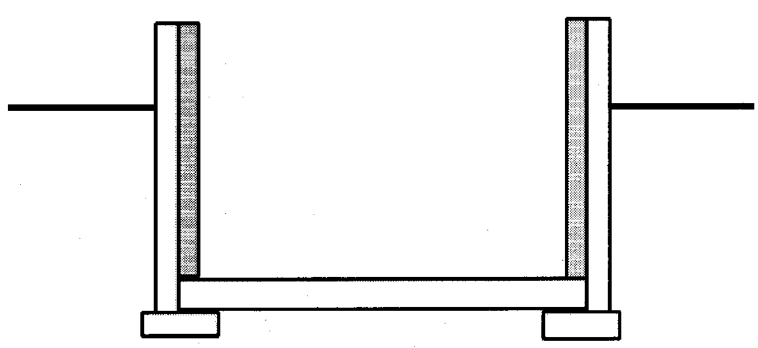

Figure 7.3: Test Case House Basement Configuration (Beausoleil-Morrison, 1996)

This configuration is defined as having wood walls and a concrete floor with the interior walls insulated over the full height. The first story is non-brick veneer or bricks thermally broken from the basement's concrete walls (Beausoleil-Morrison, 1996). The below grade portion is assumed to be 1.9 metres while the above grade portion is 0.6 metres. This configuration was used for all test case house models.

As mentioned above, the BASESIMP model requires data related to the site conditions as well as the geometry and construction of the basement. Details on temperature data were taken from BASECALC™. BASECALC™ is a computationally intensive program that performs a series of two-dimensional finite-element analyses for each foundation (Beausoleil-Morrison and Mitalas, 1997). Two steady-state and one transient two-dimensional finite-element calculations are performed; BASECALC™ then accounts for three-dimensional effects around corners and processes the finite-element results with weather data to predict energy and heat losses (BASECALC, 2006). The annually averaged soil temperature and the amplitude of ground-temperature's annual sine wave for different locations are included in the software package (BASECALC, 2006). Table 7.4 details the annual averaged soil temperature and the amplitude of the ground-temperature's annual sine wave for each simulation city as required by BASESIMP. The soil composition was assumed to be normal for all simulation cities (as defined by BASECALC™), yielding a soil conductivity of 0.85 W/m^2 K. In addition, the water table depth was assumed to be normal for all simulation cities (as defined by BASECALC™) yielding a value of 8 metres. The phase lag of the ground-temperature's annual sine wave was taken from ESP-r's CCHT[3] house model and was assumed to be 0.3825 for all simulation cities.

[3] The CCHT house represents a typical modern energy efficiency Canadian house (Purdy and Beausoleil-Morrison, 2001).

Table 7.4: Soil Properties

City	Annually averaged soil temperature (°C)	Amplitude of ground-temperature's annual sine wave (°C)
Vancouver	11.3	9.02
Prince George	6.2	9.56
Calgary	6.4	10.56
Edmonton	5.2	12.56
Regina	4.8	14.04
North Battleford	5.9	14.05
Winnipeg	6.1	15.15
Le Pas	2.7	12.41
Toronto	11.1	13.37
Ottawa	8.9	14.2
Montreal	6.4	14.42
Quebec	7.4	13.07
Saint John	7.7	10.5
Fredericton	7.7	12.52
Halifax	8.5	11.71
Sydney	8.4	10.42
Charlottetown	7.5	11.46
St. John's	6.7	8.01
Goose Bay	4.9	10.38

Once the foundation and basement walls were attributed as BASESIMP, the percentage of heat loss through each surface had to be defined. This was achieved by taking a ratio between the surface area and the total surface area as defined in Equation 7.2.

$$\%surface_i = \frac{SA_i}{SA_{Total}} \qquad [7.2]$$

Where:

$\%surface_i$ = percentage of heat loss through surface i (%)

SA_i = surface area of surface i (m^2)

SA_{Total} = total surface area of basement (m^2)

There is a limitation in BASESIMP in which the width of the foundation cannot be greater than 12 meters. Test case houses 5 and 8 have a foundation a length and width equal to 12.75 meters. In the case of these two test case house models, the length of foundation was increased to 13.55 meters and width was decreased to 12 meters. This change in dimensions kept the square footage of the house the same while effectively addressing the aforementioned limitation.

7.4 Attic Modeling

The attic was modeled as a separate zone in each of the test case house models. Equation 7.3 was used to determine the height of the attic for each test case house (Fung, 2003).

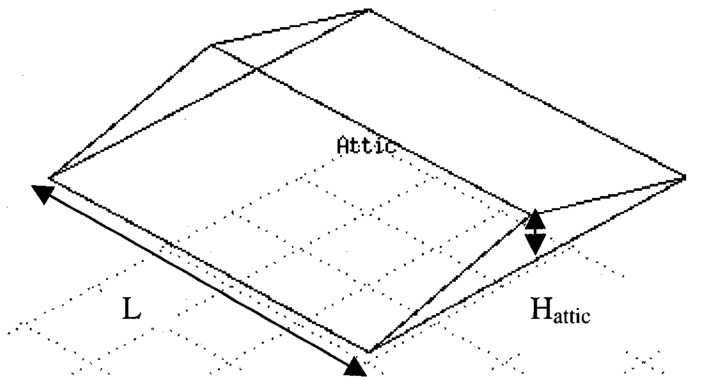

Figure 7.4: Attic Zone

$$H_{Attic} = 0.125 \times L \qquad [7.3]$$

Where:

H_{Attic} = attic height (m)

L = length of house (m)

7.5 Windows

The data required for modeling doors and windows in ESP-r was derived from both the SHEU database and the NHS database. The SHEU database details the number and type (i.e.: single pane, double pane or triple pane) of windows, and the NHS database details the distribution of the windows. The SHEU database distinguishes between 'over-sized' windows and 'regular' windows, while the NHS database gives the dimensions of 'regular' and 'large' windows. Table 7.5 details the window sizes used.

Table 7.5: Window Sizes (NRCan, 1997)

Window Type	Length x Width Dimensions (m)	Glazed Area (m^2)
Large	1.09 x 1.09	1.188
Regular	0.89 x 0.89	0.79

ESP-r has a limitation on the number of surfaces that can be inserted into one surface. For this reason, each window could not be modeled separately. Modeling conventions were determined in order to facilitate window modeling and are described below:

- All 'large' windows are evenly distributed between the front and back of the main storey. In the case of an odd number of 'large' windows, the majority were placed on the front of the main storey
- Windows with higher number of panes go on the front and back of the main storey
- Windows with higher number of panes go on the main storey
- Single pane windows go in the basement
- If the number of storeys is greater than one, the windows are evenly distributed between the main and remaining storeys

Once the window sizes, types and orientation were determined, the glazed area was combined to avoid having too many surfaces within the wall surface. Therefore, each wall has up to two[4] windows, which represent the total number of windows on that surface. Details on the number of windows, the associated type and orientation of each window for all test case houses can be found in the test case house descriptions in Appendix C.

Neither the SHEU nor NHS databases provided information regarding the type of glass used, therefore it was assumed that all windows were made of plate glass.

7.5.1 Multi-layer Construction of Triple Pane Windows

The current ESP-r MLC database does not contain a definition for a triple pane window and for the purpose of this study, a triple pane window construction had to be defined. In addition, ESP-r requires that each window construction have a distinct set of optical properties. For this reason, the optical properties for a triple pane window were determined using Windows 4, a publicly available freeware program for window and fenestration design. A triple pane window was built using Windows 4 the optical properties were imported into ESP-r.

7.6 Doors

The SHUE database details the number of wood doors and metal doors, but does not provide information regarding the orientation or RSI values. As with the windows, conventions were assumed when modeling the doors and are explained below:

[4] In the case where there were two types of windows (i.e.: double pane and triple pane) on one wall surface, they could not be combined into one representative glazed area, therefore two representative windows were needed. In the case where all windows were of the same type (i.e.: double pane), only one representative window was required.

- All wood doors were put on the front of the main storey
- All metal doors were put on the back of the main storey
- In the case of an odd number of doors, the majority were put on the back of the main storey

The RSI values for the doors were taken from Fung (2003) and are detailed in Table 7.6.

Table 7.6: Door RSI Values

Region	Door RSI
West	0.51
Prairies	0.63
Central	0.50
Atlantic	0.50

7.7 Infiltration

The Alberta Infiltration Model (AIM-2) is used to account for airflows and infiltration in ESP-r. Details on the AIM-2 model can be found in (Walker and Wilson, 1990).

In defining the AIM-2 inputs for the test case houses, the following assumptions were made:

- Terrain for buildings was assumed to be 'City Centre'
- Wall shielding was assumed to be 'Heavy'
- Weather station anemometer height was 10 metres
- All zones, including attic received infiltration

The height of the building eaves, a required AIM-2 input was calculated using Equation 7.4 (NRCan, 1996).

$$H_{eave} = 2.5 \times (storeys) + 0.5 \qquad [7.4]$$

Where:

H_{eave} = height of building eaves (m)

storeys = the number of storeys

The flue diameters for the furnace and DHW system, based on fuel type are detailed in Table 7.7.

Table 7.7: Flue Diameters (Fung, 2003)

System	Fuel Type	Diameter (mm)
Furnace	Natural Gas	152
	Oil	160
DHW	Natural Gas	100
	Oil	150

7.8 Casual Gains

To quantify the casual gains due to occupancy, a schedule of activities and associated latent and sensible gains had to be determined. The occupancy patterns used in this study were based on the CCHT Simulated Occupancy Schedule (CCHT, 2002). To avoid over-estimating the occupancy casual gains, a schedule was set for the first occupant and a modified schedule was set for the remaining occupants. Activities with high associated metabolic rates such as cooking and cleaning are rarely performed by all occupants at the same time therefore it was assumed that one occupant performed these tasks while the remaining occupants performed more moderate activities.

The ratio between sensible and latent heat gains was determined by examining the ratio based on activity level. Table 7.8 details the sensible and latent heat gains based on activity (ASHRAE, 1992).

Table 7.8: Sensible and Latent Gains by Activity

Degree of Activity	Sensible (W)	Latent (W)	Ratio
Seated at theatre - matinee	66	31	2.13
Seated at theatre - evening	72	31	2.32
Seated, very light work	72	45	1.60
Moderately active office work	73	59	1.24
Standing, light work; walking	73	59	1.24
Walking; standing	73	73	1.00
Sedentary work	81	81	1.00

Tables 7.9 and 7.10 detail the weekday and weekend activity schedule, the associated metabolic rate and the sensible to latent ratio for the first occupant. The metabolic rates associated with each activity were taken from ASHRAE (1997).

Table 7.9: Weekday Activity Schedule – First Occupant

Time	Location	Activity	Metabolic Rate (W/m^2)	Sensible:Latent Ratio
0:00	Home	Sleeping	40.0	2.32
7:00	Home	Cooking	105.0	1.00
8:00	Away	N/A	0.0	N/A
17:00	Home	House Cleaning	157.5	1.00
18:00	Home	Cooking	105.0	1.00
19:00	Home	Moderate Activity	77.0	1.24
22:00	Home	Resting	45.0	2.13
23:00	Home	Sleeping	40.0	2.32

Table 7.10: Weekend Activity Schedule – First Occupant

Time	Location	Activity	Metabolic Rate (W/m^2)	Sensible:Latent Ratio
0:00	Home	Sleeping	40.0	2.32
7:15	Home	Light Activity	60.0	1.60
23:00	Home	Sleeping	40.0	2.32

Tables 7.11 and 7.12 detail the weekday and weekend activity schedule, the associated metabolic rate and the sensible to latent ratio for remaining occupants.

Table 7.11: Weekday Activity Schedule – Remaining Occupants

Time	Location	Activity	Metabolic Rate (W/m^2)	Sensible:Latent Ratio
0:00	Home	Sleeping	40.0	2.32
7:00	Home	Light Activity	60.0	1.60
8:00	Away	N/A	0.0	N/A
17:00	Home	Moderate Activity	77.0	1.24
22:00	Home	Resting	45.0	2.13
23:00	Home	Sleeping	40.0	2.32

Table 7.12: Weekend Activity Schedule – Remaining Occupants

Time	Location	Activity	Metabolic Rate (W/m^2)	Sensible:Latent Ratio
0:00	Home	Sleeping	40.0	2.32
7:15	Home	Light Activity	60.0	1.60
23:00	Home	Sleeping	40.0	2.32

The total metabolic rate for all occupants was calculated by multiplying the weighted average of metabolic rate by the number of occupants according to Equation 7.5.

$$\text{Total Metabolic Rate} = \left(\frac{MET_1 + (MET_r \times n)}{1+n}\right) \times n \qquad [7.5]$$

Where:

MET_1 = metabolic rate of first occupant (W/m^2)

MET_r = metabolic rate of remaining occupants (W/m^2)

n = number of occupants

The total heat gain in watts was calculated by multiplying the total metabolic rate by the average surface area of a human, 1.8 m^2 (ASHRAE, 1997).

The average sensible to latent ratio for all occupants was calculated using a weighted average between the first and remaining occupants according to Equation 7.6.

$$\text{Average Sensible to Latent Ratio} = \frac{(S:L)_1 + [(S:L)_r \times n]}{1+n} \quad [7.6]$$

Where:

$(S:L)_1$ = sensible to latent ratio for first occupant

$(S:L)_r$ = sensible to latent ratio for remaining occupants

n = number of occupants

The amount of sensible and latent heat gains in watts was determined by applying the sensible to latent ratio to the total watts.

Tables 7.13 – 7.18 present the weekday and weekend sensible and latent heat gains for two, three and four occupants.

Table 7.13: Weekday Sensible and Latent Gains – Two Occupants

Time	Duration	Total Metabolic Rate (W/m^2)	Weighted Average of S:L Ratio	Total Watts	Sensible (W)	Latent (W)
0:00	7h	80.0	2.32	144.0	100.7	43.3
7:00	1h	165.0	1.40	297.0	173.3	123.8
8:00	9h	0.0	N/A	0.0	0.0	0.0
17:00	1h	234.5	1.16	422.1	226.5	195.6
18:00	1h	182.0	1.16	327.6	175.8	151.8
19:00	3h	154.0	1.24	277.2	153.3	123.9
22:00	1h	90.0	2.13	162.0	110.2	51.8
23:00	1h	80.0	2.32	144.0	100.7	43.3

Table 7.14: Weekend Sensible and Latent Gains – Two Occupants

Time	Duration	Total Metabolic Rate (W/m^2)	Weighted Average of S:L Ratio	Total Watts	Sensible (W)	Latent (W)
0:00	7h	80.0	2.32	144.0	100.7	43.3
7:00	16h	120.0	1.60	216.0	132.9	83.1
23:00	1h	80.0	2.32	144.0	100.7	43.3

Table 7.15: Weekday Sensible and Latent Gains – Three Occupants

Time	Duration	Total Metabolic Rate (W/m^2)	Weighted Average of S:L Ratio	Total Watts	Sensible (W)	Latent (W)
0:00	7h	120.0	2.32	216.0	151.0	65.0
7:00	1h	225.0	1.45	405.0	239.7	165.3
8:00	9h	0.0	N/A	0.0	0.0	0.0
17:00	1h	311.5	1.18	560.7	303.3	257.4
18:00	1h	259.0	1.18	466.2	252.2	214.1
19:00	3h	231.0	1.24	415.8	230.0	185.9
22:00	1h	135.0	2.13	243.0	165.3	77.7
23:00	1h	120.0	2.32	216.0	151.0	65.0

Table 7.16: Weekend Sensible and Latent Gains – Three Occupants

Time	Duration	Total Metabolic Rate (W/m^2)	Weighted Average of S:L Ratio	Total Watts	Sensible (W)	Latent (W)
0:00	7h	120.0	2.32	216.0	151.0	65.0
7:00	16h	180.0	1.60	324.0	199.4	124.6
23:00	1h	120.0	2.32	216.0	151.0	65.0

Table 7.17: Weekday Sensible and Latent Gains – Four Occupants

Time	Duration	Total Metabolic Rate (W/m^2)	Weighted Average of S:L Ratio	Total Watts	Sensible (W)	Latent (W)
0:00	7h	160.0	2.32	288.0	201.3	86.7
7:00	1h	285.0	1.48	513.0	306.2	206.9
8:00	9h	0.0	N/A	0.0	0.0	0.0
17:00	1h	388.5	1.19	699.3	380.0	319.3
18:00	1h	336.0	1.19	604.8	328.6	276.2
19:00	3h	308.0	1.24	554.4	306.6	247.8
22:00	1h	180.0	2.13	324.0	220.5	103.6
23:00	1h	160.0	2.32	288.0	201.3	86.7

Table 7.18: Weekend Sensible and Latent Gains – Four Occupants

Time	Duration	Total Metabolic Rate (W/m^2)	Weighted Average of S:L Ratio	Total Watts	Sensible (W)	Latent (W)
0:00	7h	160.0	2.32	288.0	201.3	86.7
7:00	16h	240.0	1.60	432.0	265.9	166.2
23:00	1h	160.0	2.32	288.0	201.3	86.6

Casual gains due to the consumption of electricity were included by manually adding 'type 5' casual gains to each test case house operation file as required by ESP-r.

7.9 Plant Modeling

7.9.1 Base Case Plant Model

In the base case, the test case houses were modeled using idealized HVAC. Idealized HVAC models can be coupled to the idealized controllers to estimate system performance. Idealized controllers look at the space heating and cooling loads required on each time step and perform the necessary heat/moisture addition/extraction. Idealized HVAC models do not actually simulate system response, but instead look at the heat injection/extraction calculated by the idealized controls and estimate the system's fuel use based on this operational pattern (Ferguson, 2006). Furnace type and capacity, fuel type, efficiency, number of zones served, and pilot and fan power were defined in the HVAC file. Specifically, the furnace type, efficiency, and fuel for each test case house, as listed in the test case house descriptions in Appendix C, were defined in this HVAC file.

While it was possible to use the idealized DHW model in the base case, it was desirable to ensure that the base and ICE cases remained as comparable as possible, thus the 3-node DHW tank model was used in both the base and ICE scenarios and is illustrated in Figure 7.5. The DHW tank size and efficiency for each test case house, as listed in the test case house descriptions in Appendix C, were defined as a model inputs for the DHW model.

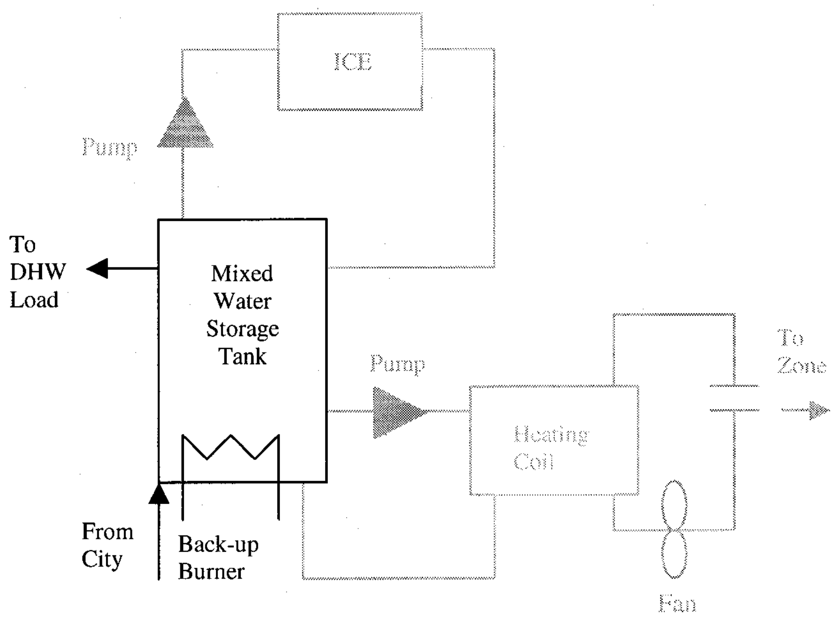

Figure 7.5: Base Case Plant Configuration

In the base case, the HVAC loads were met by idealized HVAC therefore ICE was not activated. In addition, the pumps between the DHW storage tank and ICE and the DHW tank and the heating coil were not activated. In this way, the DHW model met the DHW load while idealized HVAC met the space-heating load. While information on the DHW efficiency was available in the EGH database, there was no information available on the DHW heat injector rate – a required user input for the DHW model. Appendix E details how the heat injector rates were determined.

A description of each of the modeling components is given in the following section.

7.9.2 Cogeneration Plant Model

The plant configuration used in the ICE based cogeneration simulations is illustrated in Figure 7.6.

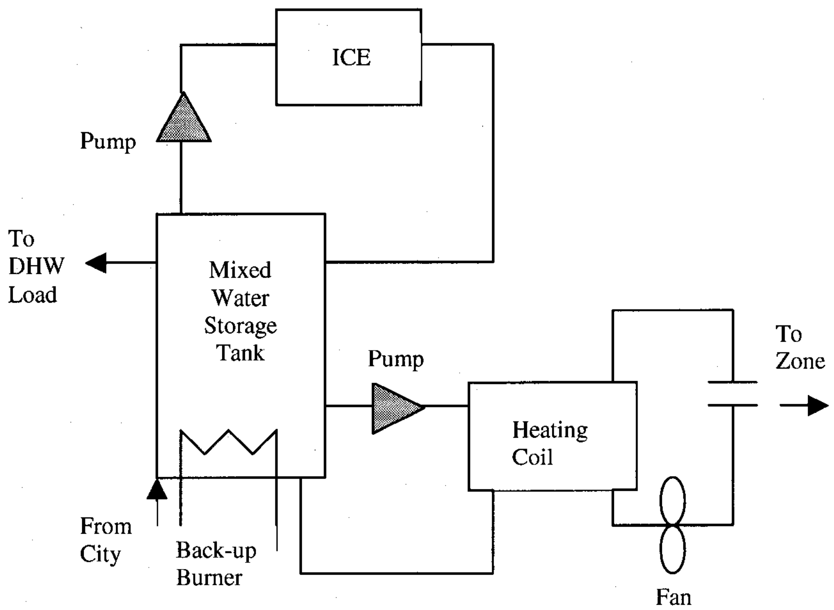

Figure 7.6: ICE Based Cogeneration Case Plant Configuration

In the cogeneration case, the thermal energy from the ICE based cogeneration system was transferred to the storage tank. The space heating requirements were met by the heating coil, which was fed by the hot water storage tank. The back up burner on the hot water storage tank ensured that the temperature in the tank did not go below the required temperature. The control aspects of the cogeneration plant model are discussed in Section 7.10.2.

The plant used in both the base and ICE cases was built using the following components from ESP-r's plant component database:

ICE cogeneration system: The ICE cogeneration system was modeled using ESP-r's 3-node ICE model, which requires one water connection. The ICE model used in this study is a simplified parametric model based on performance data quoted by manufacturers of commercially available reciprocating ICEs with rated output in the 1 – 10 kW range suitable for residential applications (Onovwiona et al., 2007). The model assumes a constant overall efficiency of approximately 80% (based on LHV). Based on this assumption and the performance data from a 6 kW Cummins gas engine, the variation of the specific fuel consumption (SFC), electrical efficiency, and heat to power ratio (HPR) as a function of part load ratio are illustrated in Figures 7.7 - 7.9.

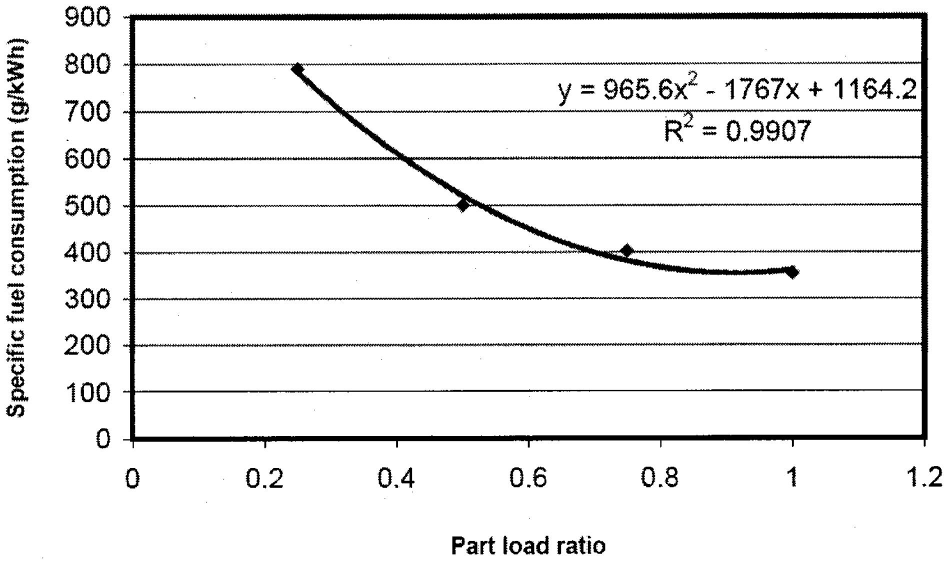

Figure 7.7: Performance Curve of 6 kW Cummins Gas Engine, SFC versus Part Load Ratio (Onovwiona, 2005)

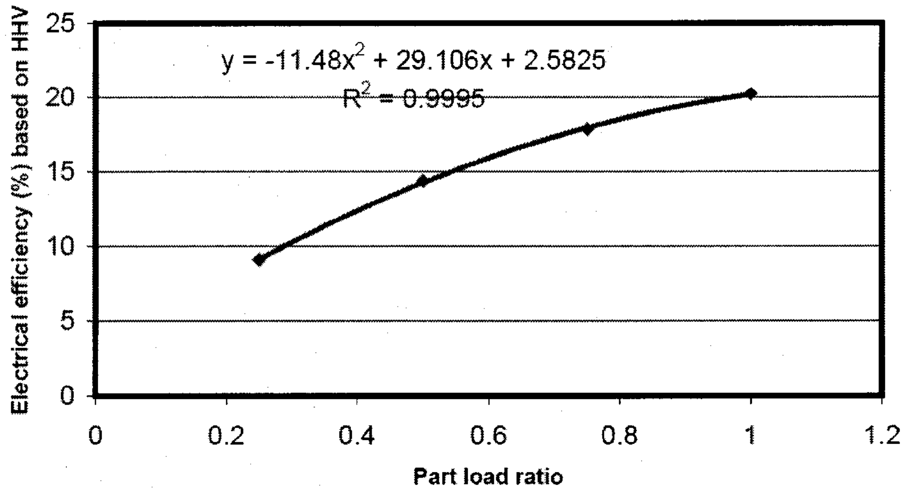

Figure 7.8: Performance Curve of 6 kW Cummins Gas Engine, Electrical Efficiency versus Part Load Ratio (Onovwiona, 2005)

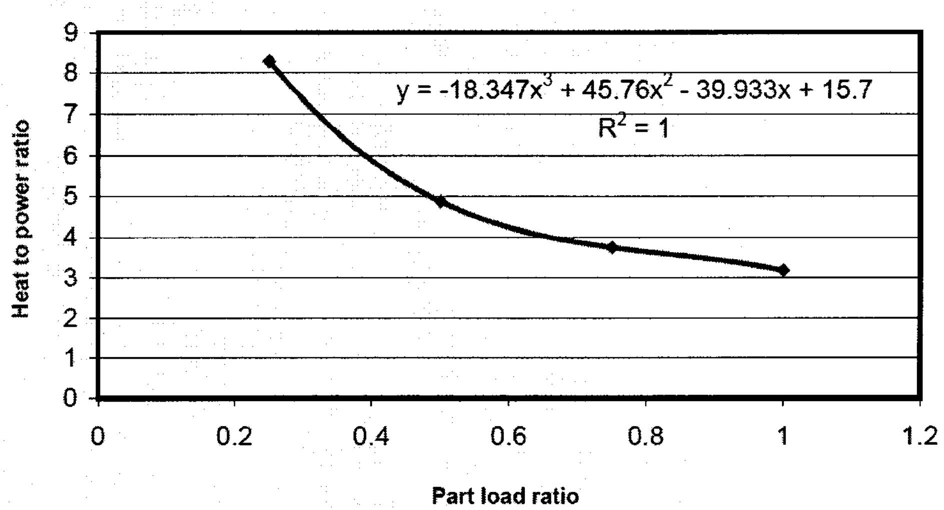

Figure 7.9: Performance Curve of 6 kW Cummins Gas Engine, Heat to Power Ratio versus Part Load Ratio (Onovwiona, 2005)

For a comprehensive review of the ICE model, refer to Onovwiona (2005).

The fuel used to run the ICE based cogeneration system was natural gas or propane, depending on the fuel used in the base case simulations. For test case houses 1-15, the fuel used ICE based cogeneration cases was natural gas. For test case houses 16-30, the fuel used in the ICE based cogeneration cases was propane.

3-node hot water tank: The hot water tank was modeled using ESP-r's 3-node hot water tank with a back-up burner. This model requires two water connections, one to service the DHW load and one to service the air-heating coil, and one air connection to provide the required combustion air. There are two options in defining the DHW draw profile, user-defined or a draw profile based on the CSA f379.1-88 Solar Domestic Hot Water System. The CSA f379.1-88 Solar Domestic Hot Water System was assumed for this study and the draw profile is illustrated in Figure 7.10 (Lopez, 2001).

The DHW demand in litres is defined by Equation 7.7 (Lopez, 2001).

$$W_{daily} = 85 + (35 \times n) \qquad [7.7]$$

Where:

W_{daily} = daily water draw (litres)

n = number of occupants

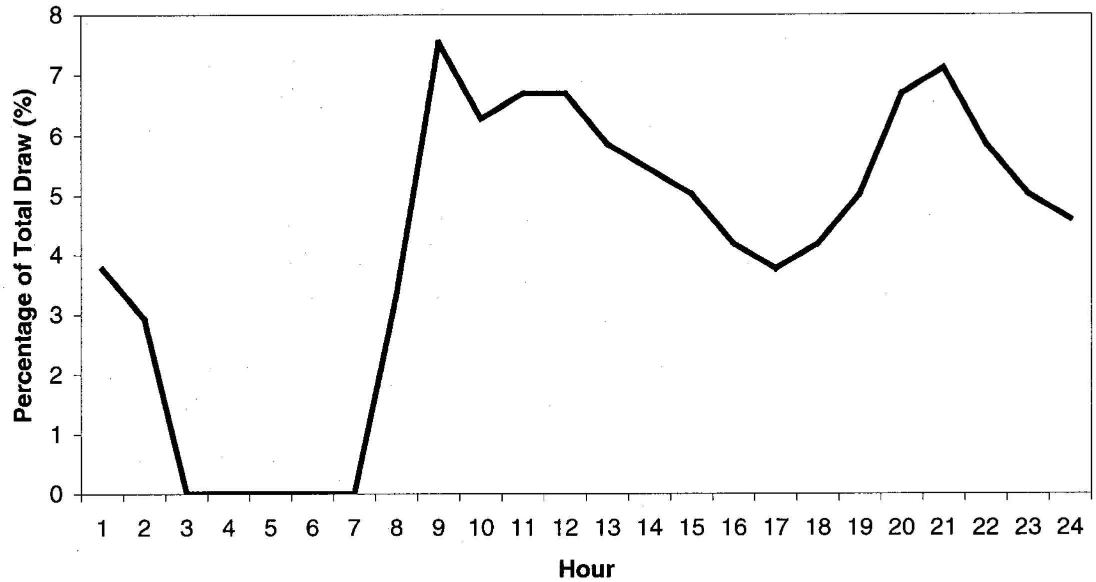

Figure 7.10: DHW Draw Profile

For all ICE based cogeneration simulations, the backup burner efficiency was assumed to be 80% (based on HHV) and the UA value for the tank was assumed to be 1.175 W/K.

Pumps: The pumps were modeled using ESP-r's single-node wet central heating (WCH) pump. This model allows for a single water connection, and calculates the temperature rise that occurs in the pump. The flow rate for the ICE pump was 1.26 x 10^{-4} m^3/s and the flow rate for the heating coil pump was 3.0 x 10^{-4} m^3/s and the rated power for each pump was 150W.

Air Heating Coil: The air-heating coil was modeled using ESP-r's 3-node air heating coil model. This model allows for one water connection and one air connection.

Fan: The fan was modeled using ESP-r's single-node centrifugal fan model. This model allows for a single air connection and calculated the temperature of the air leaving the fan. The rated power for the fan was 200W and the fan flow rate was varied between 0.1 – 0.5 m^3/s depending on the test case house specific space heating requirement.

Pipes: The pipes were modeled using ESP-r's wet central heating (WCH) pipes. This model has one water connection and calculates the temperature of the water leaving the pipe.

Air Duct: The air duct was modeled using ESP-r's single-node air duct model, which has one air connection and calculates the temperature of the air leaving the air duct.

7.10 Plant Control

7.10.1 Base Case Plant Control

As mentioned in Section 7.9.1, the base case was modeled using idealized HVAC. Idealized HVAC requires the user to input the temperature at which the zone is to be maintained. All set-point temperatures are detailed in the test case houses descriptions, which can be found in Appendix C.

The hot water storage tank was controlled by sensing the temperature of the water inside the tank. The DHW supply temperature was 55°C and a six-degree temperature band was used, thus the lower set point was 52°C and the upper set point was 58°C. If the temperature in the tank fell below 52°C, the back-up burner would be activated until the temperature in the tank reached 58°C, at which point it would shut off. To ensure that the water temperature stayed within range of the required DHW temperature, and to prevent the backup burner from repeatedly cycling on and off, a temperature band of six degrees was used as opposed to a smaller temperature band.

7.10.2 Cogeneration Plant Control

In the ICE case, control loops were imposed on some of the plant network components, namely the hot water storage tank, the supply fan and the pump between the hot water tank and the fan coil. A control loop consists of a sensor, an actuator, and an associated control law.

The plant network was controlled using three control loops:

1. **Hot water tank thermostat control**: The control loop used to control the hot water storage tank sensed the temperature of the water inside the tank and actuated the back-up burner if required. As with the base case, a six-degree temperature band around the required DHW temperature of 55°C was used and the loop was implemented using an on-off control law. In addition, temperature limits were imposed for the tank's heat dump facility, which is used to ensure that the water in the tank does not boil. The heat dump facility was activated if the temperature in the tank reached 85°C and deactivated when the temperature in the tank fell to 80°C.

2. **Fan Control**: The control loop used to control the fan sensed the dry-bulb temperature in the main zone and actuated the fan and was implemented using on-off control. Unlike the idealized HVAC model, a temperature band was required instead of a temperature set point. The temperature band used was a 1°C temperature band around the desired set point temperature as defined in the test case house descriptions is Appendix C. In both the base and cogeneration cases, heat was injected into the main zone and an inter-zone ventilation rate of 2.616 ACH was imposed to move heat the remaining zone(s). Figure 7.11 presents the main zone and basement zone temperatures for a typical winter day in both the base and cogeneration simulations for test case house 4 simulated in Calgary.

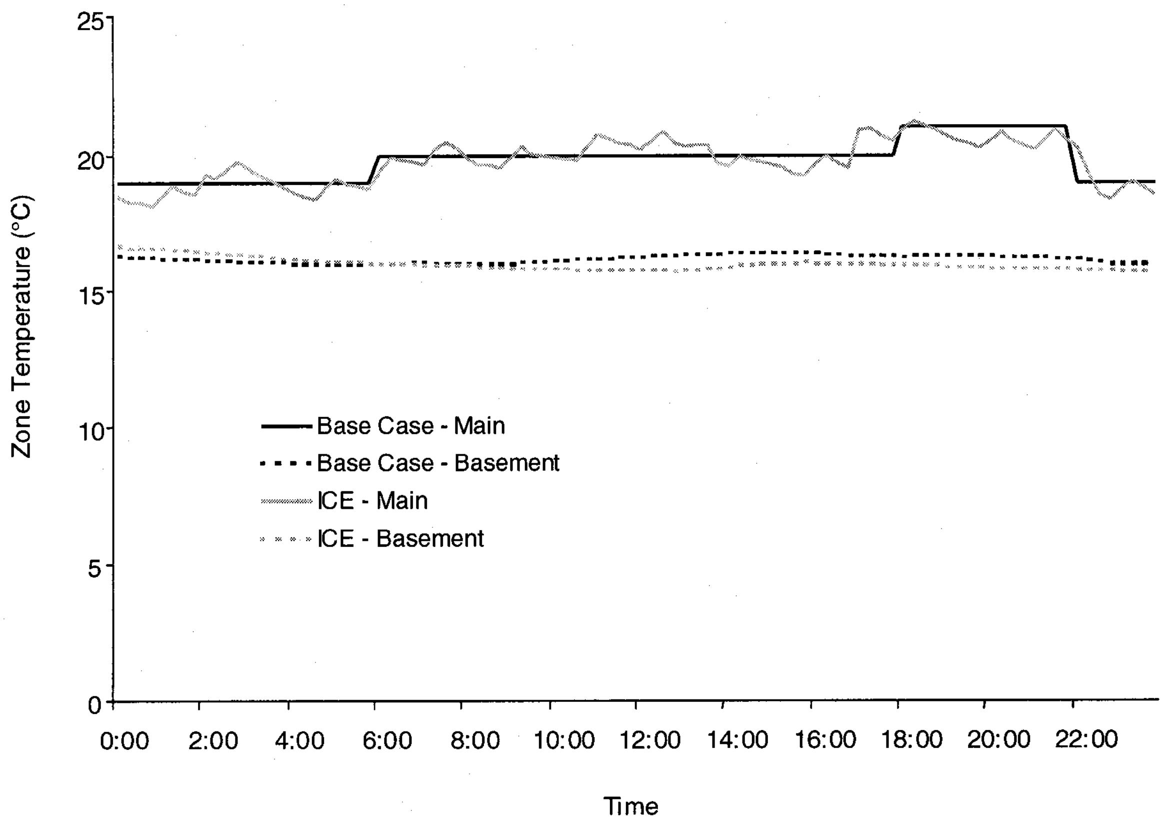

Figure 7.11: Base and Cogeneration Case – Zone Temperatures

3. **Heating-Coil Pump Control**: The control loop used to control the heating-coil pump sensed the dry-bulb temperature in the main zone and actuated the heating-coil pump and was implemented using on-off control. As with the fan control, a 1°C temperature band around the desired set point temperature as defined in the test case house descriptions was used.

The control loop used in controlling the ICE unit was modeled within the ICE model itself, and no external control was required. The ICE unit operated by following the electrical load of the building, called electricity priority control.

Chapter 8
Simulation and Sensitivity Analysis

All simulations were run using fifteen-minute time steps for both the building and plant domains. Using fifteen-minute time steps allowed for a good sub-hourly representation of building loads and system response. Since all results in this study were analysed on an annual basis, using five-minute or one-minute time steps was not necessary. In addition, to ensure that the initial building and plant conditions did not affect the results, a start-up time of three days was specified for all simulations.

8.1 Furnace Sizing Simulations

In order to determine the appropriate furnace capacity, annual simulations using fifteen-minute time steps were run with each test case house using a furnace of 50 kW capacity. The results of these simulations were used to determine the capacity of the furnace for each test case house. Specifically, the furnace output was analyzed and the highest value identified. The maximum required furnace output was multiplied by a safety factor of 1.2 and rounded to the nearest kilowatt, and this value became the furnace capacity for the test case house. The results of the furnace sizing simulations as well as the furnace capacity used are detailed in Table 8.1.

Table 8.1: Test Case House Furnace Capacity

Test Case House	Maximum Space Heating Demand (W)	Furnace Capacity (kW)
A1-Prince George	21056	25
A1-Vancouver	10565	13
A2-Prince George	13287	16
A2-Vancouver	6756	8
A3-Prince George	20323	24
A3-Vancouver	8581	10
A4-Calgary	12386	15
A4-Edmonton	14496	17
A5-Calgary	13231	16
A5-Edmonton	15562	19
A6-Calgary	13560	16
A6-Edmonton	15784	19
A7-Nprth Battleford	14549	18
A7-Regina	14299	17
A8-North Battleford	14202	17
A8-Regina	13725	17
A9-North Battleford	18635	22
A9-Regina	17441	21
A10-Le Pas	15279	18
A10-Winnipeg	13592	16
A11-Le Pas	19610	24
A11-Winnipeg	17309	21
A12-Le Pas	23463	28
A12-Winnipeg	20711	25
A13-Ottawa	8377	10
A13-Toronto	7512	9
A14-Ottawa	12494	15
A14-Toronto	10402	13
A15-Ottawa	15731	19
A15-Toronto	13096	16
A16-Montreal	10259	12
A16-Quebec	12788	15

Table 8.1 Continued: Test Case House Furnace Capacity

Test Case House	Maximum Space Heating Demand (W)	Furnace Capacity (kW)
A17-Montreal	12459	15
A17-Quebec	12542	15
A18-Montreal	16980	20
A18-Quebec	17371	21
A19-Fredericton	33343	40
A19-Saint John	29083	35
A20-Fredericton	16420	20
A20-Saint John	14270	17
A21-Fredericton	26285	32
A21-Saint John	24042	29
A22-Halifax	12255	15
A22-Sydney	11312	14
A23-Halifax	24508	30
A23-Sydney	22521	27
A24-Halifax	20222	24
A24-Sydney	18633	22
A25-Prince Edward Island	9369	11
A26-Prince Edward Island	11336	14
A27-Prince Edward Island	24881	30
A28-Goose Bay	15725	19
A28-St. John's	11878	14
A29-Goose Bay	16817	20
A29-St. John's	12636	15
A30-Goose Bay	13393	16
A30-St. John's	10454	13

It is understood that not all of the above furnace capacities are commercially available, however since the databases consulted in this work did not give any indication of the space heating equipment capacity, and because the intent was to model an ideal base case against which the ICE based cogeneration simulation results could be compared, the above methodology was used to estimate the space heating equipment capacity.

8.2 Base Case Simulations

Once the appropriate furnace size was determined, the base case simulations were run. The test case houses used in the base case simulations were modeled with conventional technologies (i.e.: natural gas/oil fired furnace and natural gas/oil/electricity based DHW system) as explained in Section 7.9.1. The test case house specific system specifications are listed in the test case house descriptions presented in Appendix C. Annual simulations using fifteen-minute time steps were run for each test case house, in their corresponding simulation cities. The results of the base case simulations were used as the basis of comparison for the subsequent ICE based cogeneration simulations. The annual simulation results for the base case models are presented in Chapter 9.

8.3 Cogeneration Simulations

The conventional energy systems used in the base case simulations were replaced by an ICE based cogeneration system and annual simulations using fifteen-minute time steps were run. The cogeneration system parameters used in the cogeneration simulations (i.e.: ICE and thermal storage capacities) are discussed in Section 8.3.1.

8.3.1 Sensitivity Analysis

To quantify the effect of varying ICE system parameters on the system performance in terms of cost and GHG emissions, annual simulations were run with four different ICE based cogeneration system configurations. Two ICE sizes and two storage tank sizes were used in the cogeneration simulations.

The ICE based cogeneration system used in this study is controlled by following the electrical demand of the house. To determine the size of ICE used in simulations, a frequency plot was generated illustrating the levels of electricity demand. Figure 8.1 illustrates the frequency distribution of the electrical demand of three test case houses.

The test case houses with the highest and lowest electrical demand in the base case simulations are plotted, as well as a test case house with an average total electrical demand.

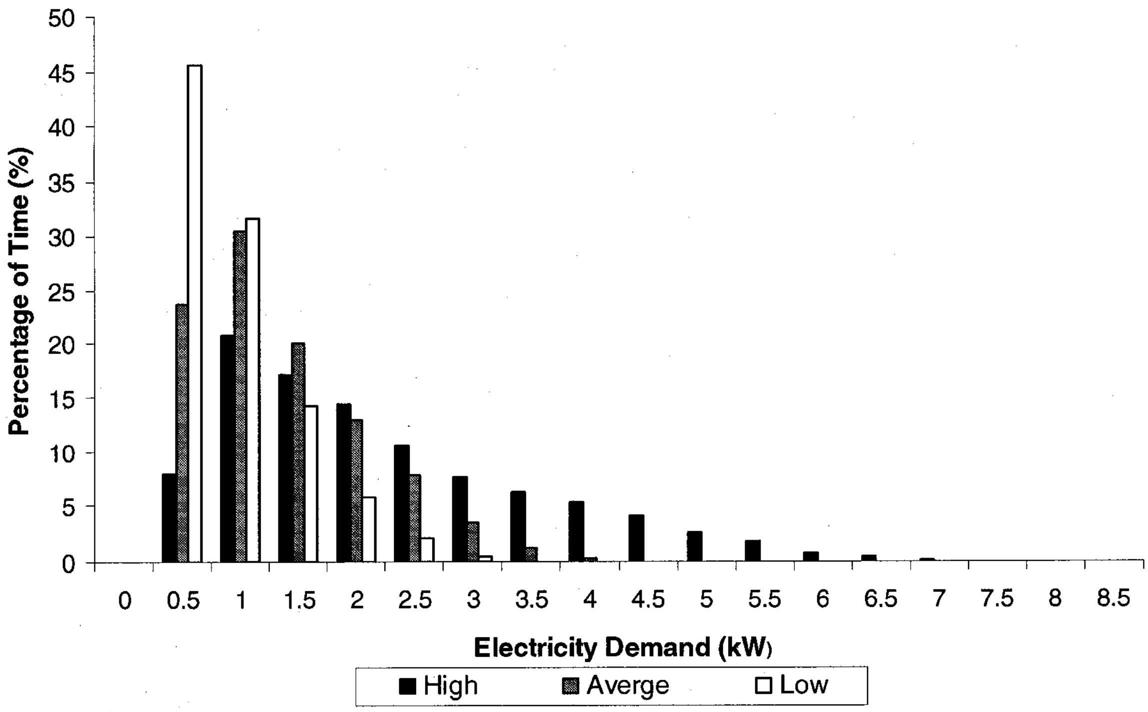

Figure 8.1: Electricity Demand Frequency Plot

It is desirable to minimize running the ICE at part load as the electrical efficiency decreases as the part load ratio decreases. In addition, according to Figure 8.1, the majority of the time the houses' electrical demand falls between 500 W to 2.0 kW (i.e.: 60% for high electrical demand, 87 % for average electrical demand, and 97% for low electrical demand), thus the ICE sizes used in simulations were 1.0 kW and 2.0 kW.

Among the literature currently available regarding the feasibility of ICE based cogeneration in residential applications, there is no indication of the sizes of thermal storage used. Onovwiona (2005) simulated a 2.0 kW, 3.5 kW and 6.0 kW ICE based cogeneration system with associated tank sizes of 300 kg and 600 kg. As the ICE capacities in the current work are 1.0 kW and 2.0 kW, it was decided that 300 kg and 450 kg tanks were to be used in simulation. In addition, both of the chosen tank sizes are commercially available.

Table 8.2 details the configurations used in the sensitivity analysis.

Table 8.2: Sensitivity Analysis Scenarios

ICE Cogeneration Model Systems	ICE Size (kW)	Tank Size (kg)
System 1	1.0	300
System 2	1.0	450
System 3	2.0	300
System 4	2.0	450

To investigate the effect of using a larger ICE and thermal storage size, the three Prince George test case houses were simulated with a 3.0 kW ICE and 1000 kg storage tank. The reason for the selection of the Prince George test case houses is that they have the highest electrical demand of all of the test case houses, as well as have among the highest thermal demand.

All results from the sensitivity analysis were compared to the base case. A summary of the simulation results is presented in Chapter 9, while the full results sets are presented in Appendix H.

Chapter 9
Simulation Results and Analysis

The ICE based cogeneration simulations were run and the results compared to the base case simulation results. Both the base case and ICE based cogeneration results were analyzed on the basis of cost, using both a flat rate and a time-of-use (TOU) pricing scheme for the cost of electricity. In addition, an analysis of the GHG emissions was performed. Tables 9.1 – 9.3 present a summary of the annual simulation results and constants for test case house 10 simulated in Le Pas, Manitoba and are used in the subsequent sample calculations. The energy requirement for the idealized HVAC system and the DHW burner are based on the HHV of the fuel used, while the energy requirement for the ICE is based on the LHV of the fuel used.

Table 9.1: Base Case Annual Simulation Results – Test Case House 10, Le Pas

Electricity Consumption (kWh/yr)	10211
Space Heating Energy Requirement (GJ/yr)	122.28
DHW Energy Requirement (GJ/yr)	24.33

Table 9.2: Base Case Constants – Test Case House 10, Le Pas

Furnace Efficiency (%)	78.0
DHW Efficiency (%)	54.3

Table 9.3: ICE Case Annual Simulation Results – Test Case House 10, Le Pas, 2 kW, 300 Litres

ICE Total Fuel Consumption (kg/yr)	4476.7
Backup Burner Output (GJ/yr)	46.16
Total Electrical Demand (kWh/yr)	11504
Total ICE Electrical Output (kWh/yr)	10512
Total Grid Import (kWh/yr)	992

The fuel heating values used in this study are presented in Table 9.4. The higher heating values (HHV) are from NRCan (2005) and the ratios of lower to higher heating values are from Çengel and Boles (2002).

Table 9.4: Fuel Heating Values

Fuel	HHV	LHV/HHV
Natural Gas	38.21 (MJ/m^3)	0.9
Heating Oil	38.38 (MJ/l)	0.947
Propane	26.38 (MJ/l)	0.943

9.1 Cost Analysis

In both the base and ICE based cogeneration cases, the total cost is based on the cost of the fuel used for space and DHW heating as well as the cost of electricity, based on both flat rate and TOU pricing. Appendix F details how the flat rate and TOU pricing scheme was determined for each province.

9.1.1 Base Case Fuel Cost

The cost of fuel is determined by summing the fuel requirement for space and domestic hot water heating and multiplying by the price of the fuel. Below is a sample calculation illustrating how the total consumption of fuel and associated cost was determined. Tables 9.1 and 9.2 detail the simulation results and analysis constants for test case house 10 simulated in Le Pas, Manitoba.

The annual consumption of natural gas for space heating is determined using Equation 9.1.

$$\text{Annual NG Consumption} = (fuel_{SH}) \times \frac{1\times10^3\,MJ}{GJ} \times \frac{1}{HHV_v} \qquad [9.1]$$

Where:

Annual NG Consumption = consumption of natural gas (m^3/yr)

$fuel_{SH}$ = annual space heating fuel requirement (GJ/yr)

HHV_v = higher heating value of fuel (MJ/m^3)

$$\text{Annual NG Consumption} = (122.28GJ)\times\frac{1\times10^3 MJ}{GJ}\times\frac{1}{38.21\frac{MJ}{m^3}} = \mathbf{3200\ m^3/yr}$$

The space heating demand is estimated using Equation 9.2 (Purdy and Haddad, 2002).

$$Demand_{SH} = \sum_{i=1}^{35040} Lf_i \times (capacity_{SS} + fan_i) \qquad [9.2]$$

Where:

$Demand_{SH}$ = estimated space heating demand (GJ/yr)

Lf_i = furnace part load ratio at time step i

$capacity_{ss}$ = steady-state furnace capacity (W)

fan_i = fan power at time step i

i = time-step[5]

The consumption of natural gas for DHW heating is determined using Equation 9.3.

$$\text{Annual NG Consumption} = (fuel_{DHW})\times\frac{1\times10^3 MJ}{GJ}\times\frac{1}{HHV_v} \qquad [9.3]$$

Where:

Annual NG Consumption = consumption of natural gas (m^3/yr)

$fuel_{DHW}$ = annual DHW energy requirement (GJ/yr)

HHV_v = higher heating value of fuel (MJ/m^3)

---

[5] The total number of time-steps, using 15 minute increments for a non-leap year is 4 time-steps per hour * 24 hours per day * 365 days per year = 35040 time-steps per year.

$$\text{Annual NG Consumption} = (24.33) \times \frac{1\times10^{3}\,MJ}{GJ} \times \frac{1}{38.21\frac{MJ}{m^{3}}} = \mathbf{637\ m^3/yr}$$

Total Annual Natural Gas Consumption = 3200 m^3/yr + 637 m^3/yr = **3837 m^3/yr**

The cost of natural gas is calculated by multiplying the total consumption in cubic metres by the price of natural gas in ¢/m^3 as defined in Equation 9.4.

$$Cost_{NG} = NG_{total} \times P_{NG} \qquad [9.4]$$

Where:

$Cost_{NG}$ = annual cost of natural gas (CAD/yr)

NG_{tot} = annual total natural gas consumption (m^3/yr)

P_{NG} = price of natural gas (¢/m^3)

$$Cost_{NG} = 3837\frac{m^3}{yr} \times 51.3\frac{¢}{m^3} = \mathbf{1968\ CAD/yr}$$

The prices of natural gas, heating oil and propane (including delivery) used in this analysis are detailed in Tables 9.5 – 9.7.

Table 9.5: Natural Gas Prices (Energy Shop, 2007)

Province	Retail Price (¢/m^3)
Manitoba	51.30
British Columbia	40.77
Ontario	49.27
Alberta	38.68
Saskatchewan	33.93

Table 9.6: Heating Oil Prices (MJ Ervin and Associates, 2007)

City	Retail Price (¢/litre)
Montreal	72.0
Quebec	64.4
Saint John	72.3
Fredericton	73.6
Halifax	71.4
Sydney	71.3
Charlottetown	69.7
St. Johns	69.7

Table 9.7: Propane Prices (MacDonald, 2007)

Province	Retail Price (¢/litre)
Nova Scotia	96.5
New Brunswick	93.5
Newfoundland	78.1
Prince Edward Island	59.0
Quebec	65.0

9.1.2 ICE Case Fuel Cost

In the ICE based cogeneration case, the fuel consumption is determined by summing the total fuel consumption of the ICE and the back-up burner output as defined in Equation 9.5. An efficiency of 80% (based on HHV) is assumed for the backup burner in all cases.

$$\text{Annual NG Consumption} = \left((ICE_F \times LHV_m) \times \frac{1}{LHV_v} \right) + (BB_{output}) \times \frac{1}{HHV_v} \qquad [9.5]$$

Where:

Annual NG Consumption = annual consumption of natural gas (m^3/yr)

ICE_F = annual ICE fuel consumption (kg/yr)

LHV_m = lower heating value of fuel per unit mass (MJ/kg)

BB_{output} = annual back-up burner output (MJ/yr)

HHV_v = higher heating value of fuel per unit volume (MJ/m^3)

$$\text{Annual NG Consumption} = \left[\left(\left((4476.7kg)\times 45\frac{MJ}{kg}\right)\times\frac{1m^3}{34.39MJ}\right)+\left(46.16GJ\times\frac{1\times 10^{03}MJ}{GJ}\right)\times\frac{1}{38.21\frac{MJ}{m^3}}\right]$$

Annual NG Consumption = **7066 m^3/yr**

The cost of natural gas is calculated by multiplying the total consumption in cubic metres by the price of natural gas in ¢/m^3 as defined in Equation 9.4.

$$Cost_{NG} = 7066\frac{m^3}{yr}\times 51.3\frac{¢}{m^3} = \mathbf{3625\ CAD/yr}$$

9.1.3 Electricity Cost

The cost of electricity is determined using a flat rate and a TOU pricing structure. Both scenarios are presented below. The same approach is used for both the base and ICE based cogeneration cases, however in the ICE based cogeneration case, the cost of electricity represents the cost of grid-imported electricity.

9.1.3.1 Flat Rate Electricity Cost Analysis

The flat rate electricity price for Manitoba is 5.69 ¢/kWh as detailed in Appendix F. To determine the cost of electricity using the flat rate price, the number of kilowatt-hours (kWh) is multiplied by the flat rate price of electricity according to Equation 9.6.

$$Cost_{el,flat} = (Demand_{el}) * P_{el,flat} \qquad [9.6]$$

Where:

$Cost_{el,flat}$ = annual cost of electricity using a flat rate electricity price (CAD/yr)

$Demand_{el}$ = annual electricity demand of test case house (kWh/yr)

$P_{el,flat}$ = flat rate price of electricity (¢/kWh)

The base case cost of electricity using a flat rate is:

$$Cost_{el,flat} = 10211\frac{kWh}{yr} \times 5.69\frac{¢}{kWh} = \textbf{581 CAD/yr}$$

As mentioned above, the cost of electricity in the ICE case represents the cost of grid-imported electricity and is determined using Equation 9.6.

The cost of grid-imported electricity using a flat rate in the ICE based cogeneration case is:

$$Cost_{el,flat} = 992\frac{kWh}{yr} \times 5.69\frac{¢}{kWh} = \textbf{56 CAD/yr}$$

9.1.3.2 Time-of-Use Electricity Cost Analysis

The total cost of electricity using the TOU scenario is calculated by summing the product of electricity demand and the cost of electricity at each time-step as defined in Equation 9.7.

$$Cost_{el,TOU} = \sum_{i=1}^{35040}(Demand_{el})_i * (P_{el,TOU})_i \qquad [9.7]$$

Where:

$Cost_{el,TOU}$ = annual cost of electricity using TOU pricing (CAD/yr)

$Demand_{el}$ = annual electricity demand of test case house (kWh/yr)

$P_{el,TOU}$ = cost of electricity according to TOU pricing at time-step i (¢/kWh)
i = time-step

The base case cost of electricity using a TOU pricing is:

$Cost_{el,TOU}$ = **615 CAD/yr**

The cost of electricity using the TOU pricing scheme in the ICE case represents the cost of grid-imported electricity and is determined using Equation 9.7.

The cost of grid-imported electricity using TOU pricing in the ICE based cogeneration case is:

$Cost_{el,TOU}$ = **65 CAD/yr**

9.2 GHG Analysis

To calculate the GHG emissions for the base and ICE based cogeneration cases, electricity and fuel emissions factors had to be determined. Table 9.8 lists the average electricity emissions factors ($EF_{el,avg}$) for the most current year for which there is available data (Environment Canada, 2006). The GHG emissions due to electricity, electricity generation by fuel source, and the average electricity emissions factors by province are presented in Appendix G.

Table 9.8: Average Electricity Emissions Factors by Province

Province	$EF_{el,avg}$ (gCO_2eq/kWh)
British Columbia	24
Alberta	861
Saskatchewan	840
Manitoba	31
Ontario	222
Quebec	8
New Brunswick	433
Nova Scotia	759
Prince Edward Island	1120
Newfoundland	21

Electricity generation in Canada is primarily from three sources, namely fossil fuels, hydro and nuclear. In general, nuclear plants and some hydro plants are operated at constant load; while fluctuations in electricity demand are met primarily by fossil fuel fired power plants and in some cases, load following hydro plants. Thus, it can be argued that the GHG emissions reduction calculated using the average electricity emissions factor result in a conservative estimate since it is assumed that the reduction in electricity consumption due to using ICE based cogeneration is uniformly distributed among all types of power plants and it does not take into account transmission and distribution losses

While a more accurate method to determine GHG emissions would be to use hourly GHG emissions factors, due to the unavailability of this data, a second set of emissions factors were determined to estimate the upper limit of GHG emissions reductions by assuming that all of the savings in electricity consumption comes from fossil fuel fired power plants including average transmission and distribution losses by province.

The high intensity electricity emissions factor ($EF_{el,hi}$) is calculated according to Equation 9.8.

$$EF_{el,hi} = \frac{GHG_{ff}}{EG_{ff} - Losses} \qquad [9.8]$$

Where:

$EF_{el,hi}$ = high intensity electricity emissions factor (gCO_2eq/kWh)

GHG_{ff} = total GHG emissions from fossil fuel fired power plants (gCO_2eq)

EG_{ff} = total electricity generation from fossil fuel fired power plants (kWh)

Losses = transmission and distribution losses (kWh)

The electricity generation and GHG emissions data for each province are presented in Appendix G, while the estimates for transmission and distribution losses were taken from Guler (2000). Note that the high intensity electricity emissions factors are calculated based the most current year for which data is available as presented in Appendix G. Table 9.9 presents the high intensity electricity emissions factors as well as the transmission and distribution losses by province.

Table 9.9: High Intensity Electricity Emissions Factors by Province and Transmission and Distribution Losses

Province	$EF_{el,hi}$ (gCO_2eq/kWh)	Transmission and Distribution Losses (%)
BC	375	8.0
AB	985	8.0
SK	1139	10.0
MB	1193	8.0
ON	954	8.0
PQ	549	8.0
NB	807	7.3
NS	916	8.3
PEI	1211	7.3
NF	779	8.7

The estimates for GHG emission reductions presented in this work provide and upper and lower limit. The GHG emissions reductions calculated using the average electricity emissions factor are conservative estimates, providing a lower limit; whereas the GHG emissions reductions calculated using the high intensity electricity emissions factor are liberal estimates, providing an upper limit. The actual GHG emission reduction are somewhere between these two limits.

In provinces where the dominant fuel for electricity generation is fossil based (i.e. AB, SK, NS, PEI), there is a relatively small difference (an average of 170 gCO_2eq/kWh) between the average and high intensity electricity emissions factor. In provinces where hydro and nuclear are the dominant fuel for electricity generation (i.e. BC, MB, PQ, NF), there is a large difference (as much as 1162 gCO_2eq/kWh) between the average and high intensity electricity emissions factor. In provinces where there is no dominant fuel for electricity generation (i.e. ON, NB), there is a moderate difference (average of 533 gCO_2eq/kWh) between the average and high intensity electricity emissions factors. In the provinces that have either a mixed generation capacity (ON, NB) or are dominated by hydro and nuclear (BC, MB, PQ, NF), it is likely that the nuclear and some hydro plants are operated at constant capacity and the peak loads are satisfied by fossil fuel fired plants, and in some cases load following hydro plants. Thus, it is likely that the GHG reductions are close to that calculated using the high intensity emissions factors. However, to determine an accurate electricity emissions factor, more information regarding the time-of-year and time-of-day power dispatching rules is required. In addition, when the data becomes available, GHG emissions should be analyzed on an hourly basis using hourly electricity emissions factors.

9.2.1 Base Case GHG Analysis

The GHG emissions due to electricity are calculated by multiplying the total electricity demand by the electricity emissions factor for the province as defined in Equations 9.9 and 9.10. Two estimates of the GHG emissions are given using the average and high intensity electricity emissions factors as discussed in Section 9.2. In Manitoba, the average electricity GHG emissions factor is 31 gCO_2eq/kWh and the high intensity electricity GHG emissions factor is 1193 gCO_2eq/kWh (Environment Canada, 2006).

$$GHG_{el,avg} = (Demand_{el}) \times (EF_{el,avg}) \qquad [9.9]$$

Where:

$GHG_{el,avg}$ = annual GHG emissions due to electricity using the average electricity emissions factor (tonnes/yr)

$Demand_{el}$ = annual electricity demand of test case house (kWh/yr)

$EF_{el,avg}$ = average GHG emissions factor for electricity (gCO_2eq/kWh)

$$GHG_{el,hi} = (Demand_{el}) \times (EF_{el,hi}) \qquad [9.10]$$

Where:

$GHG_{el,hi}$ = annual GHG emissions due to electricity using the high intensity electricity emissions factor (tonnes/yr)

$Demand_{el}$ = annual electricity demand of test case house (kWh/yr)

$EF_{el,hi}$ = high intensity GHG emissions factor for electricity (gCO_2eq/kWh)

The electricity GHG emissions using the average electricity emissions factor are:

$$GHG_{el,avg} = \left(10211\frac{kWh}{yr}\right) \times \left(\frac{31gCO_2eq}{kWh}\right) \times \frac{tonne}{1 \times 10^{06}\,g} = \mathbf{0.32\ tonnes/yr}$$

The electricity GHG emissions using the high intensity electricity emissions factor are:

$$GHG_{el,hi} = \left(10211\frac{kWh}{yr}\right)\times\left(\frac{1193gCO_2eq}{kWh}\right)\times\frac{tonne}{1\times10^{06}g} = \textbf{12.18 tonnes/yr}$$

The GHG emissions due to the burning of fuel for space and DHW heating are calculated using Equation 9.11, using the fuel emissions factors listed in Table 9.10 (Aube, 2001).

Table 9.10: Fuel Emissions Factors

Fuel	Emissions Factor (CO_2eq)	Unit
Natural Gas	1.856	kg/m^3
Light Oil	2.835	kg/litre
Propane	1.602	kg/litre

$$GHG_{th} = (Energy_{th}) * \frac{1}{HHV_v} * (EF_F) \qquad [9.11]$$

Where:

GHG_{th} = annual fuel GHG emissions (tonnes/yr)

$Energy_{th}$ = annual thermal energy requirement of test case house (GJ/yr)

HHV_v = higher heating value of fuel per unit volume (MJ/m^3)

EF_F = GHG emissions factor for fuel (gCO_2eq/m^3)

$$GHG_{th} = (122.28GJ + 24.33GJ)\times\frac{1\times10^{03}MJ}{GJ}\times\frac{1}{38.21\frac{MJ}{m^3}}\times1.86\frac{kg}{m^3}\times\frac{tonne}{1\times10^{03}kg} = \textbf{7.12 tonnes/yr}$$

The total GHG emissions are calculated by summing the GHG emissions due to electricity and the GHG emissions due to the burning of fuel as defined by Equations 9.12 and 9.13. Two estimates of the total GHG emissions are given using the average and high intensity electricity GHG emissions as discussed in Section 9.2.

$$GHG_{tot,avg} = GHG_{el,avg} + GHG_{th} \qquad [9.12]$$

Where:

$GHG_{tot,avg}$ = total annual GHG emissions using average electricity emissions factors (tonnes/yr)

$GHG_{el,avg}$ = annual GHG emissions due to electricity using average electricity emissions factor (tonnes/yr)

GHG_{th} = annual GHG emissions due to fuel (tonnes/yr)

$$GHG_{tot,hi} = GHG_{el,hi} + GHG_{th} \qquad [9.13]$$

Where:

$GHG_{tot,hi}$ = total annual GHG emissions using high intensity electricity emissions factors (tonnes/yr)

$GHG_{el,hi}$ = annual GHG emissions due to electricity using high intensity electricity emissions factor (tonnes/yr)

GHG_{th} = annual GHG emissions due to fuel (tonnes/yr)

The total GHG emissions using the average electricity emissions are:

$GHG_{tot,avg}$ = 0.32 tonnes + 7.12 tonnes = **7.44 tonnes/yr**

The total GHG emissions using the high intensity electricity emissions are:

$GHG_{tot,hi}$ = 12.18 tonnes + 7.12 tonnes = **19.30 tonnes/yr**

9.2.2 ICE Case GHG Analysis

The GHG emissions due to electricity are calculated by multiplying the total grid-imported electricity by the emissions factor for the province as defined in Equations 9.14 and 9.15. Two estimates of the GHG emissions are given using the average and high intensity electricity emissions factors as discussed in Section 9.2. In Manitoba, the average electricity GHG emissions factor is 31 gCO_2eq/kWh and the high intensity electricity GHG emissions factor is 1193 gCO_2eq/kWh (Environment Canada, 2006).

$$GHG_{el,avg} = (Demand_{el,grid}) * (EF_{el,avg}) \qquad [9.14]$$

Where:

$GHG_{el,avg}$ = annual GHG emissions due to electricity using average electricity emissions factor (tonnes/yr)

$Demand_{el,grid}$ = annual grid-imported electricity (kWh/yr)

$EF_{el,avg}$ = average GHG emissions factor for electricity (gCO_2eq/kWh)

$$GHG_{el,hi} = (Demand_{el,grid}) * (EF_{el,hi}) \qquad [9.15]$$

Where:

GHG_{el} = annual GHG emissions due to electricity using high intensity electricity emissions factor (tonnes/yr)

$Demand_{el,grid}$ = annual grid-imported electricity (kWh/yr)

$EF_{el,hi}$ = high intensity GHG emissions factor for electricity (gCO_2eq/kWh)

The electricity GHG emissions using the average electricity emissions factor are:

$$GHG_{el,avg} = 992\frac{kWh}{yr} \times 31\frac{gCO_{2eq}}{kWh} \times \frac{tonne}{1\times10^{06}\,g} = \mathbf{0.03\ tonnes/yr}$$

The electricity GHG emissions using the high intensity electricity emissions factor are:

$$GHG_{el,hi} = 992\frac{kWh}{yr} \times 1193\frac{gCO_{2eq}}{kWh} \times \frac{tonne}{1\times10^{06}\,g} = \mathbf{1.18\ tonnes/yr}$$

The GHG emissions due to the burning of fuel is calculated using Equation 9.16.

$$GHG_{th} = \left[\left((ICE_F \times LHV_m) \times \frac{1}{LHV_v}\right) + \left(BB_{output} \times \frac{1}{HHV_v}\right)\right] \times EF_F \qquad [9.16]$$

Where:

GHG_{th} = annual fuel GHG emissions (tonnes/yr)

ICE_F = annual ICE fuel consumption (kg/yr)

LHV_m = lower heating value of fuel per unit mass (MJ/kg)

LHV_v = lower heating value of fuel per unit volume (MJ/m^3)

BB_{output} = annual back-up burner output (MJ/yr)

HHV_v = higher heating value of fuel per unit volume (MJ/m^3)

EF_F = GHG emissions factor for fuel (gCO_2eq/m^3)

$$GHG_{th} = \left[\left[\left(\left(4476.7kg \times 45\frac{MJ}{kg}\right) \times \frac{1}{34.39\frac{MJ}{m^3}}\right) + \left(46.16GJ \times \frac{1\times10^{03}\,MJ}{GJ} \times \frac{1}{38.21\frac{MJ}{m^3}}\right)\right] \times 1.86\frac{kg}{m^3}\right] \times \frac{tonne}{1\times10^{03}\,kg}$$

GHG_{th} = **13.12 tonnes/yr**

The total GHG emissions are calculated by summing the emissions due to electricity and the burning of fuel as defined by Equations 9.12 and 9.13. Note that in the ICE based cogeneration case, the electricity represents the grid-imported electricity as defined in Equations 9.14 and 9.15. Two estimates of the total GHG emissions are given using the average and high intensity electricity GHG emissions as discussed in Section 9.2.

The total GHG emissions using the average electricity emissions are:

$GHG_{tot,avg}$ = 0.03 + 13.12 = **13.15 tonnes/yr**

The total GHG emissions using the high intensity electricity emissions are:

$GHG_{tot,hi}$ = 1.18 + 13.12 = **14.30 tonnes/yr**

9.3 Annual Simulation Results

The above analysis was carried out for all test case houses. The base case annual fuel cost and GHG emissions are presented in Figures 9.1 - 9.20. The detailed simulation results are presented in Appendix H.

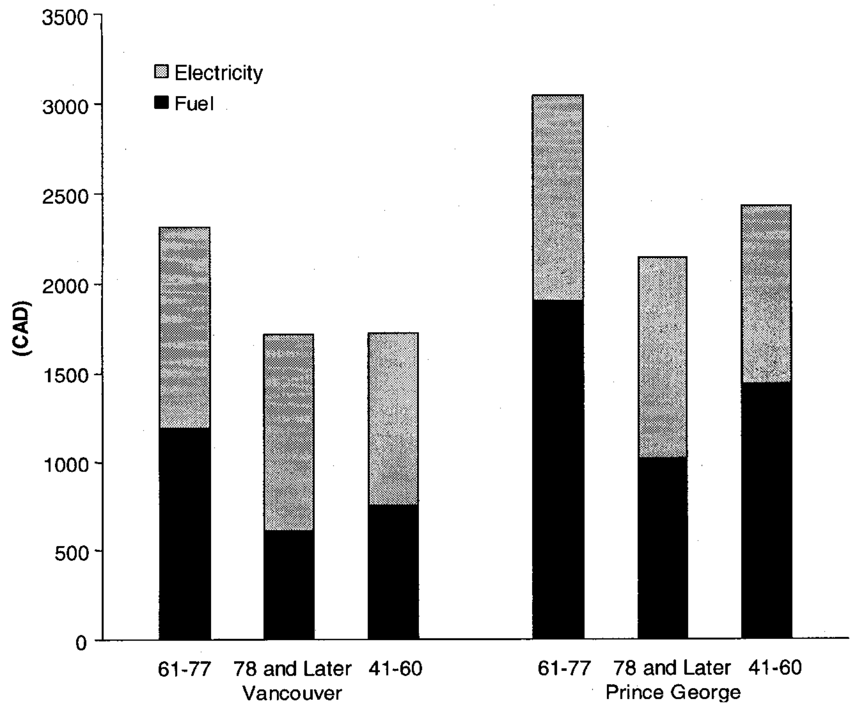

Figure 9.1: Base Case Fuel Costs – British Columbia

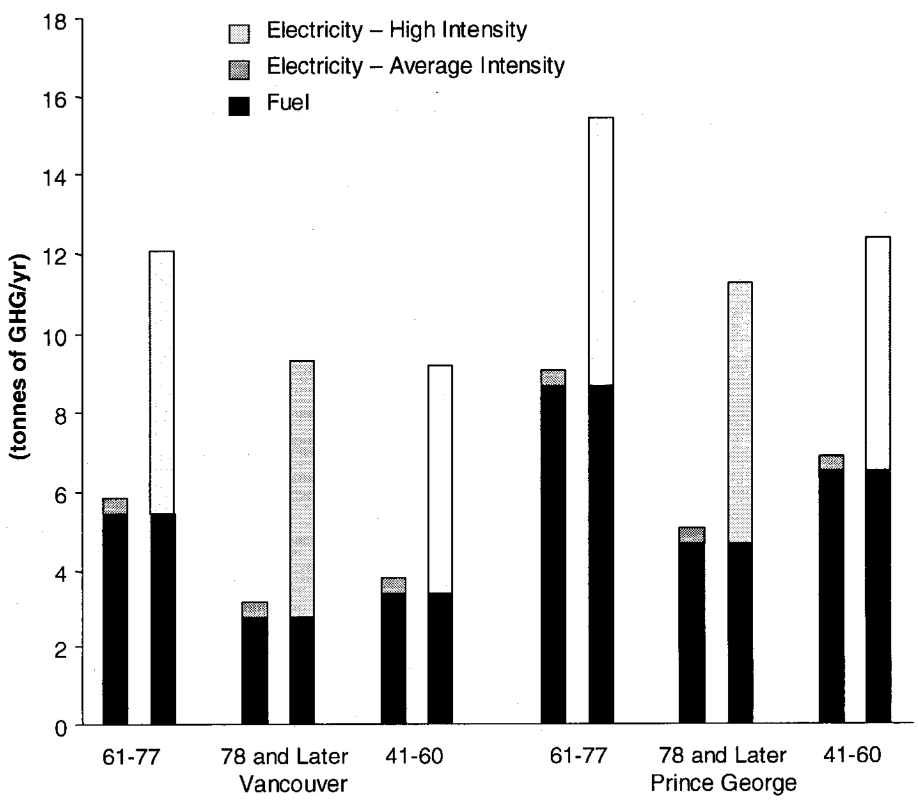

Figure 9.2: Base Case GHG Emissions – British Columbia

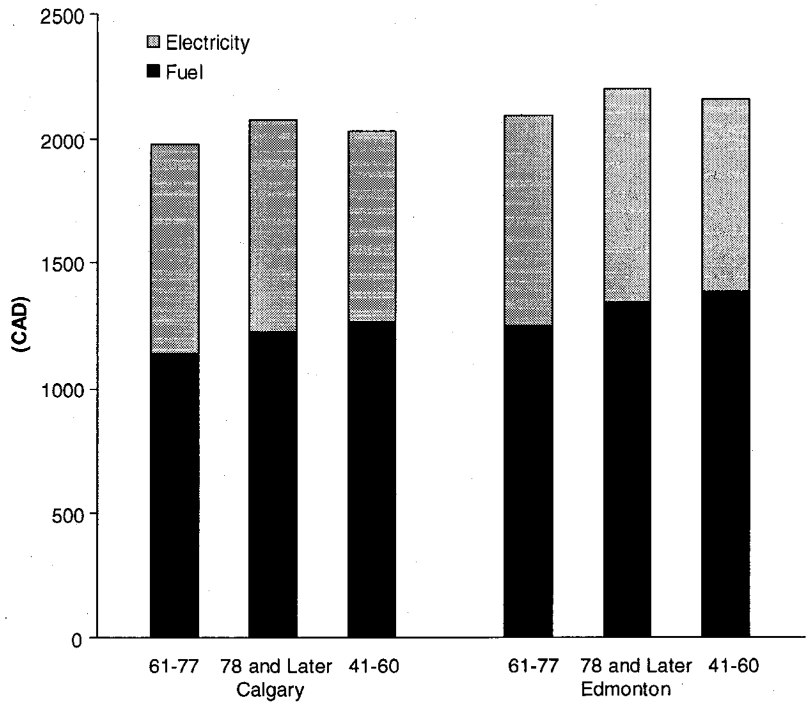

Figure 9.3: Base Case Fuel Costs – Alberta

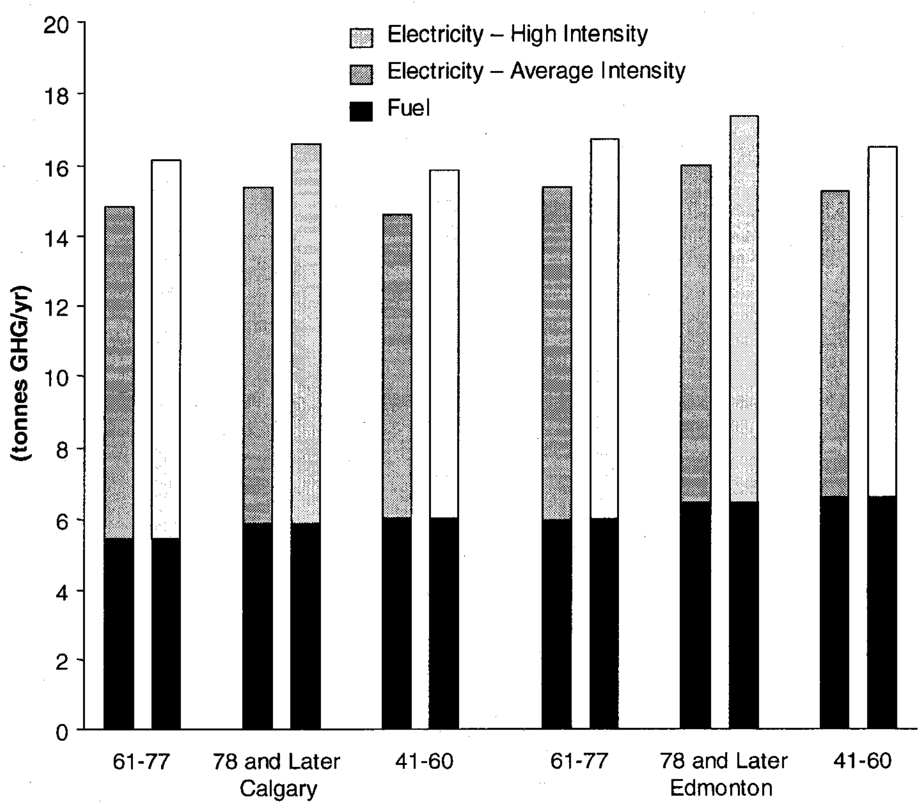

Figure 9.4: Base Case GHG Emissions – Alberta

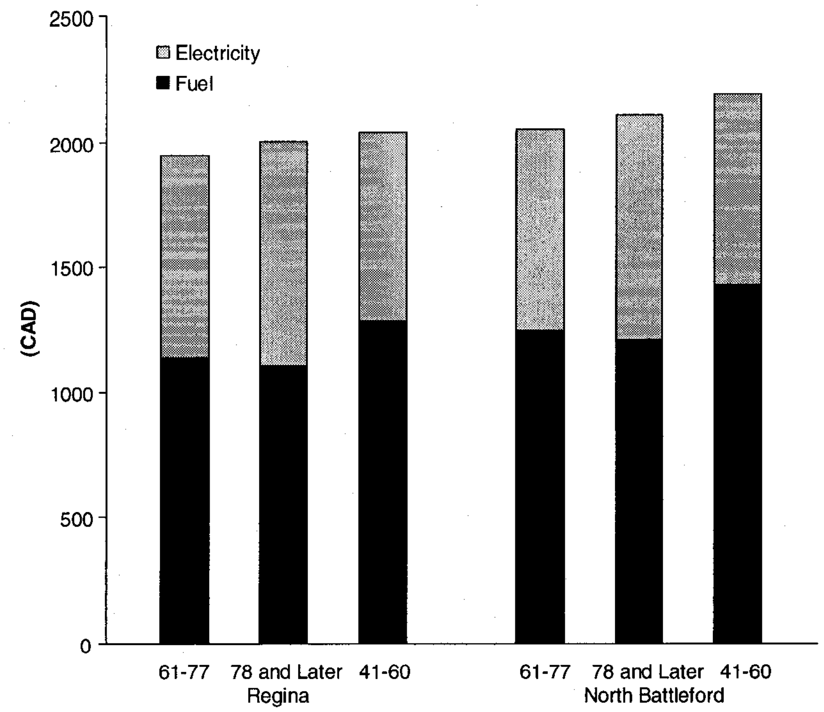

Figure 9.5: Base Case Fuel Costs – Saskatchewan

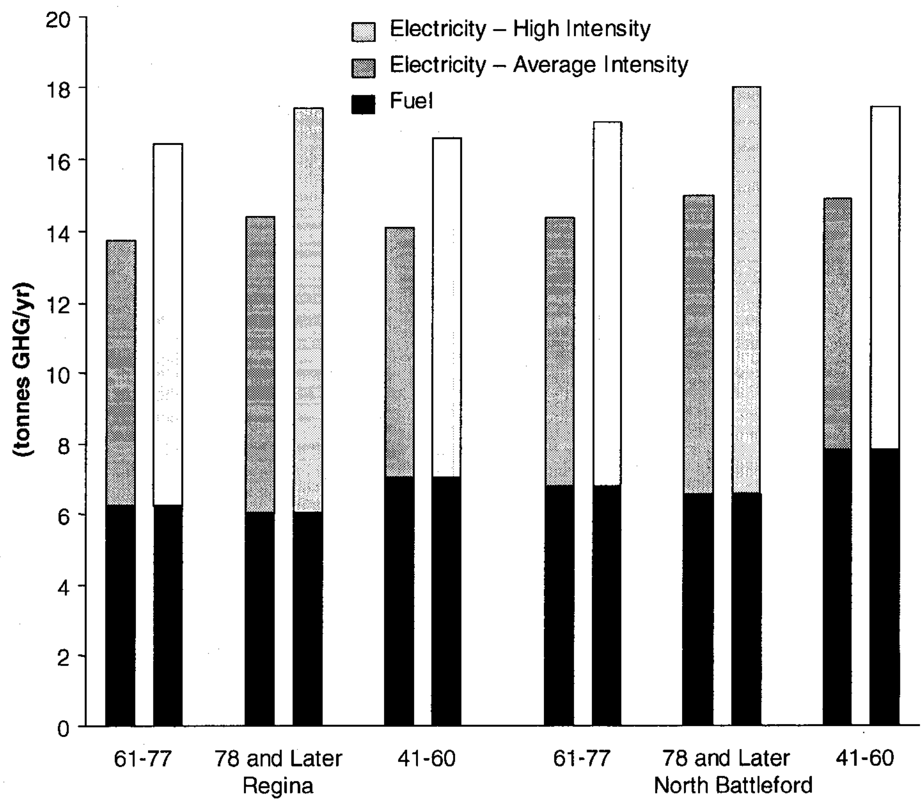

Figure 9.6: Base Case GHG Emissions – Saskatchewan

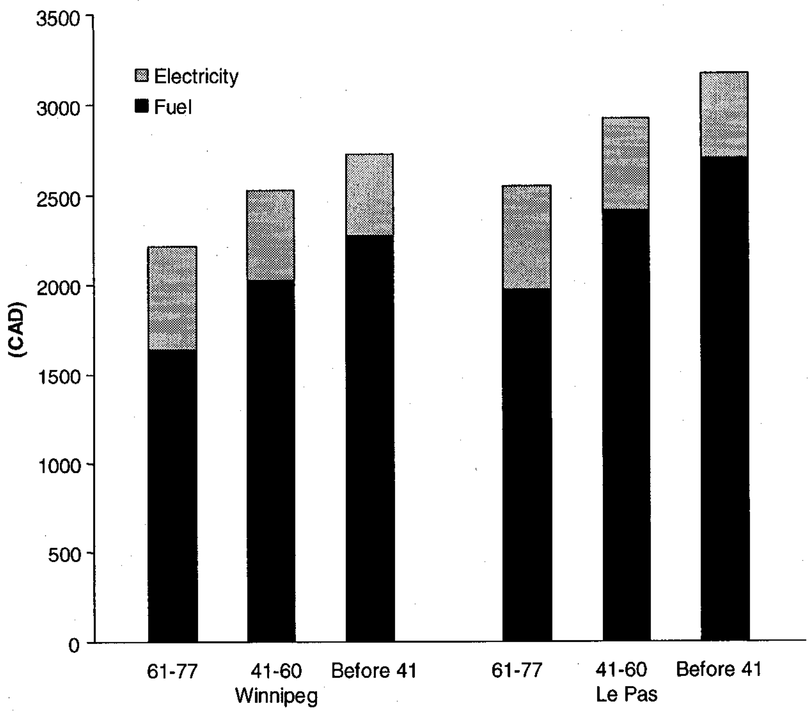

Figure 9.7: Base Case Fuel Costs – Manitoba

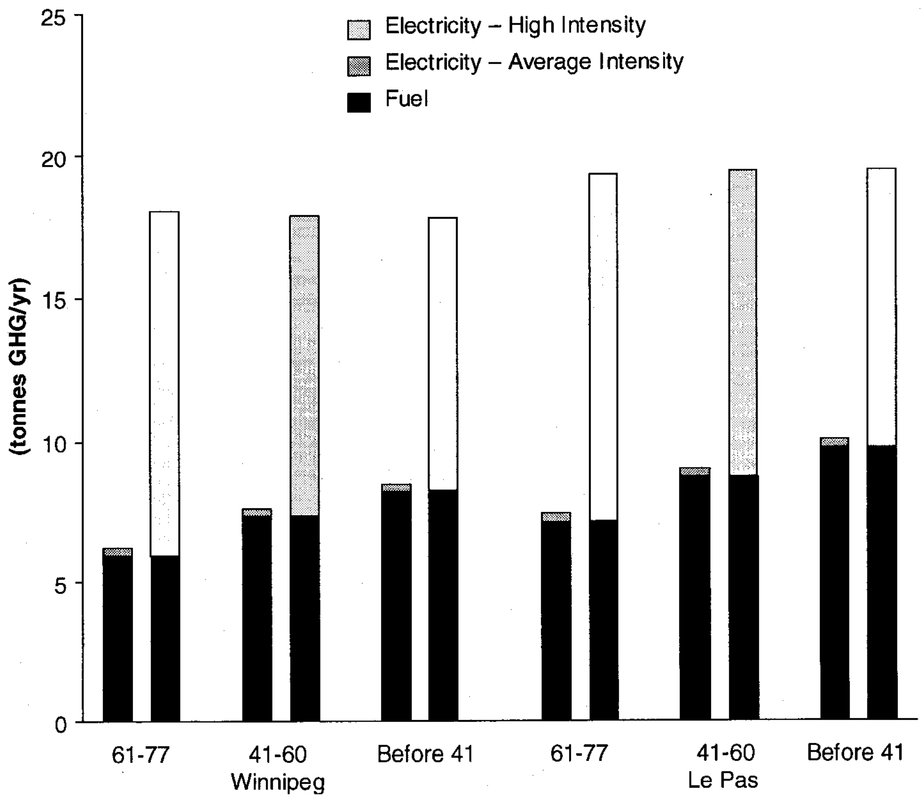

Figure 9.8: Base Case GHG Emissions – Manitoba

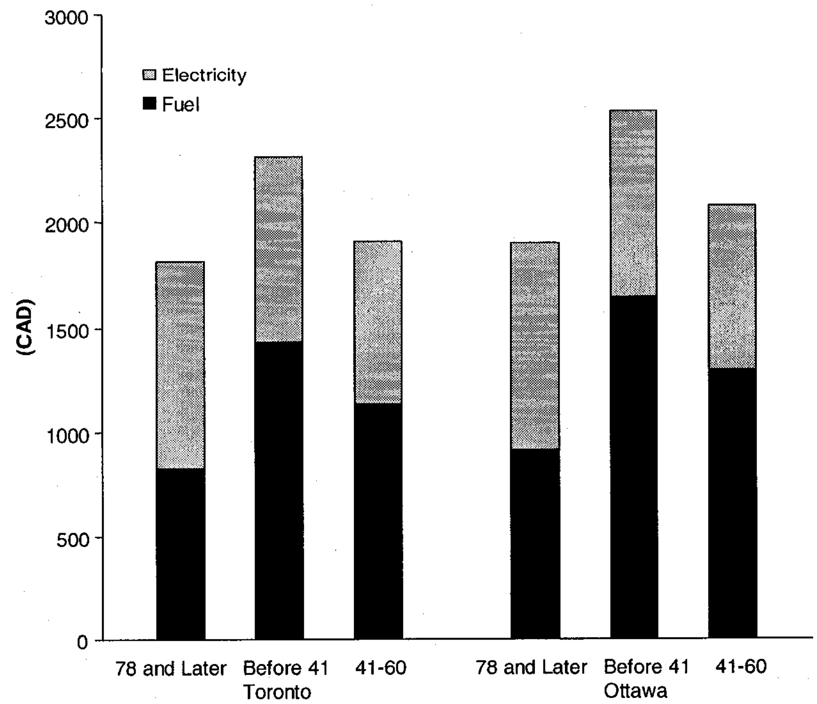

Figure 9.9: Base Case Fuel Costs – Ontario

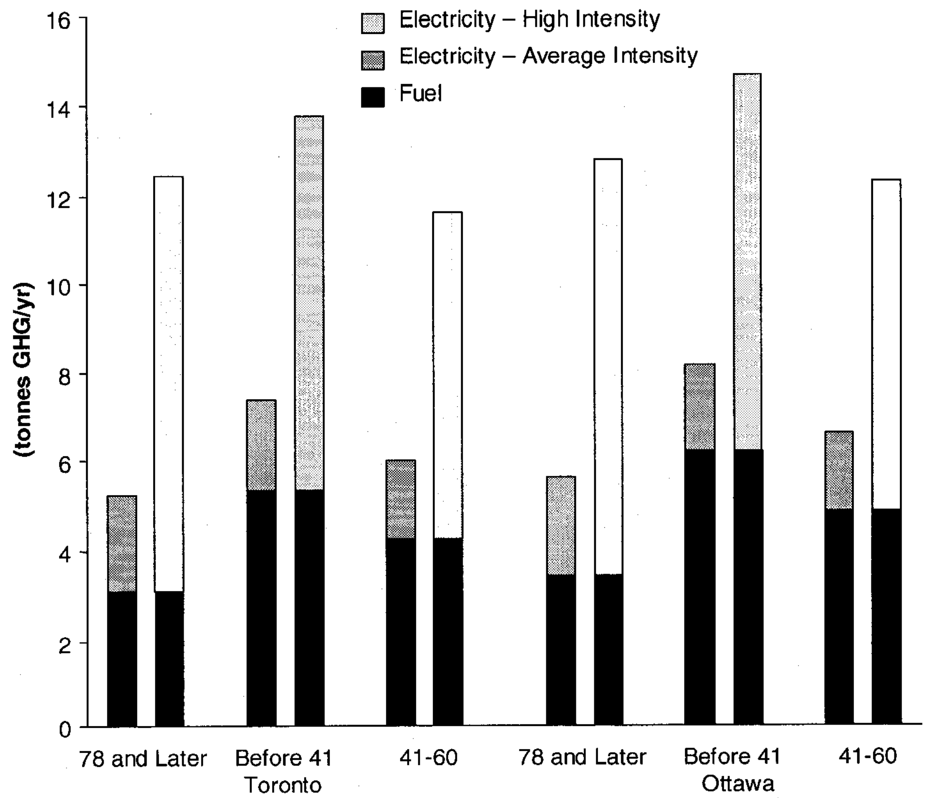

Figure 9.10: Base Case GHG Emissions – Ontario

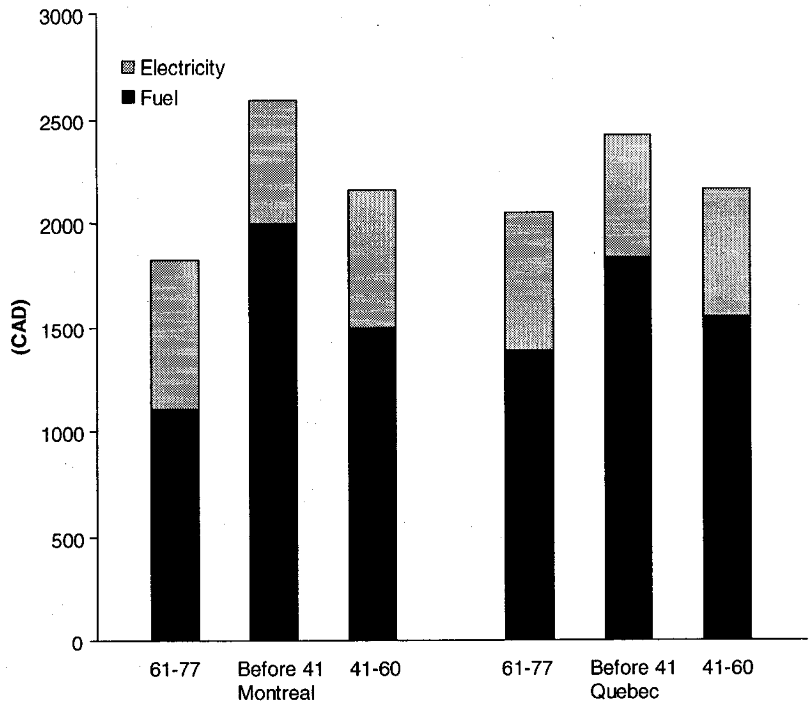

Figure 9.11: Base Case Fuel Costs – Quebec

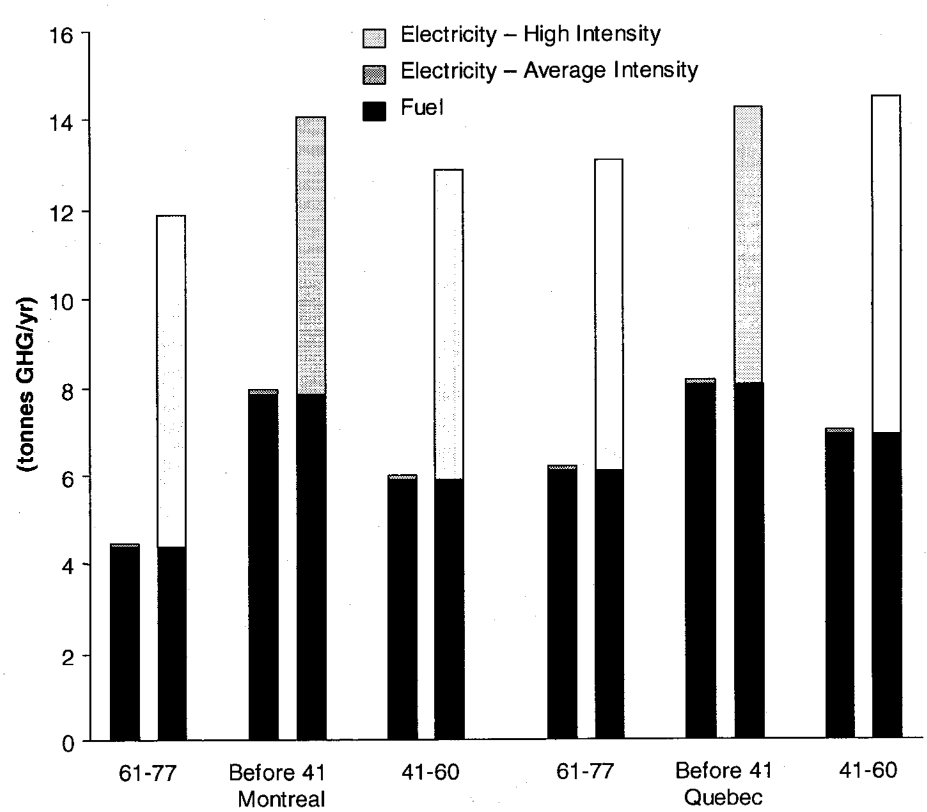

Figure 9.12: Base Case GHG Emissions – Quebec

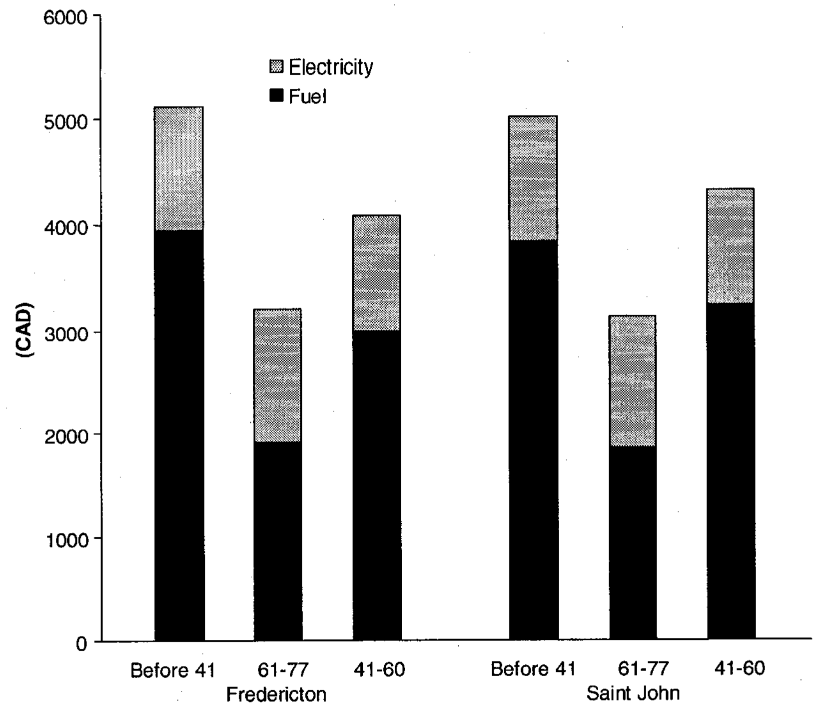

Figure 9.13: Base Case Fuel Costs – New Brunswick

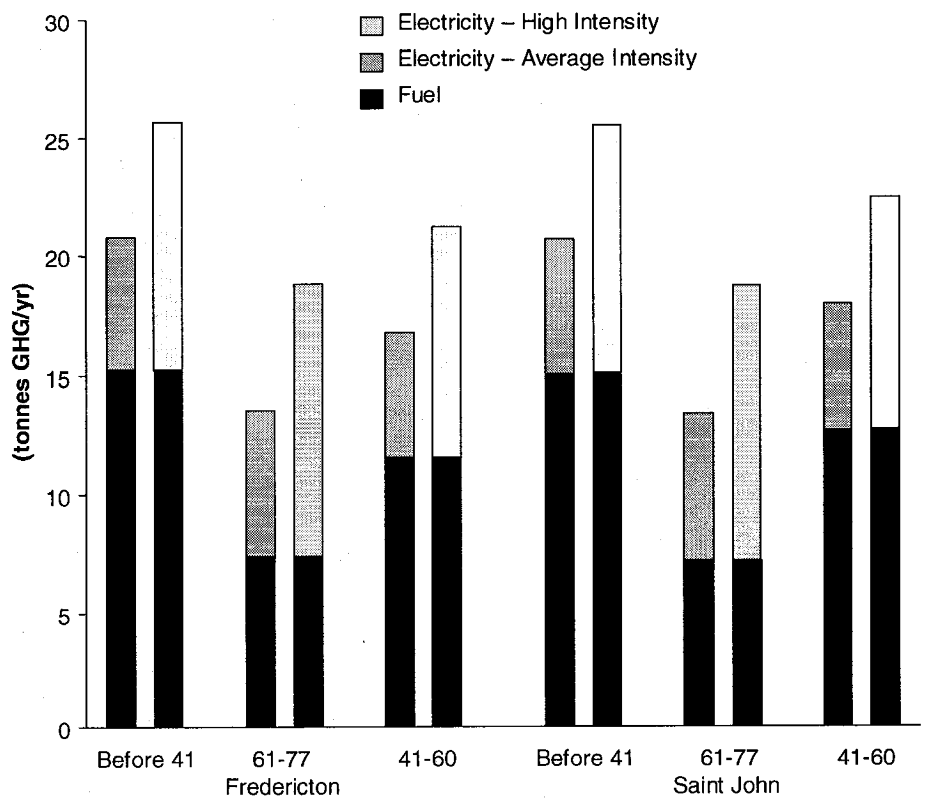

Figure 9.14: Base Case GHG Emissions – New Brunswick

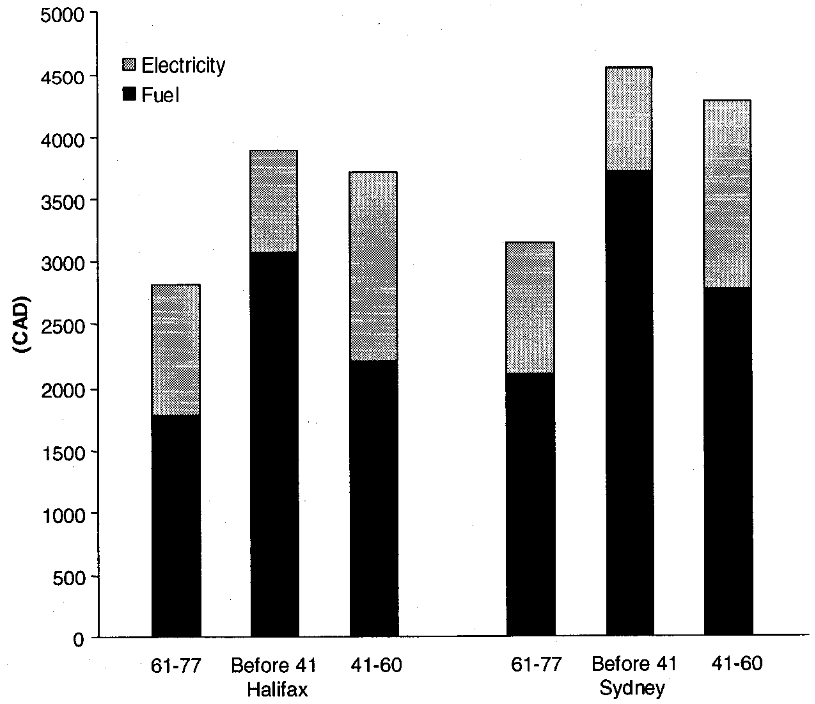

Figure 9.15: Base Case Fuel Costs – Nova Scotia

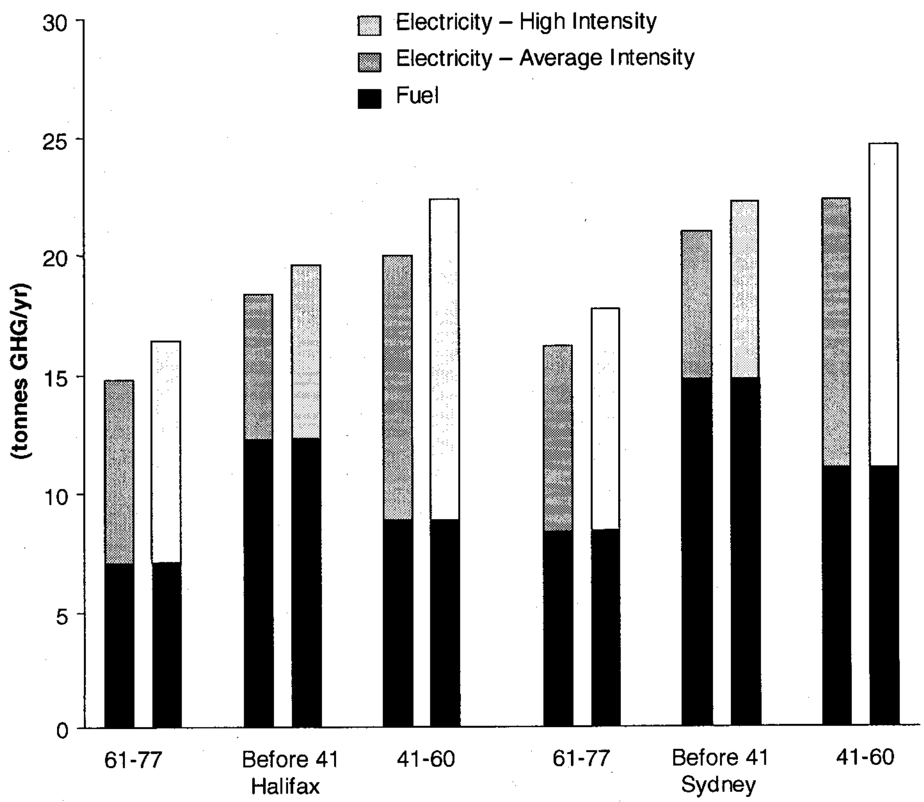

Figure 9.16: Base Case GHG Emissions – Nova Scotia

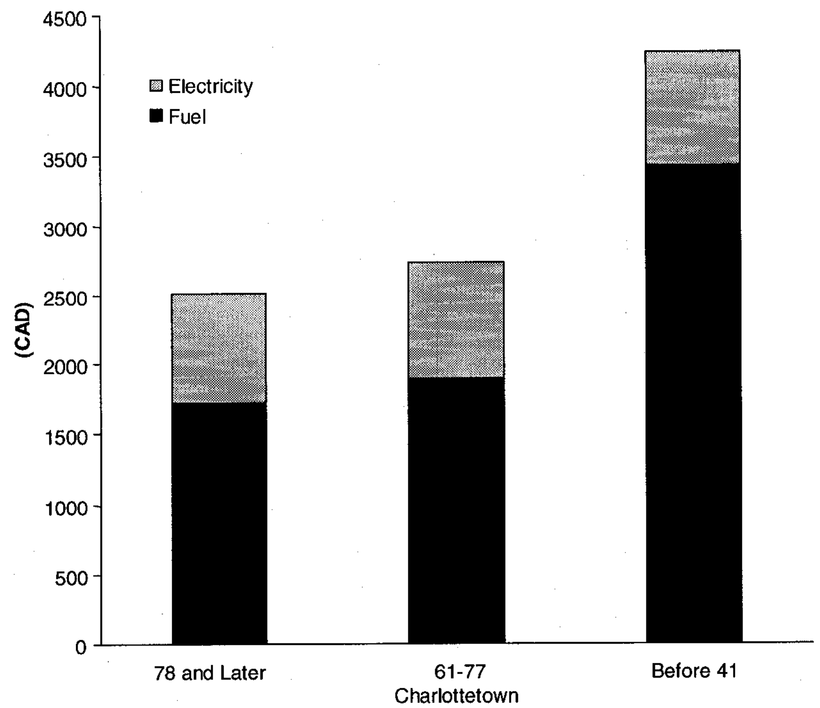

Figure 9.17: Base Case Fuel Costs – Prince Edward Island

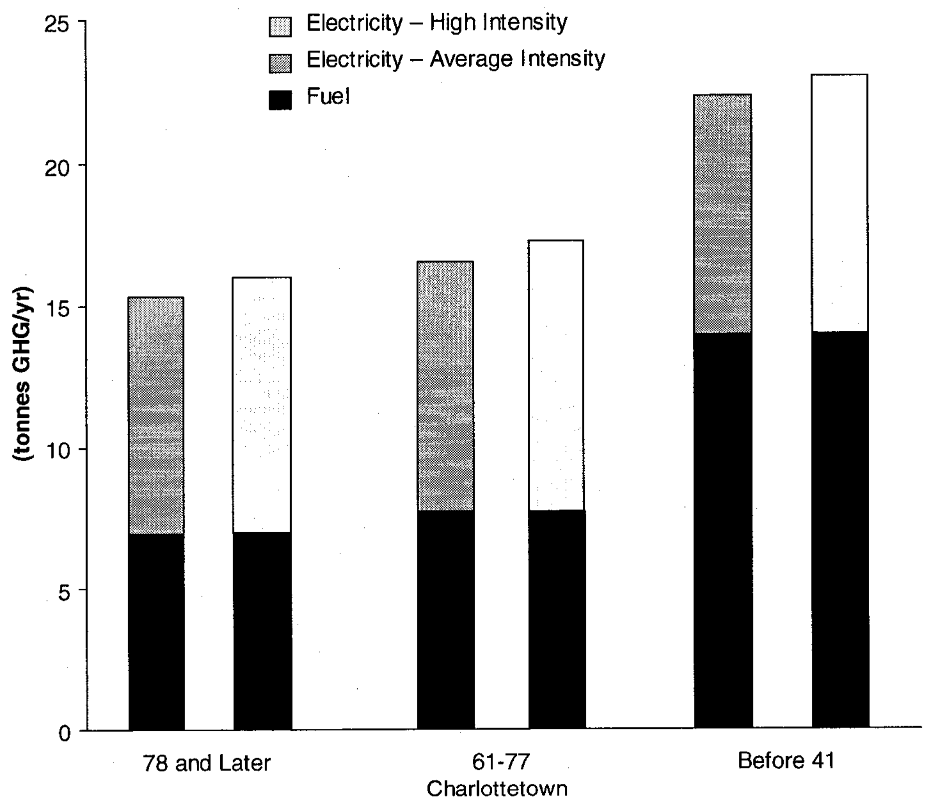

Figure 9.18: Base Case GHG Emissions – Prince Edward Island

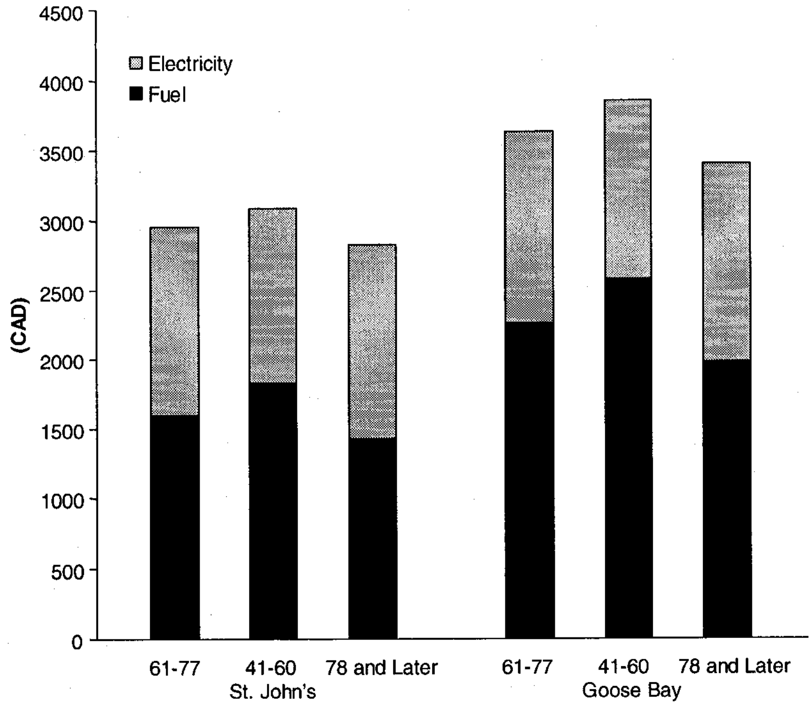

Figure 9.19: Base Case Fuel Costs – Newfoundland

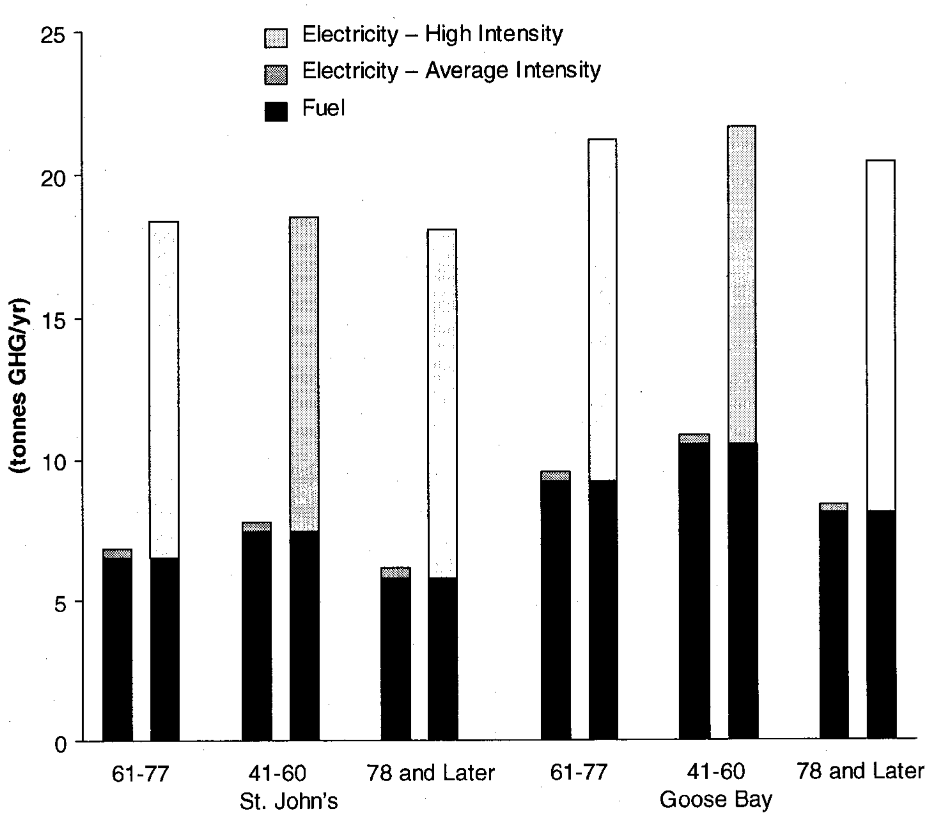

Figure 9.20: Base Case GHG Emissions – Newfoundland

9.3.1 ICE Based Cogeneration System Performance

The CHP efficiency of the ICE based cogeneration system is presented in Figure 9.21 as a function of the total annual thermal demand (space and DHW thermal demand) of the test case house.

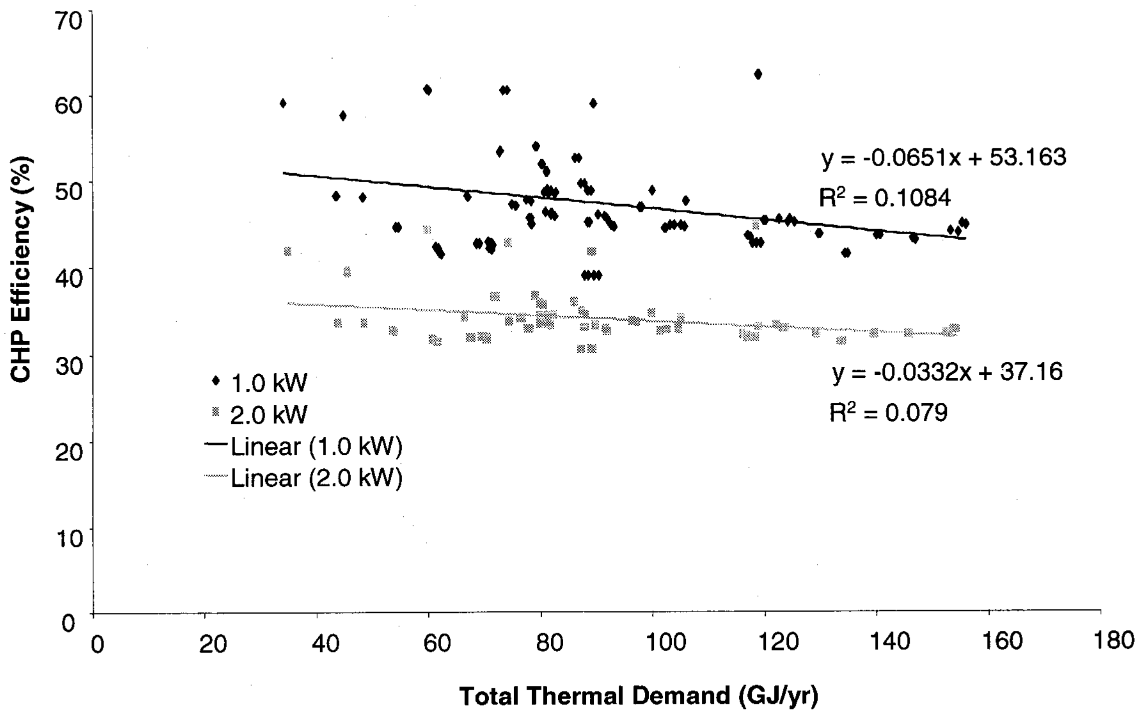

Figure 9.21: Total Thermal Demand vs. CHP Efficiency

In general, the CHP efficiency of the 1.0 kW system is higher than the 2.0 kW system as more of the heat generated can be utilized. The 2.0 kW system produces more surplus heat than the 1.0 kW system, thereby reducing the annual CHP efficiency. Using the 1.0 kW system, the annual CHP efficiencies are between ~40 % – 65 % and using the 2.0 kW system, the annual CHP efficiencies are between ~30 % – 45 %. The correlation between annual thermal demand and annual CHP efficiency is not strong (R^2 less than 0.15) because there are many factors that affect the annual CHP efficiency other than total annual thermal demand. Factors including the thermal output from the ICE based cogeneration system, electrical demand of the test case house, electrical efficiency of the ICE based cogeneration system, length and severity of the heating season, and temporal thermal demands all affect the annual CHP efficiency.

Figure 9.22 illustrates the annual CHP efficiency versus the quotient of test case house annual electrical demand ($Demand_{el}$) and annual space heating demand ($Demand_{SH}$).

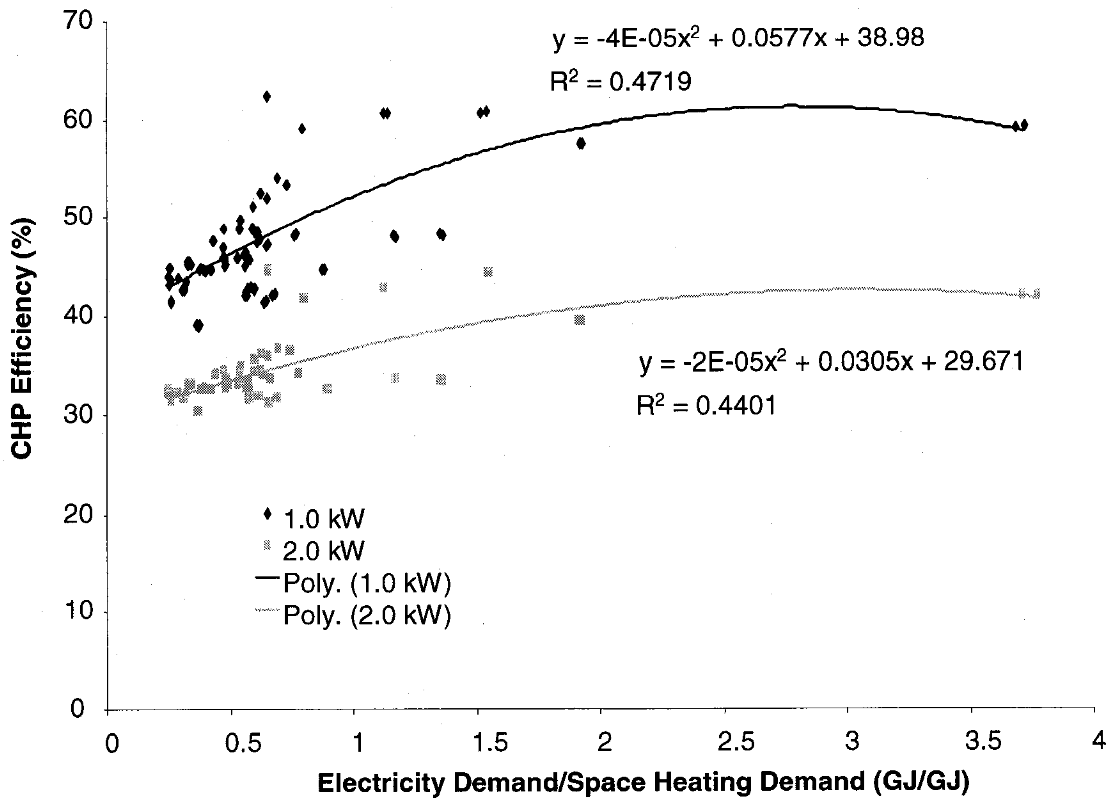

Figure 9.22: $Demand_{el}$ / $Demand_{SH}$ vs. CHP Efficiency

In general, the annual CHP efficiency increases as the ratio of electrical to space heating demand increases. The test case houses in British Columbia have high (> 1000 kWh/GJ) electrical demand to space heating demand ratios due to their high electrical demands (~20,000 kWh/yr). Including the effect of test case house specific annual electrical demand results in an increase in the prediction performance to $R^2 \approx 0.5$.

9.3.2 Fuel Cost Comparison

In all cases, the fuel costs in the cogeneration simulations is greater than the fuel costs in the base case. In the base case, only the energy required by the house was consumed, either through grid-imported electricity, or consuming fuel for the space and domestic hot water heating equipment. Since the cogeneration system used in this study followed the electricity demand of the house, heat was generated all year, which could not be fully utilized during the non-space heating months. The inability to fully utilize all of the generated energy leads to a fuel cost increase in all cases.

The change in total fuel cost (natural gas/propane and electricity) compared to the base case is calculated according to Equation 9.17 where a negative value indicates an increase in fuel cost.

$$\Delta \cos t = \frac{\cos t_{BC} - \cos t_{ICE}}{\cos t_{BC}} \times 100\% \qquad [9.17]$$

Where:

Δcost = change in fuel cost relative to base case cost (%)

$cost_{BC}$ = total fuel cost in base case simulation (CAD/yr)

$cost_{ICE}$ = total fuel cost in ICE based cogeneration simulation (CAD/yr)

Figure 9.23 presents the increase in fuel cost for the ICE based cogeneration simulations.

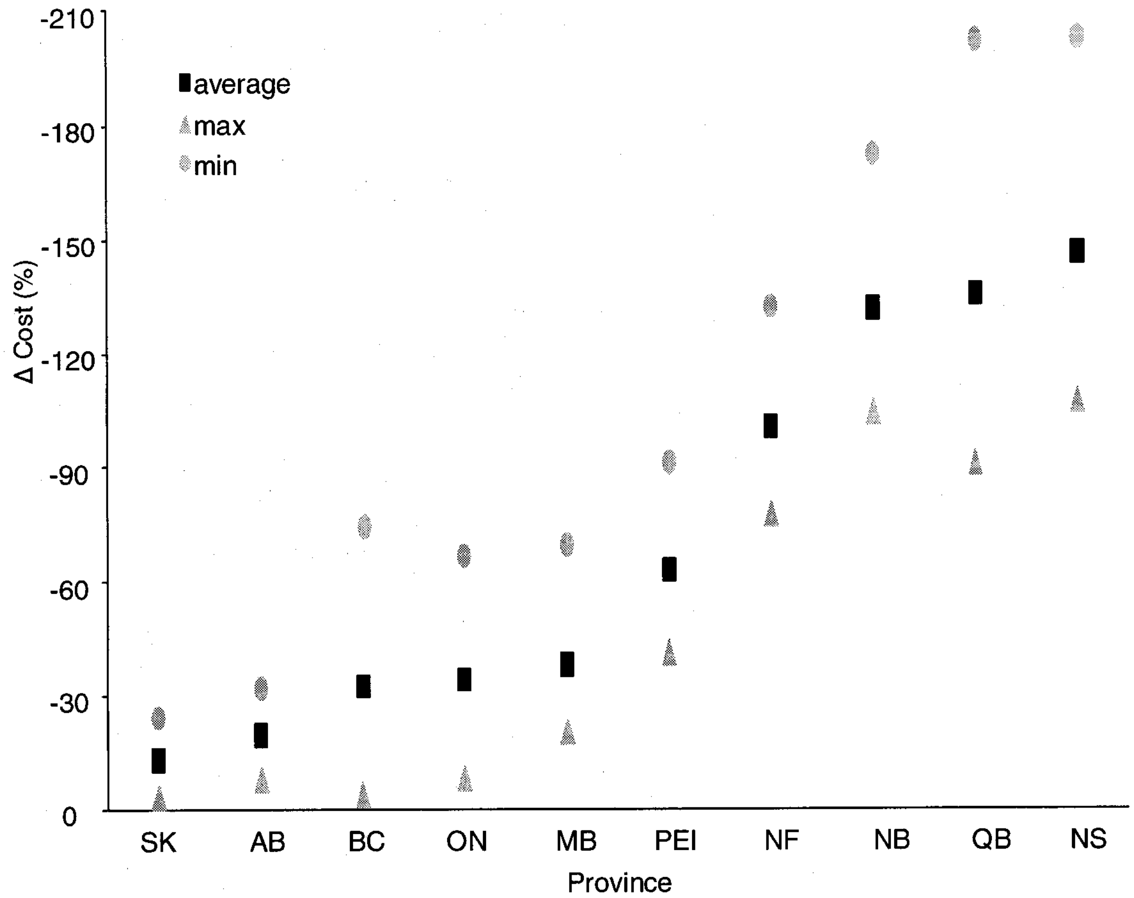

Figure 9.23: ICE Based Cogeneration Case – Comparative Fuel Costs

The economic viability of the ICE based cogeneration system in terms of fuel costs is dependent on the provincial fuel and electricity prices. The ICE based cogeneration system displaces grid-imported electricity in place of increased fuel consumption, thus the economics are favourable in provinces with relatively high electricity prices and relatively low fuel prices. A comparison of the results in Saskatchewan and Manitoba highlight this difference. In Saskatchewan, the prices are 34 ¢/m^3 and 8.99 ¢/kWh for natural gas and electricity, respectively. In Manitoba, the prices are 51 ¢/m^3 and 5.69 ¢/kWh, for natural gas and electricity respectively. The ICE based system is more economically viable in Saskatchewan with a cost difference compared to the base case for System 1 of between -19.6% to -5.0% compared to –80.9% to –23.1% for the same system in Manitoba. In addition, the difference in fuel costs between the base and ICE based cogeneration cases in New Brunswick, Nova Scotia, and Newfoundland are considerably higher compared to the remaining provinces because, due to the unavailability of natural gas, the ICE based cogeneration system was fuelled by propane, the most expensive of the fuels used in this study. In Quebec, while the price of propane is comparable to the price of heating oil, the fuel prices are relatively high and the electricity prices are the lowest in the country with a flat rate price of 5.22 ¢/kWh. This combination of higher fuel prices and lower electricity prices leads to a higher fuel cost for the ICE based cogeneration system compared to the base case. Prince Edward Island performed the best in terms of fuel costs compared the remaining provinces in Eastern Canada. This is a result of subsidized propane prices, however, compared to Western Canada, the cost of fuel is still high.

Figure 9.24 illustrates the total increase in fuel cost versus fuel and electricity prices for Saskatchewan and Quebec.

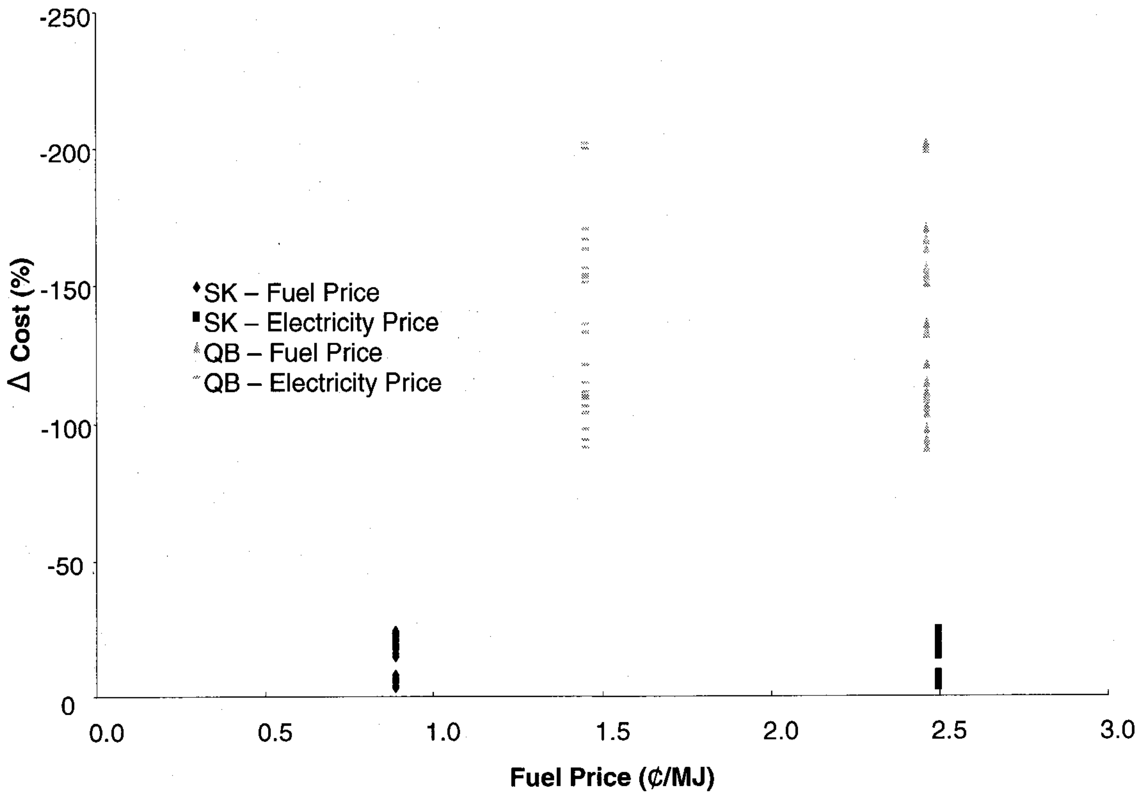

Figure 9.24: Total Fuel Cost Increase – Saskatchewan and Quebec

As can be seen from Figure 9.24, the increase in fuel cost compared to the base case is considerably higher in provinces where the price of fuel is higher than the price of electricity, when compared in ¢/MJ. In Saskatchewan the flat rate price of electricity is 8.99 ¢/kWh and the price of natural gas is 34 ¢/m^3 leading to a cost increase compared to the base case of, on average 6% using the 1.0 kW system and 20% using the 2.0 kW system. In Quebec, the flat rate price of electricity is 5.22 ¢/kWh and the price of propane is 65 ¢/litre leading to a cost increase compared to the base case of 110% using the 1.0 kW system and 160% using the 2.0 kW system. In general, the higher the fuel price and the lower the electricity price, the larger the increase in total fuel cost compared to the base case

Table 9.11 lists the fuel price difference between electricity and fuel for all of the provinces where the difference is calculated using Equation 9.18.

$$Price_{diff} = Price_{elec} - Price_{fuel} \quad [9.18]$$

Where:

$Price_{diff}$ = difference between electricity and fuel prices(¢/MJ)

$Price_{elec}$ = price of electricity (¢/MJ)

$Price_{fuel}$ = price of fuel (¢/MJ)

Table 9.11: Fuel Price Differences

	Electricity Price (¢/MJ)	Fuel Price (¢/MJ)	Difference (¢/MJ)
BC	1.76	1.07	0.69
AB	2.14	1.01	1.13
SK	2.50	0.89	1.61
MB	1.58	1.34	0.24
ON	2.78	1.29	1.49
QB	1.45	2.46	-1.01
NB	2.51	3.54	-1.03
NS	2.81	3.66	-0.84
PEI	2.97	2.24	0.73
NF	2.48	2.96	-0.48

In provinces where the electricity price (¢/MJ) is less than the fuel price (¢/MJ), the increase in total fuel cost compared to the base case is higher than in provinces where the fuel price (¢/MJ) is less than the electricity price (¢/MJ). This relationship is illustrated in Figure 9.25.

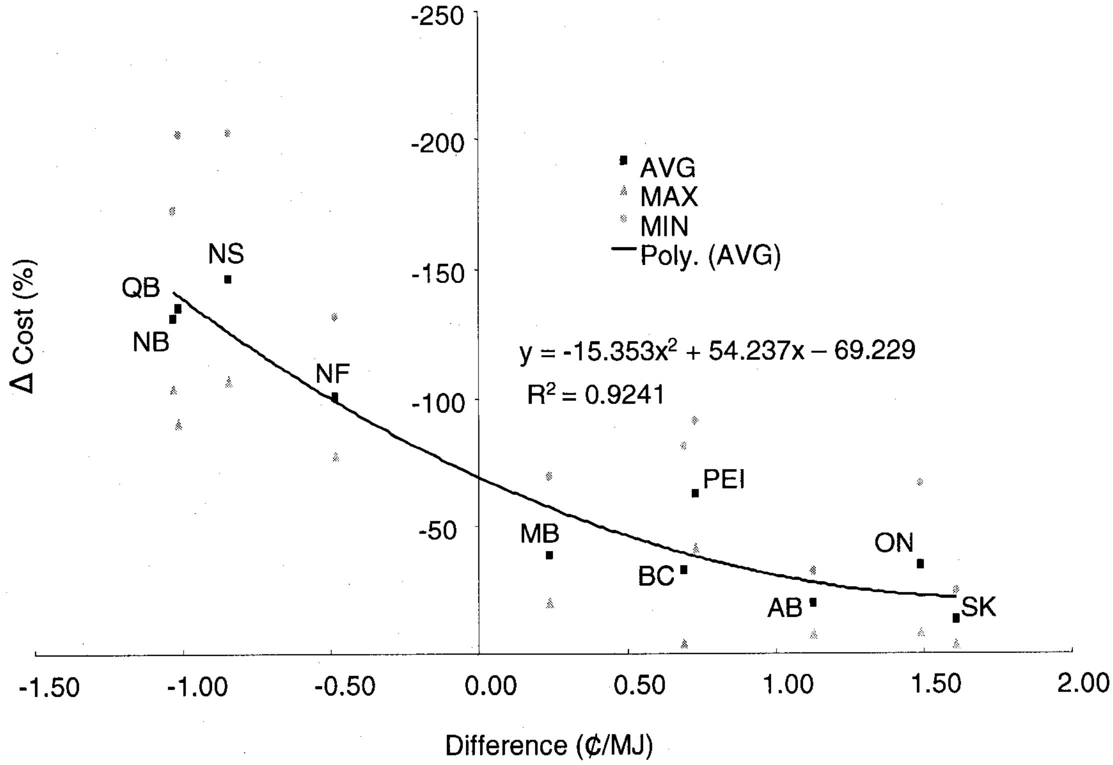

Figure 9.25: Fuel Cost Difference vs. Delta Cost

As illustrated in Figure 9.25, the increase in fuel costs compared to the base case is less in provinces where the difference between the electricity and fuel price is higher. The results for Ontario illustrate another important point. Test case houses 13 and 15 have relatively low space heating demands, (< 60 GJ/yr) thus, while the pricing structure in Ontario is such that the increase in fuel costs compared to the base case should be low, this is not the case in these two test case houses. Since the thermal demand of these two houses is not high enough to utilize the heat generated by the cogeneration system, the increase in fuel cost compared to the base case is high. Test case house 14 has a higher space heating demand (~80GJ) and the pricing structure in Ontario is favorable (i.e. electricity price higher than fuel price when compared in ¢/MJ), thus the total increase in fuel costs compared to the base case is lower compared to test case houses 13 and 14. Therefore, to be able to estimate the fuel cost increase expected using ICE based cogeneration, both the local electricity and fuel prices must be known, as well as the house specific energy demands.

Since the ICE based cogeneration system displaces grid-imported electricity in place of increase fuel consumption, the total fuel cost (including both natural gas/propane and electricity) is more dependant on the local fuel price than on the local electricity price. Figure 9.26 shows the relationship between fuel price (natural gas or propane) and the total increase in fuel cost compared to the base case.

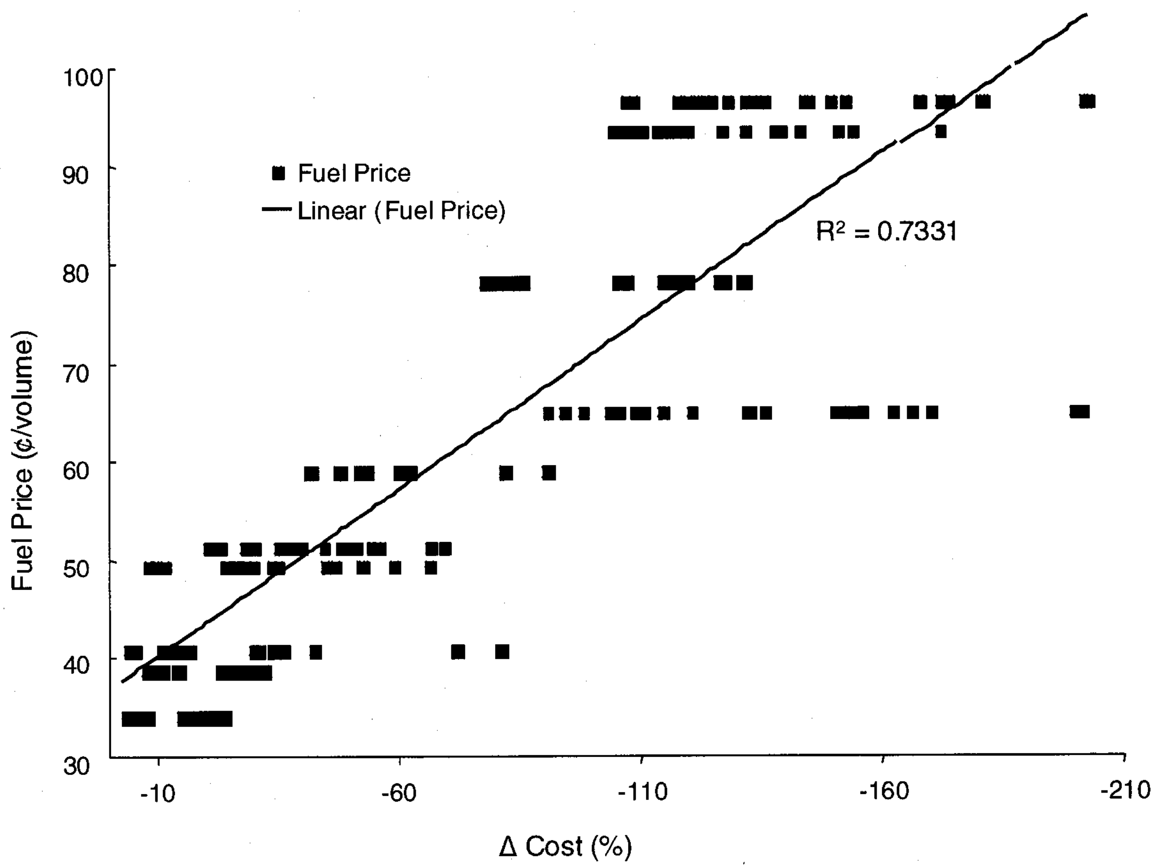

Figure 9.26: Total Fuel Increase vs. Fuel Price

As illustrated in Figure 9.26, the increase total fuel cost increases as the fuel price increases. While the amount thermal energy generated by the cogeneration system in the non-space heating months may be comparable in different test case houses, the cost to the consumer depends on the local fuel cost. The cost of this wasted energy is a major contributing factor as to why the total fuel costs increase in all cases.

9.3.3 GHG Emissions Comparison

The potential reductions in GHG emissions using the ICE based cogeneration system compared to the base case is dependent on the local electricity emissions factor.

The total GHG emissions (from electricity and fuel) compared to the base case is calculated according to Equation 9.19 where a positive value indicates a reduction in GHG emissions. Two estimates of the total GHG emissions are given using the average and high intensity electricity GHG emissions as discussed in Section 9.2.

$$\Delta GHG = \frac{GHG_{BC} - GHG_{ICE}}{GHG_{BC}} \times 100\% \qquad [9.19]$$

Where:

ΔGHG = change in GHG emissions relative to base case GHG emissions (%)

GHG_{BC} = total GHG emissions in base case simulation (tonnes/yr)

GHG_{ICE} = total GHG emissions in ICE based cogeneration simulation (tonnes/yr)

Figure 9.27 presents the difference in total GHG emissions using the 1.0 kW ICE based cogeneration system compared to the base case as a function of electricity emissions factor.

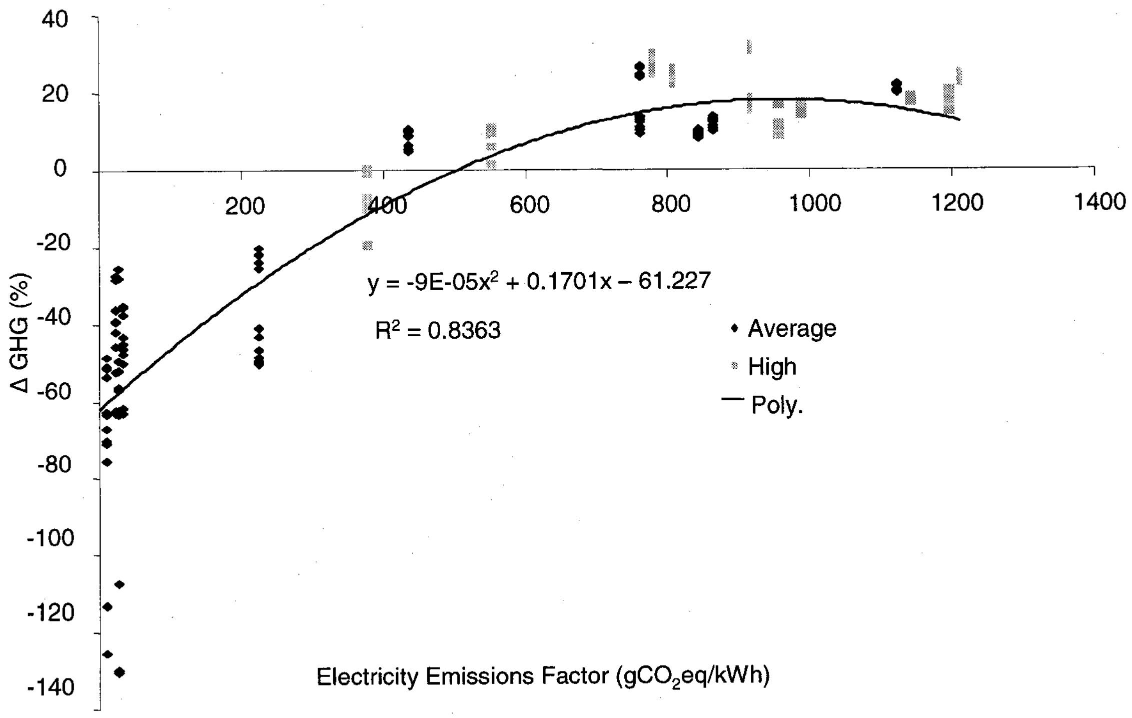

Figure 9.27: Electricity Emissions Factor vs. Comparative GHG Emissions – 1.0 kW ICE System

As can be seen in Figure 9.27, using the 1.0 kW ICE based cogeneration system results in a net reduction of GHG when the provincial electricity emissions factor is greater than approximately 400 gCO2eq/kWh.

Test case houses simulated in Alberta, Saskatchewan, New Brunswick, Nova Scotia and Prince Edward Island, when evaluated using the average electricity emissions factor realized a net GHG reduction using ICE based cogeneration. Using the high intensity electricity emissions factor, all test case houses except for those in British Columbia, realized a net GHG reduction.

Figure 9.28 presents the difference in total GHG emissions using the 2.0 kW ICE based cogeneration system compared to the base case as a function of electricity emissions factor.

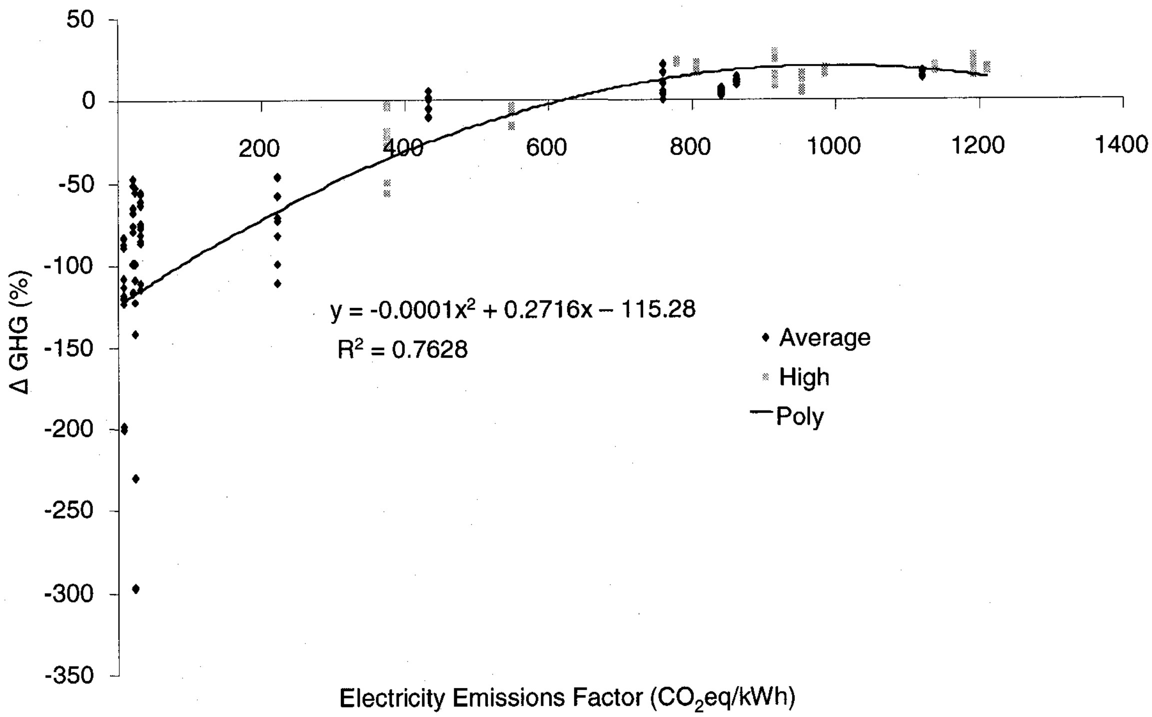

Figure 9.28: Electricity Emissions Factor vs. Comparative GHG Emissions – 2.0 kW ICE System

As can be seen in Figure 9.28, using the 2.0 kW ICE based cogeneration system results in a net reduction of GHG when the provincial electricity emissions factor is greater than approximately 750 gCO2eq/kWh.

Test case houses simulated in Alberta, Saskatchewan, Nova Scotia and Prince Edward Island, when evaluated using the average electricity emissions factor realized a net GHG reduction using ICE based cogeneration. Using the high intensity electricity emissions factor, all test case houses except for those in British Columbia and Quebec, realized a net GHG reduction.

According to the polynomial trend line used in both Figures 9.27 and 9.28, the GHG reductions decrease when the electricity emissions factor is approximately 1200 gCO2eq/kWh. This is a result of the test case house specific electricity demands being lower in PEI compared to the test case houses in provices with electricity emissions factors around 800 – 900 gCO2eq/kWh (i.e Saskatchewan and Alberta). GHG reductions depend on both electricity demand and electricity emissions factor, thus because there is less electrical demand, there is a smaller GHG reduction, even though the electricity emissions factor is higher.

The province specific results are presented in Figures 9.29 and 9.30.

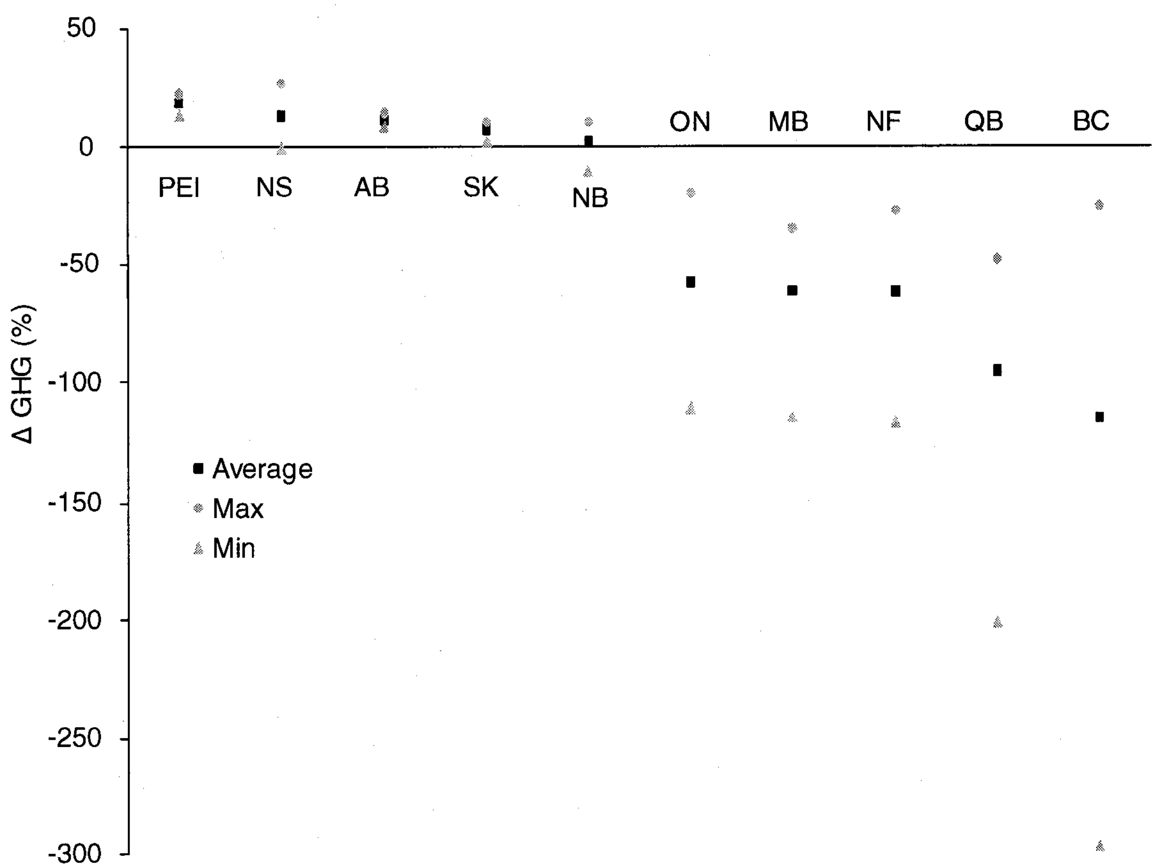

Figure 9.29: Comparative GHG Emissions using Average Electricity Emissions Factor – by Province

As illustrated in Figure 9.29, all four ICE based cogeneration systems simulated provided a GHG reduction in the test case houses in Alberta, Saskatchewan, and Prince Edward Island when evaluated using the average electricity emissions factor. In Nova Scotia, all four ICE based cogeneration systems provided a reduction in GHG emissions using the average electricity emissions factor except for system four in test case house 22 simulated in Halifax. In the remaining provinces, British Columbia, Manitoba, Ontario, Quebec, and Newfoundland, simulations using the ICE based cogeneration system resulted in an increase in GHG emissions when evaluated using the average electricity emissions factor.

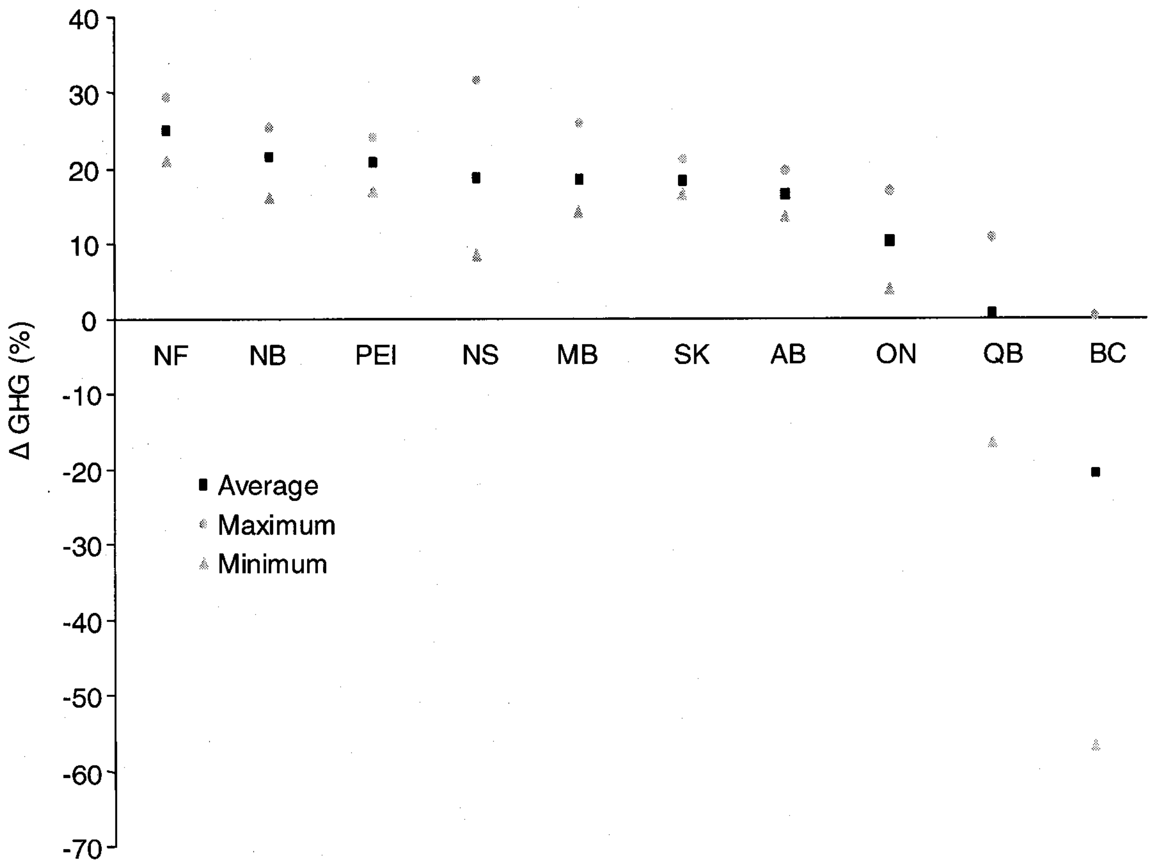

Figure 9.30: Comparative GHG Emissions using High Intensity Electricity Emissions Factor – by Province

Using the high intensity electricity emissions factor as illustrated in Figure 9.30, all four ICE based cogeneration systems provided a reduction in GHG emissions in all test case houses in Alberta, Saskatchewan, Manitoba, Ontario, New Brunswick, Nova Scotia and Prince Edward Island. In Quebec, the 1.0 kW ICE system provided a reduction in GHG emissions, however, the 2.0 kW system resulted in an increase in GHG emissions and in British Columbia, owing to the relatively low high intensity electricity emissions factor (385 gCO_{2eq}/kWh) the single only system to result in a GHG reduction was system 1 in test case house 1 simulated in Prince George.

9.3.4 Backup Burner and Heat Dump

The amount of thermal energy required from the backup burner and the amount of heat dumped are important parameters when understanding how the overall cogeneration system operates, how much additional thermal energy is required and how much surplus thermal energy is not utilized. Figure 9.31 presents the annual backup burner output as a function of annual space heating demand.

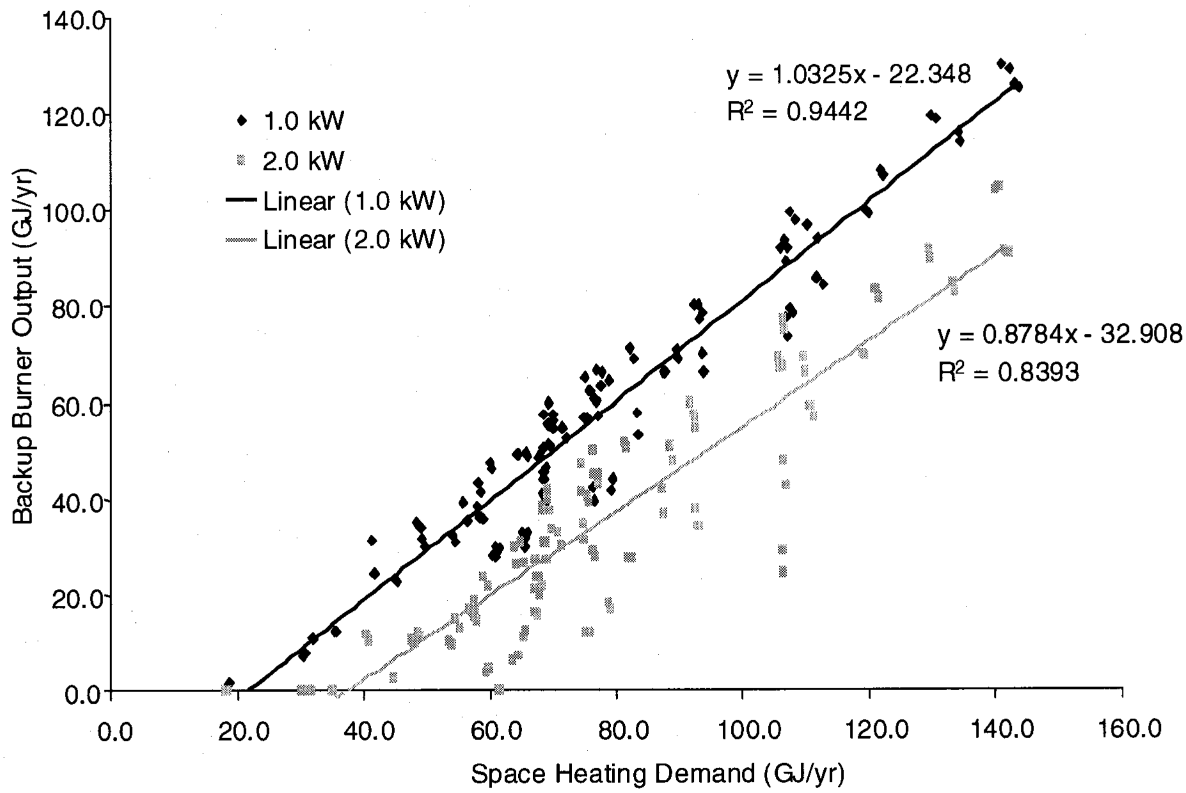

Figure 9.31: Space Heating Demand vs. Backup Burner Output

The cogeneration system operated in electricity priority control mode, thus the amount of thermal energy generated by the cogeneration system is dependent on the electricity demand of the house. Using the 1.0 kW system, the annual thermal output from the ICE based cogeneration system is between 70 – 80 GJ/yr. As illustrated in Figure 9.31, the backup burner output, in the 1.0 kW case, is dependent on the space heating demand with a high prediction performance of $R^2 = 0.9442$. The prediction performance in the 2.0 kW case is lower, $R^2 = 0.8393$, because the range of thermal output from the ICE based cogeneration system is larger, 115 – 140 GJ depending on the electricity demand of the test case house. In the cases of low space heating demand (less than 30GJ/yr), the 2.0 kW system was able to satisfy the thermal demand of the house without any contribution from the backup burner.

Figure 9.32 presents the annual backup burner output as a function of total annual thermal demand (sum of space and DHW demand).

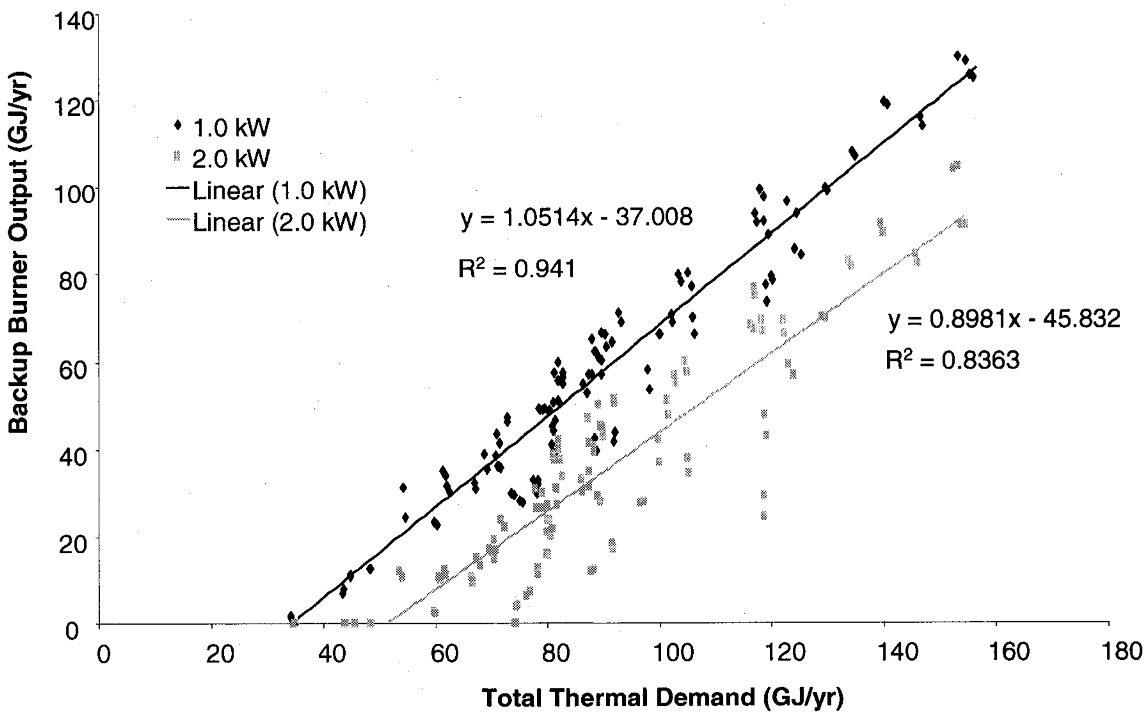

Figure 9.32: Total Thermal Demand vs. Backup Burner Output

As illustrated in Figure 9.32, the backup burner output, in the 1.0 kW case, is dependent on the space heating demand with a high prediction performance of $R^2 = 0.941$. The prediction performance in the 2.0 kW case is lower, $R^2 = 0.8363$. Including the DHW demand to determine the required backup burner output only slightly reduces the prediction performance (< 0.5%).

To account for the test case house specific electrical demand and the associated effect on backup burner output, the backup burner output is plotted as a function of electricity demand divided by space heating demand in Figure 9.33.

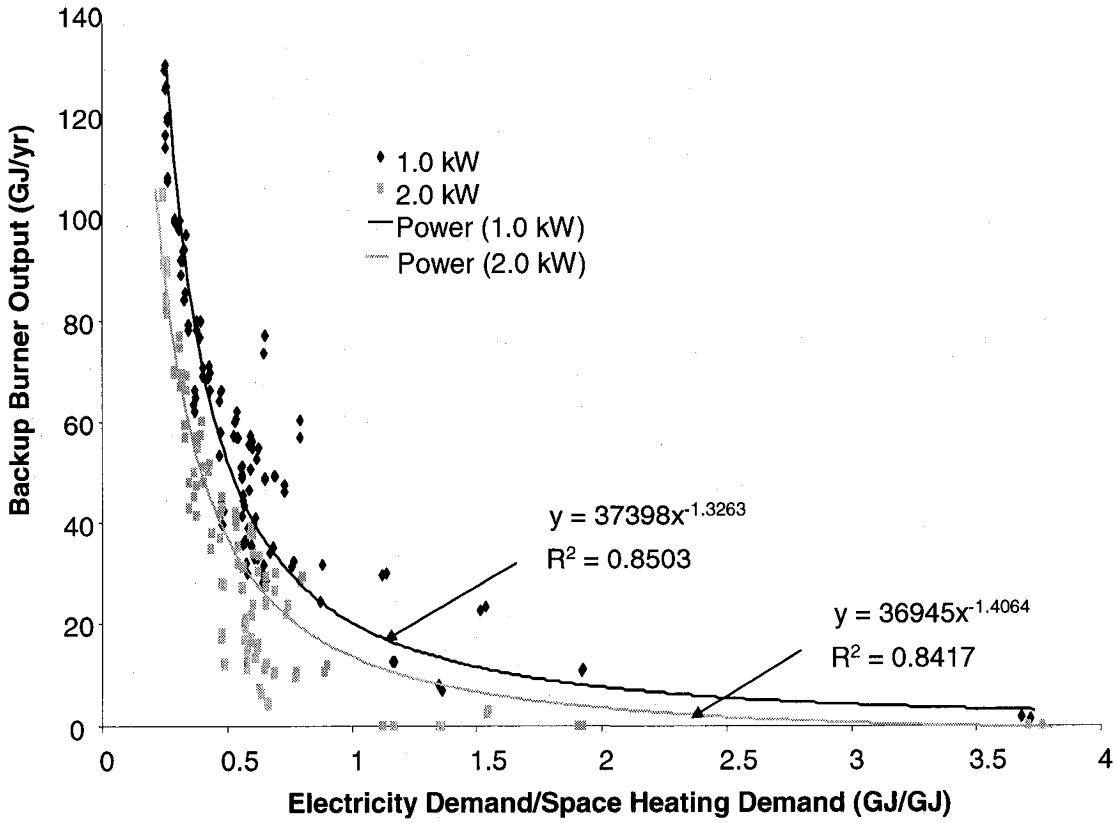

Figure 9.33: Demand$_{el}$ / Demand$_{SH}$ vs. Backup Burner Output

The amount of heat dumped is a function of:

- Length of heating season
- Thermal output from the ICE based cogeneration system
- DHW demand
- Electricity demand
- Insulation level of test case house
- Site altitude[6]

[6] The maximum power output is de-rated depending on the site altitude above sea level which also de-rates the thermal output of the ICE based cogeneration system.

Figures 9.34 – 9.37 present the annual space heating demand, annual DHW demand, total annual thermal demand, and ratio of annual electrical demand to annual space heating demand vs. the annual heat dump.

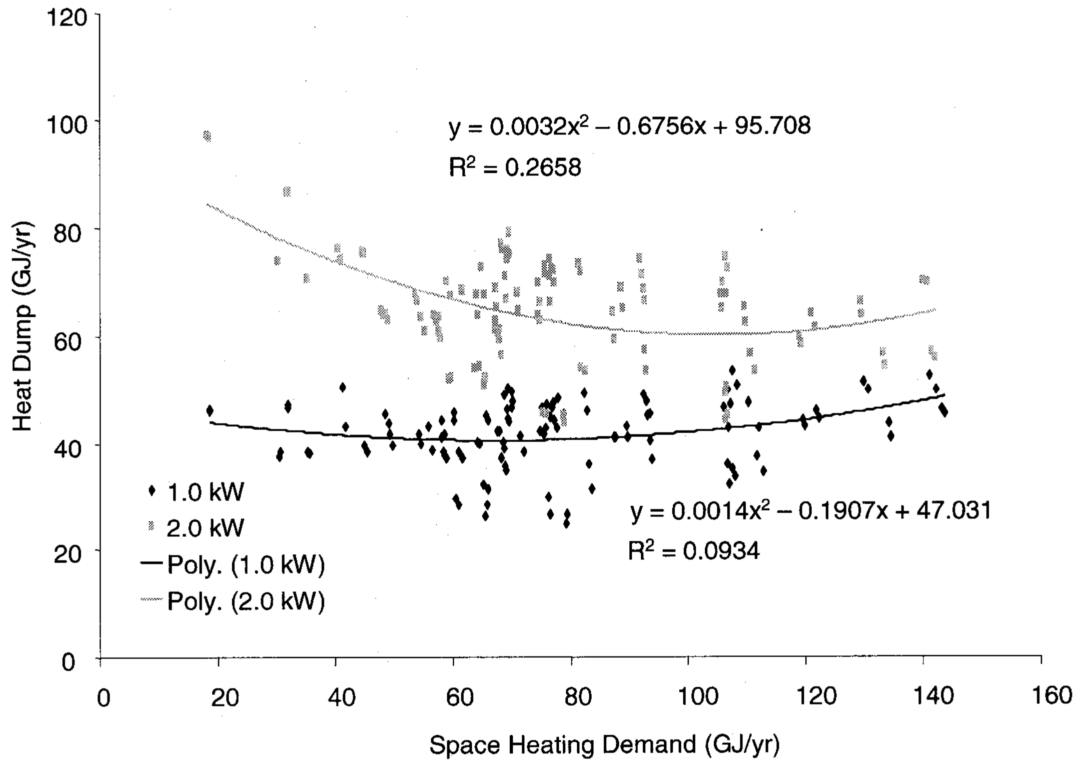

Figure 9.34: Space Heating Demand vs. Heat Dump

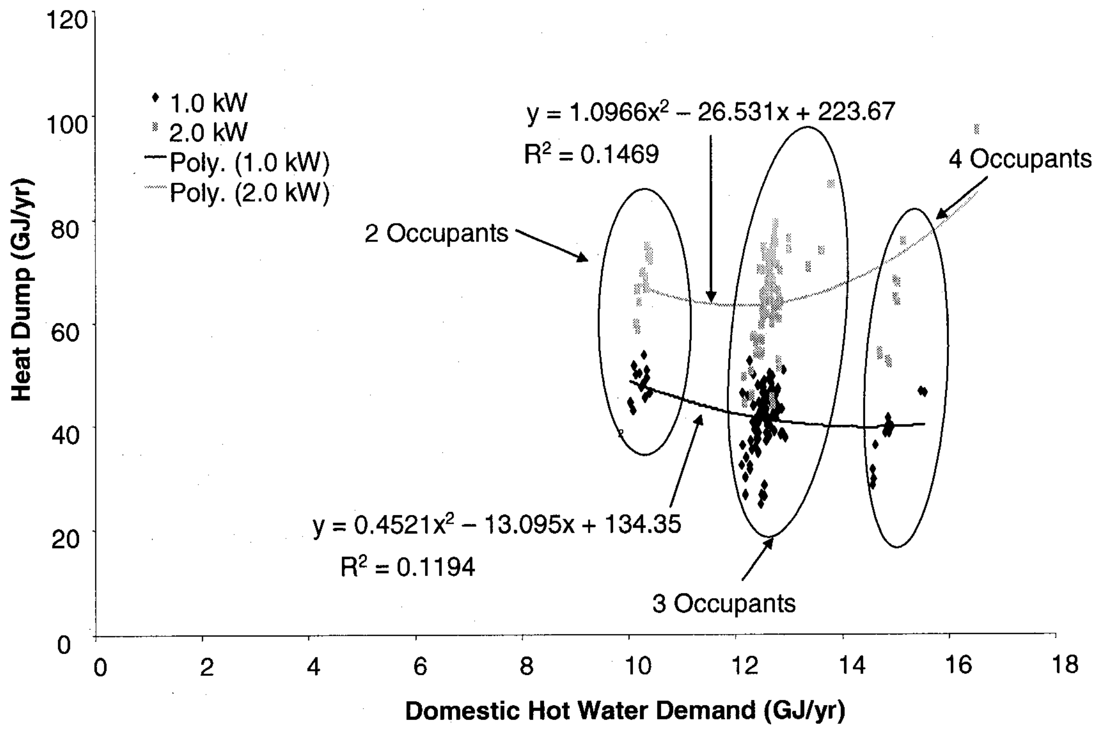

Figure 9.35: Domestic Hot Water Demand vs. Heat Dump

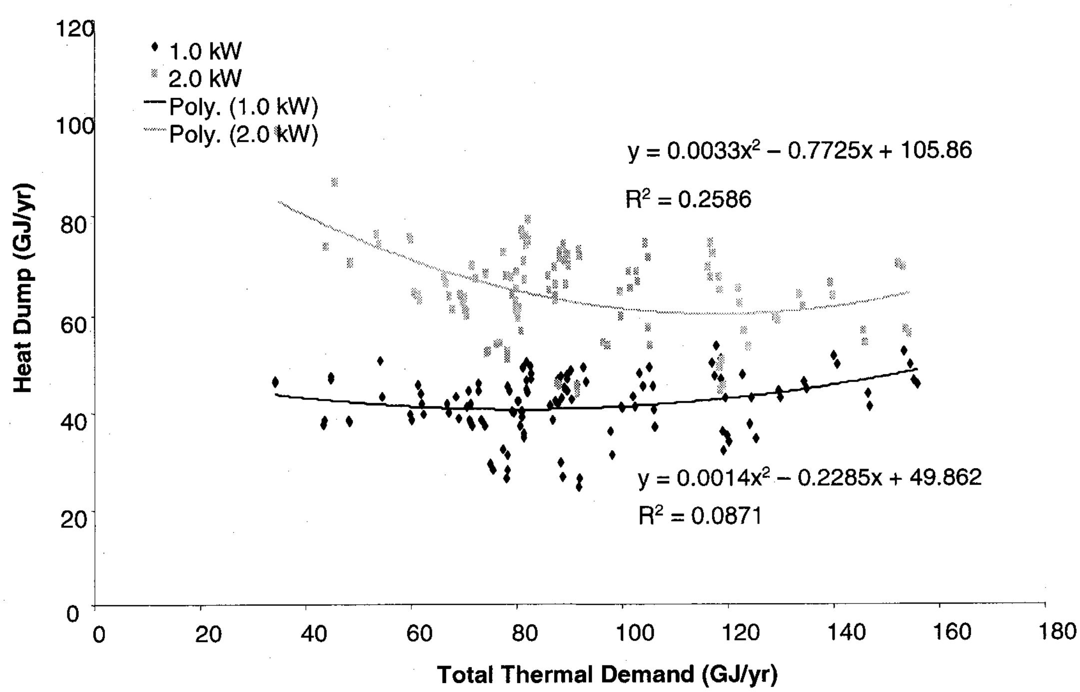

Figure 9.36: Total Thermal Demand vs. Heat Dump

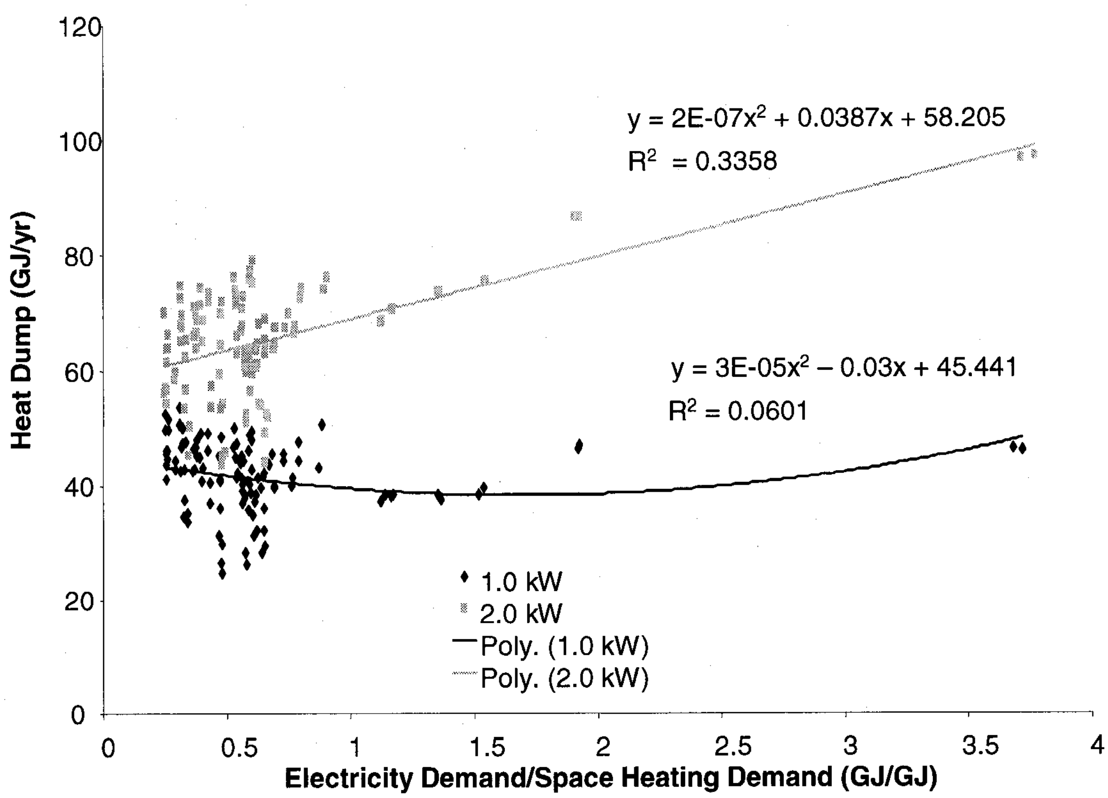

Figure 9.37: Demand$_{el}$ / Demand$_{SH}$ vs. Heat Dump

Due to the number of variables involved in determining the annual heat dump, Figures 9.34 – 9.37 show that there is not a direct correlation between annual space heating demand, annual DHW demand, total annual thermal demand, electricity demand divided by space heating demand and annual heat dump.

Figures 9.34 – 9.37 show the range of heat dump using the 1.0 kW and 2.0 kW systems. Using the 1.0 kW system, the heat dump is between 25 – 50 GJ/yr and using the 2.0 kW system, the annual heat dump is between 45 – 100 GJ/yr.

As mentioned in Section 9.3.1, since the cogeneration system used in this study followed the electricity demand of the house, heat was generated all year, which could not be fully utilized during the non-space heating months. The inability to fully utilize all of the generated energy leads to a fuel cost increase in all cases. Figure 9.38 illustrates the increase in fuel cost as a function of annual heat dump.

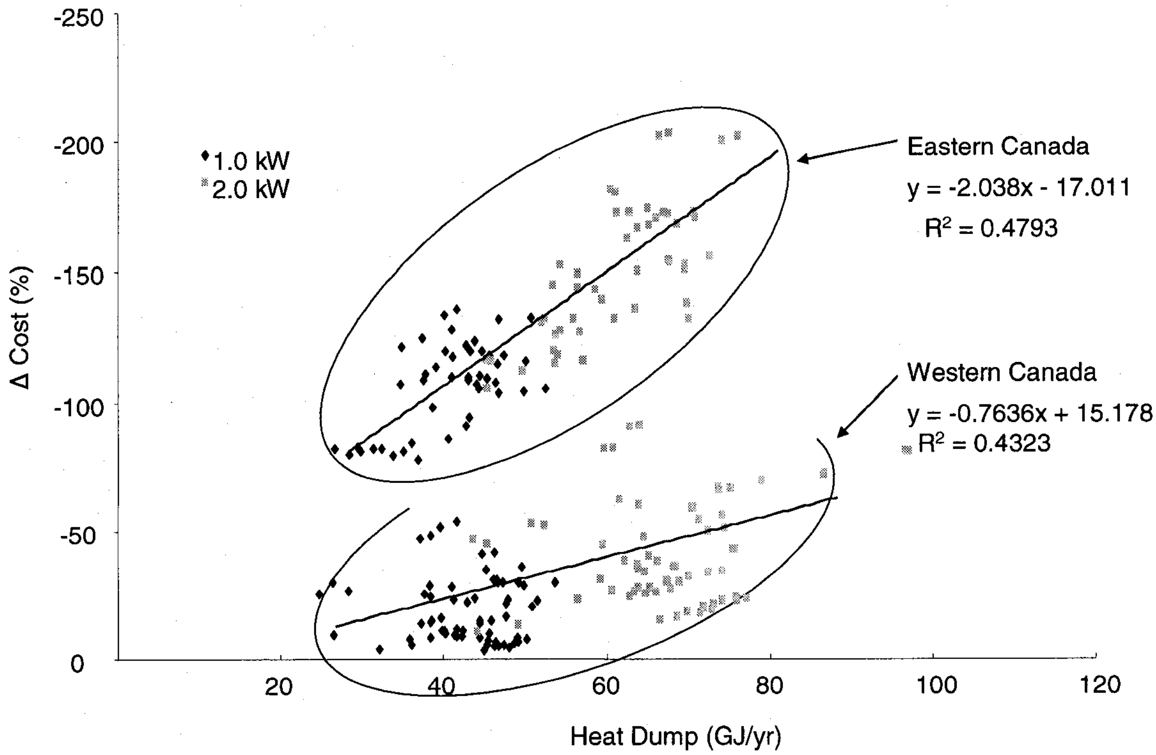

Figure 9.38: Heat Dump vs. Increase in Fuel Cost

As can be seen in Figure 9.38 as the amount of heat dumped increases, so to does the increase in fuel cost compared to the base case. As expected, the magnitude of annual heat dump and of increase in fuel cost compared to the base case are greater using the 2.0 kW system compared to the 1.0 kW system. Figure 9.38 also illustrates that, due to the high fuel prices in Eastern Canada compared to Western Canada (in many cases, more than double), even if the annual heat dump is comparable between two houses, the fuel pricess have a marked effect on the overall increase in fuel cost. This effect is seen clearly in Figure 9.38 where there are two distinct groups of data, segregated due to the large difference in fuel prices.

9.4 Regional and National Results

The annual simulation results can be extrapolated to comment on the economic and environmental impacts of using ICE based cogeneration at a regional and national level. Four cases are presented here:

- Selecting the ICE based cogeneration system for each test case house which maximizes the GHG reductions using the average electricity emissions factor

- Selecting the ICE based cogeneration system for each test case house which minimizes the increase in fuel costs using the average electricity emissions factor

- Selecting the ICE based cogeneration system for each test case house which maximizes the GHG reductions using the high intensity electricity emissions factor

- Selecting the ICE based cogeneration system for each test case house which minimizes the increase in fuel costs using the high intensity electricity emissions factor

In all cases, only the test case houses using the ICE based cogeneration system which resulted in a net GHG reduction compared to the base case are considered in this analysis, with one exception; the results for test case house 1 simulated with system 1 in Prince George are not included in the analysis because the reduction in GHG emissions is very small (<0.05 tCO2eq/yr) and, for the sake of this analysis, are considered inconsequential. Using the average electricity emissions factors, test case houses using the ICE based cogeneration system which result in a net GHG reduction compared to the base case are the test case houses in Alberta, Saskatchewan, New Brunswick, Nova Scotia and Prince Edward Island. Using the high intensity electricity emissions factor, all test case houses except for the British Columbia test case houses resulted in a net GHG reduction compared to the base case and are considered in this analysis.

To determine the GHG reductions and associated increase in fuel costs, the results from each test case house are multiplied by the weighing factor in the SHEU database. For the purpose of this extrapolation, it is assumed that all of the houses in the test case group (i.e.: province, vintage and space heating fuel type group) are located in the two simulation cities. Table 9.12 lists the SHEU weighing factors for each test case house.

Table 9.12: Test Case House SHEU Weighing Factors

Test Case House	Province	Vintage	Space Heating Fuel Type	SHEU Weighing Factor
4	AB	1961-1977	Natural Gas	195889
5	AB	1978 and later	Natural Gas	152023
6	AB	1941-1960	Natural Gas	102455
7	SK	1961-1977	Natural Gas	73206
8	SK	1978 and later	Natural Gas	53821
9	SK	1941-1960	Natural Gas	52328
10	MB	1961-1977	Natural Gas	50603
11	MB	1941-1960	Natural Gas	48801
12	MB	before 1941	Natural Gas	38044
13	ON	1978 and later	Natural Gas	444964
14	ON	before 1941	Natural Gas	287837
15	ON	1941-1960	Natural Gas	276848
16	PQ	1961-1977	Oil	111517
17	PQ	before 1941	Oil	64932
18	PQ	1941-1960	Oil	50048
19	NB	before 1941	Oil	15438
20	NB	1961-1977	Oil	14416
21	NB	1941-1960	Oil	13858
22	NS	1961-1977	Oil	42123
23	NS	before 1941	Oil	40453
24	NS	1941-1960	Oil	27521
25	PEI	1978 and later	Oil	7537
26	PEI	1961-1977	Oil	7371
27	PEI	before 1941	Oil	6873
28	NF	1961-1977	Oil	16340
29	NF	1941-1960	Oil	13568
30	NF	1978 and later	Oil	10056

The SHEU weighing factor for each test case house is divided between the two simulation cities using the ratio of the population of the two simulation cities according to Equation 9.20. Table 9.13 list the population figures for each of the simulation cities

(Statistics Canada, 2007) and Table 9.14 lists the city specific SHEU weighing factors used to extrapolate the test case house results.

$$WF_{1,2} = WF_{SHEU} \times \frac{P_{1,2}}{P_1 + P_2} \qquad [9.20]$$

Where:

WF_1 = weighing factor for simulation city 1

WF_2 = weighing factor for simulation city 2

WF_{SHEU} = SHEU weighing factor

P_1 = population of simulation city 1

P_2 = population of simulation city 2

Table 9.13: Simulation City Population

City	Population
Calgary	988193
Edmonton	730372
North Battleford	13190
Regina	179246
Le Pas	5589
Winnipeg	633451
Ottawa	812129
Toronto	2503281
Montreal	1620693
Quebec	491142
Fredericton	50535
Saint John	68043
Halifax	372679
Sydney	102250
Charlottetown	32174
Goose Bay	7572
St. John's	100646

Table 9.14: City Specific Weighing Factors

Test Case House	Simulation City	SHEU Weighing Factor	City Specific Weighing Factor
1	Prince George	186858	20436
	Vancouver		166422
4	Calgary	195889	112638
	Edmonton		83251
5	Calgary	152023	87415
	Edmonton		64608
6	Calgary	102455	58913
	Edmonton		43542
7	North Battleford	73206	5018
	Regina		68188
8	North Battleford	53821	3689
	Regina		50132
9	North Battleford	52328	3587
	Regina		48742
10	Le Pas	50603	443
	Winnipeg		50160
11	Le Pas	48801	427
	Winnipeg		48374
12	Le Pas	38044	333
	Winnipeg		37711
13	Ottawa	444964	108997
	Toronto		335968
14	Ottawa	287837	70507
	Toronto		217330
15	Ottawa	276848	67816
	Toronto		209033
16	Montreal	111517	85582
	Quebec		25935
17	Montreal	64932	49831
	Quebec		15101
18	Montreal	50048	38409
	Quebec		11640

Table 9.14 Continued: City Specific Weighing Factors

Test Case House	Simulation City	SHEU Weighing Factor	City Specific Weighing Factor
19	Fredericton	15438	6579
	Saint John		8859
20	Fredericton	14416	6144
	Saint John		8272
21	Fredericton	13858	5906
	Saint John		7952
22	Halifax	42123	33054
	Sydney		9069
23	Halifax	40453	31744
	Sydney		8709
24	Halifax	27521	21596
	Sydney		5925
25	Charlottetown	7537	7537
26	Charlottetown	7371	7371
27	Charlottetown	6873	6873
28	Goose Bay	16340	1143
	St. John's		15196
29	Goose Bay	13568	949
	St. John's		12619
30	Goose Bay	10056	704
	St. John's		9352

The high intensity GHG reductions for each test case house is calculated by summing the results of the two simulation cities for each test case house as defined in Equation 9.21. For example, the GHG reduction (in tonnes) for test case house 4 simulated in Calgary is multiplied by its corresponding weighing factor as listed in Table 9.14 and added to the GHG reduction (in tonnes) for test case house 4 simulated in Edmonton which is multiplied by its corresponding weighing factor as listed in Table 9.14. The results indicate the high intensity GHG reductions of test case house 4 and the associated increase in fuel costs. The same procedure is used to determine the GHG reductions for each test case house.

$$GHG_{i,MAX} = \left(\left(GHG_{i,C1} - GHG_{i,C1,BC}\right) \times WF_{i,C1}\right) + \left(\left(GHG_{i,C2} - GHG_{i,C2,BC}\right) \times WF_{i,C2}\right) \quad [9.21]$$

Where:

$GHG_{i,MAX}$ = maximum GHG reduction for test case house i (tonnes/yr)

$GHG_{i,C1}$ = GHG emissions for test case house i simulated in city 1 (tonnes/yr)

$GHG_{i,C1,BC}$ = base case GHG emissions for test case house i simulated in city 1 (tonnes /yr)

$WF_{i,C1}$ = weighing factor for simulation city 1, test case house i

$GHG_{i,C2}$ = GHG emissions for test case house i simulated in city 2 (tonnes/yr)

$GHG_{i,C2,BC}$ = base case GHG emissions for test case house i simulated in city 2 (tonnes /yr)

$WF_{i,C2}$ = weighing factor for simulation city 2, test case house i

i = test case house number

The results for the Prairie region using the average electricity emissions factor are presented in Table 9.15 where the ICE based cogeneration system selected for each test case house and simulation city is the system that results in the highest GHG reduction compared to the base case.

Table 9.15: GHG Reductions using Average Electricity Emissions Factor – Prairie Region

Test Case House	Simulation City	System	Maximum GHG Reductions (kt)	Cost Increase (MCAD)
4	Calgary	3	352	116.2
	Edmonton	3		
5	Calgary	3	288	61.9
	Edmonton	1		
6	Calgary	1	206	0.3
	Edmonton	1		
7	North Battleford	1	98	9.2
	Regina	1		
8	North Battleford	1	69	7.6
	Regina	1		
9	North Battleford	1	70	5.8
	Regina	1		

For the Prairie region, selecting the ICE based cogeneration system that maximizes the GHG reductions; the average increase in fuel cost per tonne of GHG saved is 185 CAD with a GHG reduction of 1083 kt. Table 9.16 list the results for the Atlantic Region.

Table 9.16: GHG Reductions using Average Electricity Emissions Factor – Atlantic Region

Test Case House	Simulation City	System	Maximum GHG Reductions (kt)	Cost Increase (MCAD)
19	Fredericton	1	66	82.6
	Saint John	1		
20	Fredericton	1	16	54.6
	Saint John	1		
21	Fredericton	1	37	65.1
	Saint John	1		
22	Halifax	1	153	159.1
	Sydney	1		
23	Halifax	1	205	206.5
	Sydney	1		
24	Halifax	1	299	121.5
	Sydney	1		
25	Charlottetown	1	25	9.8
26	Charlottetown	1	27	9.6
27	Charlottetown	1	31	12.0

For the Atlantic region, selecting the ICE based cogeneration system that maximizes the GHG reductions; the average increase in fuel cost per tonne of GHG saved is 839 CAD with a GHG reduction of 859 kt.

The same analysis is conducted selecting the ICE based cogeneration system that results in the lowest increase in fuel cost, where the increase in fuel cost is calculated using Equation 9.22.

$$Cost_{i,MIN} = \left(\left(Cost_{i,C1} - Cost_{i,C1,BC}\right)\times WF_{i,C1}\right) + \left(\left(Cost_{i,C2} - Cost_{i,C2,BC}\right)\times WF_{i,C2}\right) \qquad [9.22]$$

Where:

$Cost_{i,MIN}$ = minimum increase in fuel cost for test case house i (CAD/yr)

$Cost_{i,C1}$ = fuel cost for test case house i simulated in city 1 (CAD/yr)

$Cost_{i,C1,BC}$ = base case fuel cost for test case house i simulated in city 1 (CAD/yr)

$WF_{i,C1}$ = weighing factor for simulation city 1, test case house i

$Cost_{i,C2}$ = fuel cost for test case house i simulated in city 2 (CAD/yr)

$Cost_{i,C2,BC}$ = base case fuel cost for test case house i simulated in city 2 (CAD/yr)

$WF_{i,C2}$ = weighing factor for simulation city 2, test case house i

i = test case house number

The results for the Prairie region are presented in Table 9.17.

Table 9.17: Minimum Cost Increase using Average Electricity Emissions Factor – Prairie Region

Test Case House	Simulation City	System	Minimum Cost Increase (MCAD)	GHG Reductions (kt)
4	Calgary	1	50.1	331
	Edmonton	2		
5	Calgary	2	31.3	281
	Edmonton	1		
6	Calgary	1	17.6	204
	Edmonton	2		
7	North Battleford	1	9.2	98
	Regina	1		
8	North Battleford	1	7.6	69
	Regina	1		
9	North Battleford	1	5.8	70
	Regina	1		

For the Prairie region, selecting the ICE based cogeneration system that minimizes the increase in fuel cost; the average increase in fuel cost per tonne of GHG saved is 115 CAD with a GHG reduction of 1053 kt.

For the Atlantic region, the selection of ICE based cogeneration system such that the increase in fuel costs is minimized results in the same ICE based cogeneration systems as in the case where the GHG reduction is maximized. Thus, whether maximizing the GHG reductions or minimizing the increase in fuel cost, the average increase in fuel cost per tonne of GHG saved is 839 CAD with a potential GHG reduction of 859 kt.

The same analysis is conducted using the high intensity electricity emissions factors and the results are presented in Tables 9.18 – 9.21. The results of selecting the ICE based cogeneration system for each test case house that maximizes the GHG reductions and multiplying by their associated weighing factors for the Prairie region are presented in Table 9.18.

Table 9.18: GHG Reductions using High intensity Electricity Emissions Factor – Prairie Region

Test Case House	Simulation City	System	Maximum GHG Reductions (kt)	Cost Increase (MCAD)
4	Calgary	3	582	116.2
	Edmonton	3		
5	Calgary	3	458	86.0
	Edmonton	3		
6	Calgary	3	314	50.3
	Edmonton	3		
7	North Battleford	3	225	10.5
	Regina	1		
8	North Battleford	3	182	24.0
	Regina	3		
9	North Battleford	3	157	6.7
	Regina	1		
10	Le Pas	3	188	74.2
	Winnipeg	1		
11	Le Pas	3	163	34.9
	Winnipeg	3		
12	Le Pas	3	104	30.0
	Winnipeg	1		

For the Prairie region, selecting the ICE based cogeneration system that maximizes the GHG reductions; the average increase in fuel cost per tonne of GHG saved is 182 CAD with a GHG reduction of 2373 kt. Table 9.19 presents the results for the Central region.

Table 9.19: GHG Reductions using High intensity Electricity Emissions Factor – Central Region

Test Case House	Simulation City	System	Maximum GHG Reductions (kt)	Minimum Cost Increase (MCAD)
13	Ottawa	2	658	205.7
	Toronto	2		
14	Ottawa	1	326	153.2
	Toronto	1		
15	Ottawa	2	658	62.0
	Toronto	2		
16	Montreal	1	96	252.8
	Quebec	1		
17	Montreal	1	86	140.0
	Quebec	1		
18	Montreal	1	67	120.0
	Quebec	1		

For the Central region, selecting the ICE based cogeneration system that maximizes the GHG reductions; the average increase in fuel cost per tonne of GHG saved is 494 CAD with a potential GHG reduction of 1891 kt. Table 9.20 presents the results for the Atlantic region.

Table 9.20: GHG Reductions using High intensity Electricity Emissions Factor – Atlantic Region

Test Case House	Simulation City	System	Maximum GHG Reductions (Mt)	Minimum Cost Increase (MCAD)
19	Fredericton	1	92	82.6
	Saint John	1		
20	Fredericton	1	66	54.6
	Saint John	1		
21	Fredericton	1	68	65.1
	Saint John	1		
22	Halifax	1	109	159.1
	Sydney	1		
23	Halifax	1	131	206.5
	Sydney	1		
24	Halifax	1	193	121.5
	Sydney	1		
25	Charlottetown	1	28	9.8
26	Charlottetown	1	31	9.6
27	Charlottetown	1	34	12.0
28	Goose Bay	1	83	40.2
	St. John's	1		
29	Goose Bay	1	74	33.2
	St. John's	1		
30	Goose Bay	1	54	23.5
	St. John's	1		

For the Atlantic region, selecting the ICE based cogeneration system that maximizes the GHG reductions; the average increase in fuel cost per tonne of GHG saved is 849 CAD with a potential GHG reduction of 963 kt.

Using the high intensity electricity emissions factors, the same analysis is conducted selecting the ICE based cogeneration system that results in the lowest increase in fuel cost. The results for the Prairie region are presented in Table 9.21.

Table 9.21: Minimum Cost Increase using High intensity Electricity Emissions Factor – Prairie Region

Test Case House	Simulation City	System	Minimum Cost Increase (MCAD)	GHG Reductions (kt)
4	Calgary	1	50.1	477
	Edmonton	2		
5	Calgary	2	31.3	391
	Edmonton	1		
6	Calgary	1	17.6	277
	Edmonton	2		
7	North Battleford	1	9.2	225
	Regina	1		
8	North Battleford	1	7.6	164
	Regina	1		
9	North Battleford	1	5.8	156
	Regina	1		
10	Le Pas	1	39.1	158
	Winnipeg	1		
11	Le Pas	1	34.6	162
	Winnipeg	1		
12	Le Pas	1	29.8	104
	Winnipeg	1		

For the Prairie region, selecting the ICE based cogeneration system that minimizes the increase in fuel cost; the average increase in fuel cost per tonne of GHG saved is 232 CAD with a potential GHG reduction of 969 kt.

For the remaining two regions, namely, Central and Atlantic regions, the selection of the ICE based cogeneration system such that the increase in fuel costs is minimized results in the same ICE based cogeneration system as in the case where the GHG reduction potential is maximized. Thus, whether maximizing the GHG reductions or minimizing the increase in fuel cost, the average increase in fuel cost per tonne of GHG saved is 494

CAD with a GHG reduction of 1891 kt in the Central region and 849 CAD with a GHG reduction of 963 kt in the Atlantic region.

Table 9.22 summarizes the results of the above analysis and presents the GHG reduction potential and fuel cost increase at a national level.

Table 9.22: Regional and National GHG Reductions and Fuel Cost Increase

Region	Average Electricity Emissions Factor				High Intensity Electricity Emissions Factor			
	GHG Reduction		Cost Minimization		GHG Reduction		Cost Minimization	
	GHG Reduction (kt)	Cost Increase (M$)	GHG Reduction (kt)	Cost Increase (M$)	GHG Reduction (kt)	Cost Increase (M$)	GHG Reduction (kt)	Cost Increase (M$)
Prairie	1083	201	1053	121	2373	433	969	225
Central	-	-	-	-	1891	934	1891	934
Atlantic	859	721	859	720	963	818	963	818
Canada	**1942**	**922**	**1912**	**841**	**5227**	**2185**	**3823**	**1977**

As expected, the potential GHG reductions are much higher when the high intensity electricity emissions factor is used, 5200 kt compared to 1900 kt, when the ICE based cogeneration system that results in the highest GHG reductions is used. In the Atlantic region, the same ICE based system for each test case house results in both the highest GHG emissions reduction and the lowest increase in fuel cost when evaluated using the average electricity emissions factor. The same is true in the Central and Atlantic regions using the high intensity electricity emissions factor. In the Prairie region, using the different electricity emissions factors resulted in different ICE based cogeneration systems achieving the highest GHG reductions and the lowest increase in fuel costs. As listed in Table 9.22, there is a potential for between 1900 kt – 5200 kt of GHG reductions in Canada using electricity priority controlled ICE based cogeneration in residential applications. Table 9.23 details the average cost per tonne of GHG reductions under the four cases examined here.

Table 9.23: Increased Fuel Cost per Tonne of GHG Reduction - Canada

Average Electricity Emissions Factor		High Intensity Electricity Emissions Factor	
GHG Reduction	Cost Minimization	GHG Reduction	Cost Minimization
CAD/tonne	CAD/tonne	CAD/tonne	CAD/tonne
475	440	418	517

At a national level, the most economical (in terms of fuel cost savings) way to reduce GHG emissions using ICE based cogeneration depends on the electricity emissions factor used. Using the average electricity emissions factor, selecting the ICE based cogeneration system which minimizes the increase in fuel costs results in a cost of 440 CAD per tonne of GHG reductions compared to 475 CAD per tonne of GHG reductions using the ICE based system that maximizes GHG reductions. The situation is reversed when using the high intensity electricity emissions factor where selecting the ICE based cogeneration system which maximizes the GHG reductions results in a cost of 418 CAD per tonne of GHG reductions compared to 517 CAD per tonne of GHG reductions using the ICE based system that minimizes the increase in fuel costs.

As can be seen from the annual simulation results, as well as the results at a regional level, the GHG reduction potential of using ICE based cogeneration and the associated increase in fuel costs vary from province to province. The GHG reductions realized using ICE based cogeneration is higher in provinces with high electricity emissions factors, and the increase in fuel costs using ICE based cogeneration are less in provinces with high electricity prices and low fuel prices. The GHG reduction achieved using ICE based cogeneration and the associated increase in fuel costs are most favourable in Alberta and Saskatchewan, owing to their high electricity emissions factors and low fuel prices.

To better understand the GHG reduction potential, the percentage of houses in the total housing stock considered in the above analysis and the percentage of total residential GHG emissions are presented below. Table 9.24 presents the total number of single detached houses in each region (Statistics Canada, 2005), and the total number of houses considered in the above analysis.

Table 9.24: Representation of Single Detached Homes by Test Case Houses

Region	Total Number of Houses	Number of Houses Considered	Percentage (%)
Prairies	1303050	767170	59
Central	3818305	1236146	32
Atlantic	632430	215553	34

The number of houses considered in the above analysis represent 59%, 32% and 34% of the single detached houses in the Prairie, Central and Atlantic regions respectively. The total residential GHG emissions by region are presented in Table 9.25 (Environment Canada, 2006).

Table 9.25: Total Residential GHG Emissions – by Region

Region	Residential Sector GHG Emissions (kt)
Prairies	11200
Central	24800
Atlantic	2820

Table 9.26 lists the potential percentage of residential GHG reductions assuming that all of the houses that realized a net GHG reduction using the ICE based cogeneration system install the system.

Table 9.26: Potential Percentage of Residential GHG Emissions Reduction

Region	Percentage of Houses	% of Regional Residential GHG Emissions			
		Average Electricity Emissions Factor		High Intensity Electricity Emissions Factor	
		GHG Reduction	Cost Minimization	GHG Reduction	Cost Minimization
Prairies	59	10	9	21	9
Central	32	0	0	8	8
Atlantic	34	30	30	34	34

If all of the houses in these regions which realized a net GHG emissions reduction using ICE based cogeneration actually installed the ICE based cogeneration system, residential GHG emissions would be reduced by 10 - 21%, 8% and 30 – 34% in the Prairie, Central and Atlantic regions respectively.

9.5 Discussion

Maintenance and capital costs were not considered in this analysis, but have been estimated to be between 0.005 – 0.032 $/kWh and 800 – 1300 $/kW, respectively (Onovwiona and Ugursal, 2006). While the capital cost of ICE based cogeneration systems are the lowest compared to micro-turbine, fuel cell, and Stirling engine based cogeneration systems, the maintenance costs are the highest compared to these other prime movers. For a comprehensive review of the capital and maintenance costs of various residential cogeneration systems, refer to (Onovwiona and Ugursal, 2006). In addition, the value of distributed generation was not considered in the analysis. It can be argued that using ICE based cogeneration can provide savings by reducing investment in electricity generation capacity, reducing investment in electricity transmission, and distribution infrastructure and avoiding transmission losses.

The ICE based cogeneration model used in this work is able to follow the electricity demand precisely. In reality however, an actual system would not be able to exactly follow the electrical demand of the house. Thus, either battery storage, or the ability to export to the grid would likely be required. Also, the ICE based cogeneration system did not modulate its output between time steps, rather instantaneously adjusted its output to match the demand at the give time step. It is recognized that this is not realistic behaviour, and that an actual system would continuously adjust its power output. In addition, the ICE based cogeneration model used in this study has a maximum electrical efficiency of 22.48%. It is recognized that there are commercially available system with electrical efficiencies as high as 30% (Senertec, 2005) and using these systems would likely provide a further reduction in fuel costs GHG emissions compared to the figures determined in this work.

In general, operating residential CHP systems to follow electric load is not the best way to utilize the energy generated. Especially in residential applications, electrical loads fluctuate dramatically depending on the time of day, and to a lesser extent, on the time of year. In most residential applications, there is not a large enough year round constant thermal demand to utilize all of the thermal energy generated. Unless the thermal energy can be used during the non-space heating months by a heat-driven cooling system, the annual CHP efficiency is reduced thereby reducing the potential fuel cost savings and GHG reductions potential. While electricity priority controlled residential cogeneration has its drawbacks, thermal priority controlled residential cogeneration does as well. In the case of thermal priority controlled residential cogeneration, the system is idle likely idle during much of the non-space heating season which leads to an increase in payback time. In general, implementing, sizing and controlling residential cogeneration systems continues to be a challenge and is dependent on many factors including:

- House specific thermal demands
- House specific electrical demands
- Local fuel prices and availability
- Local electricity prices
- Electricity emissions factors

- Local regulations on connecting distributed generation devices to central electricity grid
- High capital costs compared to conventional systems
- Lack knowledge and understanding regarding cogeneration among home owners

Chapter 10
Conclusions and Recommendations

10.1 Conclusions

As stated in Section 1.4, the objectives of this research project were to model a group of test case houses using a high-resolution building simulation program, to evaluate the efficiency of the ICE based cogeneration systems and its ability to meet the thermal and electrical demands of the test case houses and to determine the economical (in terms of fuel cost) and environmental impacts of using ICE based cogeneration systems for residential use in Canada. The said objectives were successfully achieved as follows:

1) Information from three Canadian databases, namely the 1993 Survey of Household Energy Use (SHEU 1993) (Statistics Canada, 1993), the EnerGuide for Houses (EGH) (NRCan, 2005a) and New Housing Survey (NHS) (NRCan, 1997) databases was used to generate 57 independent houses models to be used as test case houses. The test case house models were created using the high-resolution building simulation software ESP-r and used in subsequent simulations.

2) The houses models developed in ESP-r were used as the basis to perform a sensitivity analysis on the ICE based cogeneration model. Two different ICE capacities, namely a 1 kW and 2 kW ICE system and two different hot water storage tank sizes, namely 300 litre and 450 litre tank were simulated in all of the test case house models. To comment on the economic and environmental impacts of using ICE based cogeneration; the test case houses were first simulated using the existing equipment. The results of the base case simulations were used as the basis of comparison for the ICE based cogeneration simulations.

3) The performance in terms of electrical and CHP efficiencies of the ICE based cogeneration system in Canada was investigated. Each of the four systems was

simulated in each of the test case house models and it was determined that performance of the ICE based cogeneration systems is dependent on the thermal and electrical loads of the house, on climate, especially the severity and duration of the heating season, and on the constructional characteristics of the house.

4) The economic viability in terms of fuel cost of the ICE based cogeneration system was investigated. The flat rate electricity price for each province was determined and a time-of-use (TOU) pricing scenario was developed for each province. The economic viability of each test case house was evaluated using both the flat rate and TOU electricity pricing. It was determined that the economic viability, in terms of fuel costs, of the ICE based residential cogeneration controlled using electricity priority control is dependent on the provincial fuel and electricity prices. In provinces with relatively low fuel prices and relatively high electricity prices (e.g. Saskatchewan and Alberta) using the 1.0 kW ICE based cogeneration system resulted in an increase (< 15%) in cost in all of the test case houses. In provinces with relatively high fuel prices and low electricity prices (e.g. Quebec), the fuel cost using the ICE based cogeneration system was considerably higher (>90%) compared to the base case.

5) The potential reduction of GHG emissions using the ICE based cogeneration system was investigated. A GHG emissions analysis, including analysis on the carbon dioxide (CO_2), nitrogen oxide (N_2O) and methane (CH_4) emissions was performed on each of the test case house models for the base case scenario as well as each of the four ICE based cogeneration cases. Using both an average electricity emissions factor and a high intensity electricity emissions factor for each province (Environment Canada, 2006) as well as the emissions factors for the fuels used in this study, namely natural gas, oil and propane (CANMET, 2001) the total GHG emissions for each of the system configurations was calculated and compared the emissions profile for the base case scenario. Using

the average electricity emissions factor, it was determined that the GHG reduction potential was dependent on the provincial electricity emissions factor. In provinces where the electricity generation mix is such that the emissions factor is high, (>750 gCO_2eq/kWh), using the ICE based cogeneration system resulted in a reduction of GHGs. Specifically, the use of the ICE based cogeneration reduced GHG emissions when compared to the base case in all test case houses in Alberta, Saskatchewan, and Prince Edward Island. Using the 1.0 kW ICE based cogeneration system in New Brunswick and Nova Scotia resulted in a reduction of GHGs. In the remaining provinces, namely British Columbia, Manitoba, Ontario, Quebec and Newfoundland, the use of the ICE based cogeneration system increased the GHG emissions, as the electricity emissions factors were relatively low (<750 gCO_2eq/kWh). Using the high intensity electricity emissions factor, the use of the ICE based cogeneration reduced GHG emissions when compared to the base case in all test case houses in Alberta, Saskatchewan, Manitoba, Ontario, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland. Using the 1.0 kW ICE based cogeneration system in Quebec resulted in a reduction of GHGs. In British Columbia, the use of the ICE based cogeneration system increased the GHG emissions.

6) The annual simulation results were extrapolated to comment on the GHG reductions and associated increase in fuel costs at a regional and national level using ICE based cogeneration. Four cases were considered, selecting the ICE based cogeneration system that resulted in the highest GHG reduction compared to the base case for each test case house and selecting the ICE based cogeneration system that resulted in the lowest increase in fuel cost for each test case house, using both the average and high intensity electricity emissions factor for each province. Using the average electricity emissions factor, selecting the ICE based cogeneration system which minimized the increase in fuel costs resulted in a fuel cost increase of 440 CAD per tonne of GHG reductions compared to 475 CAD

per tonne of GHG reductions using the ICE based system that maximized GHG reductions. The situation is reversed when using the high intensity electricity emissions factor where selecting the ICE based cogeneration system which maximized the GHG reductions resulted in a fuel cost increase of 420 CAD per tonne of GHG reductions compared to 515 CAD per tonne of GHG reductions using the ICE based system that minimized the increase in fuel costs. In Canada, there is a potential for between 1900 kt – 5200 kt of GHG reductions using electricity priority controlled ICE based cogeneration in residential applications.

10.2 Recommendations

Although the test case house models created in this work use the most recently available data and are the most comprehensive house models representing the Canadian housing stock to be modeled using ESP-r, it is recommended that the following improvements could be made to better represent the energy demand and associated costs and GHG emissions of the Canadian residential sector. Note that most of the proposed recommendations are dependent on the availability of accurate data.

- The details on house construction could be updated as more recent data representative of the Canadian housing stock becomes available. Specifically, information on the windows, including orientation, window sizes and details on the properties of the glazing material could be updated to better represent the effect of windows on the thermal demand of the building.

- Information on the occupancy schedule and the associated activities could be improved. Currently, there is a lack of accurate data detailing the activities of occupants in Canadian homes. Such information is vital in determining the casual gains due to occupants, which has a significant impact on the thermal balance of the building.

- The ICE based cogeneration model used in this work is controlled using electricity priority control. To better understand the economic viability and GHG reduction potential of ICE based cogeneration in Canadian climates, a study on the feasibility of ICE based cogeneration controlled using thermal priority control could be conducted. Using the recently available ESP-r ICE based cogeneration model capable of being controlled using thermal priority control, an analogous study could be performed to be able to provide a more comprehensive picture of the feasibility of ICE based cogeneration. In addition, the control scheme used on the pumps and fan was on/off control. Investigating the use of proportional control schemes (e.g. P, PD, PID control schemes) could potentially results in better results in terms of potential cost and GHG savings.

- It is well understood that the performance of cogeneration systems is highly dependent on the utilization of the heat generated. To improve the overall CHP efficiency of the ICE based cogeneration model, a heat driven cooling cycle (e.g. desiccant cooling system) could be coupled to the ICE based cogeneration system to better utilize the heat generated in the non-space heating months. When the heat generated by the ICE based cogeneration system is fully utilized, CHP efficiencies of 80% could be achieved. By employing a heat-driven cooling system, the heat that is generated could be used during the summer months thereby improving the annual performance of an ICE based cogeneration system. However, this improvement may only be applicable in Central Canada where the need for cooling is the greatest.

- The current study simulated two ICE capacities with two thermal storage capacities for houses with an electrical demand ranging from 10,000 kWh/yr to 20,000 kWh/yr and a thermal demand ranging from 20 GJ/yr to 145 GJ/yr. Due to the wide ranges of electrical and thermal demands, the ICE based cogeneration systems simulated were potentially over or under-sized. Thus, the results of this study are intended to be a base upon which further studies can be based. Optimization of the ICE capacity, thermal storage capacity, pump and fan capacities based on the electrical and thermal demands of the test case houses will likely improve the performance of the ICE based cogeneration system.

- The electricity emissions factors used in this study were annual average values. Using electricity emissions factors based on time of day and time of year could provide more accurate estimates of GHG emissions.

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Appendix A

Database Details

Table A.1 lists the data available in the SHEU database.

Table A.1: Data available in SHEU

Inquiry Field	Description
1	Sequence number
2	Survey date
3	Province
4	Size of area of residence
5	Weight
6	Type of dwelling
7	Owner/renter
8	Number of household members
9	Number of employed household members
10	Number of household members less than 15 years of age
11	Number of household members age 15 or more
12	Number of children less than 2 years of age
13	Number of children from 2 to 5 years of age
14	Number of children from 6 to 14 years of age
15	Number of household members from 15 to 19 year of age
16	Household composition
17	Age of first member
18	Sex of first member
19	Marital status of first member
20	Relationship to head of first member
21	Labor force status of first member
22	Education of first member
23	Age of second member
24	Sex of second member
25	Marital status of second member
26	Relationship to head of second member
27	Labor force status of second member
28	Education of second member
29	Age of third member
30	Sex of third member
31	Marital status of third member

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
32	Relationship to head of third member
33	Labor force status of third member
34	Recoded education of third member
35	Collection type
36	Did you receive the guide we mailed you?
37	Best person to answer questions?
38	Have you completed the guide?
39	How many refrigerators do you use?
40	Main refrigerator: make and model flag
41	Second refrigerator: make and model flag
42	Age main refrigerator
43	Age second refrigerator
44	Doors main refrigerator
45	Doors second refrigerator
46	Size of main refrigerator
47	Size of secondary refrigerator
48	Main refrigerator frost-free or manually defrosted
49	Second refrigerator frost-free or manually defrosted
50	Automatic ice-maker in the door (main)
51	Automatic ice-maker in the door (second)
52	Cooking appliances
53	If separate cook top, what fuel
54	Other cooking appliances
55	Stove: make and model flag
56	How old is your stove/oven?
57	What fuel(s) does your stove/oven use
58	Does your oven have the self-cleaning feature?
59	How often is the self-cleaning feature used?
60	Is it a convention oven?
61	Do you use an exhaust fan in your kitchen?
62	Does it have an outdoor vent?
63	Do you use a microwave oven?
64	How often is your microwave used for reheating?
65	How often is your microwave of used for defrosting?
66	How often is your microwave used for cooking?
67	Do you use a dishwasher?

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
68	Dishwasher: make and model flag
69	How old is your dishwasher?
70	Is it built-in dishwasher?
71	Is it a compact or standard size dishwasher?
72	does your dishwasher have the air dry option
73	Is it heat dry only?
74	Do you usually dry the dishes with?
75	How many loads of dishes do you do in an average week?
76	How many freezers do you use?
77	Main freezer: make and model flag
78	Second freezer: make and model flag
79	Age of main freezer
80	Age of second freezer
81	Is your main freezer a chest or upright?
82	Is your second freezer a chest or upright?
83	What is the size of your main freezer?
84	What is the size of your second freezer?
85	Do you use a washing machine?
86	Type of washing machine
87	Washing machine: make and model flag
88	How old is your washing machine?
89	What size (tub capacity) is the washing machine?
90	Do you have a hot water temp option for washing?
91	Do you have a warm water temp option for washing?
92	Do you have a cold water temp option for washing?
93	Do you have a hot water temp option for rinsing?
94	Do you have a warm water temp option for rinsing?
95	Do you have a cold water temp option for rinsing?
96	What water temperature do you use most often for washing?
97	And for rinsing?
98	Can you choose the water level in your washing machine depending on your needs?
99	Do you use this feature?
100	On an average week in winter, how many loads of laundry do you wash?
101	Loads of laundry washes in summer?
102	Washer/dryer combination
103	Do you use a clothes dryer in your house or apartment?

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
104	Clothes dryer: make and model flag
105	What size (drum size) is your clothes dryer?
106	How old is your clothes dryer?
107	Does your clothes dryer use?
108	Does your clothes dryer have manual timer?
109	Does your clothes dryer have an automatic shut off when the clothes are dry?
110	Does your clothes dryer have cool-done or perm press setting?
111	Do you regularly use the manual timer?
112	Do you regularly use the automatic shut off?
113	Do you regularly use the cool-down or perm press setting?
114	On an average week in winter, how many loads of laundry do you dry in the clothes dryer?
115	On an average week in summer, how many loads of laundry do you dry in the clothes dryer?
116	How many color TV sets?
117	How many black and white TV sets?
118	How many VCRS?
119	How many CD players?
120	How many other separate stereo systems?
121	How many computers?
122	How many electric blankets?
123	How many waterbed heaters?
124	How many portable humidifiers?
125	How many portable dehumidifiers?
126	How many car block heaters?
127	How many interior car warmers?
128	How many water coolers?
129	How many fish tanks with pump, heater and light?
130	How many bathroom exhaust fans?
131	Apartment or house
132	Do you have a heat pump?
133	Is your heat pump air source or ground source?
134	How old is it?
135	How much power does your heat pump have (BTU)?
136	Do you use a back-up furnace with your heat pump?
137	What fuel does this furnace use?

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
138	What is the heating equipment that heats most of the house?
139	How many furnaces, boilers or woodstoves?
140	Fuel used for primary heating
141	Second fuel used by the primary heating system
142	What is the efficiency rating of the heating equipment (gas or oil only)?
143	Furnace (oven): make and model flag
144	How old is the heating equipment?
145	Do you use a central electronic air filter?
146	Do you use central electronic humidifier?
147	Do you use a central electronic dehumidifier?
148	Do you use a programmable thermostat with a timer?
149	Do you have a wood burning fireplace in your home?
150	How many wood burning fireplaces?
151	Does it have glass doors?
152	Does it have a fireplace insert?
153	How old is it?
154	About how often do you use the fireplace during the heating season?
155	Do you have a gas burning fireplace in your home?
156	How many gas burning fireplaces?
157	Supplementary heating equipment - wood stove?
158	How old is it?
159	What area is it heating?
160	On average, how often do you use it during the heating season?
161	Supplementary heating equipment - electric baseboards?
162	First area for supplementary baseboards
163	Second area for supplementary baseboards
164	Third area for supplementary baseboards
165	Supplementary heating equipment - portable heaters
166	Where was the supplementary portable heater used?
167	Fuel for supplementary portable heater
168	Any other supplementary heating
169	First area for other supplementary heating
170	Second area for other supplementary heating
171	Third area for other supplementary heating
172	Fuel for other supplementary heating

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
173	Use of supplementary heating
174	During the last heating season, would you say you used your supplementary heating system?
175	Use of wood for heating
176	How many cords of wood do you use in an average year?
177	What type of wood is it?
178	At what temp do you usually maintain most of your home during the heating season (6AM-6PM)?
179	At what temp do you usually maintain most of your home during the heating season (6PM-10PM)?
180	At what temp do you usually maintain most of your home during the heating season (10PM-6AM)?
181	How many storeys, excluding the basement does your house have?
182	What are most of the exterior walls of your house made of?
183	What other material, if any, is used on the exterior walls?
184	To your knowledge, have any improvements been made to the insulation of the walls, excluding siding?
185	Was the insulation added to the outside or put inside the wall?
186	When was the insulation added?
187	To your knowledge, have any improvements been made to the insulation of the roof or the attic, excluding replacement of the roof?
188	When were the improvements made?
189	Approximately, what is the total heated living are of your house (sq. feet), excluding basement and garage?
190	Total number of heated rooms excluding basement, attic and bathrooms?
191	Does this house have a basement?
192	What is the square footage of your basement or crawl space?
193	Are the basement walls (foundation) insulated on the inside?
194	How are the basement walls insulated?
195	To your knowledge, have any improvements been made to the insulation of the basement walls?
196	When were these improvements made?
197	Not including the carpeting or flooring, is the basement floor insulated?
198	Is it fully or partially insulated?
199	To your knowledge, have any improvements been made to the insulation of the basement floors?

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
201	Is the basement usually heated?
202	How much of the basement is area is heated?
203	Do you have a heated garage solely for the use of your household?
204	Is your garage attached to your house?
205	Is your garage under a heated room?
206	Does it have an insulated door?
207	Do you have an attic?
208	Do you have a heated solarium or sunroom?
209	Do you have any wood doors that lead to the outside or unheated areas?
210	How many wood doors with storm doors?
211	How many wood doors without storm doors?
212	Do you have any metal doors that lead to outside or unheated areas?
213	How many metal doors with storm doors?
214	How many metal doors without storm doors?
215	Do you have any patio doors that lead to outside or unheated areas?
216	How many patio doors?
217	Do you have any other exterior doors that lead to outside or unheated areas?
218	How many other exterior doors?
219	Do you feel there are any air leaks or drafts around your doors?
220	Do they all leak?
221	Were any of your exterior doors replaced?
222	When were the exterior doors replaced?
223	Have improvements been made to the weather-stripping/caulking of the doors?
224	When were the improvements made?
225	Was it done by a professional?
226	Do you have any skylights?
227	How many skylights are triple pane?
228	How many skylights are double pane?
229	How many skylights are single pane?
230	In the heated part of your house, do you have any triple pane windows?
231	How many are triple pane picture (oversized) windows?
232	How many are triple pane other size windows?
233	In the heated part of your house, do you have any double pane windows?
234	How many are double pane picture (oversized) windows?
235	How many are double pane other size windows?

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
236	In the heated part of your house, do you have any single pane windows with storm windows?
237	How many single pane picture (oversized) windows with storm windows?
238	How many are single pane other size windows with storm windows?
239	In the heated part of your house, do you have and single pane windows without storm windows?
240	How many are single pane picture (oversized) windows without storm windows?
241	How many are single pane other size windows without storm windows?
242	Excluding storm windows what are most of your window frames made of?
243	Do you feel there are any air leaks or drafts around your windows?
244	Do all of the windows leak?
245	Have any of your windows been replaced?
246	When were any of the windows replaced?
247	Have any improvements been made to the caulking or weather-stripping of the windows?
248	When were the improvements made?
249	Was it done by a professional?
250	Do you have a central ventilation system (air exchanger)?
251	Does it have heat recovery (heat exchanger)?
252	When is it used?
253	Do you use a central vacuum cleaner?
254	Do you use a sump pump?
255	Do you use a water softener?
256	Do you have a swimming pool solely for the use of your household?
257	Do you use a pool heater?
258	What kind of pool heater do you use?
259	Do you use a timer with your pool heater?
260	Do you use a solar blanket?
261	Do you have a hot tub/Jacuzzi/whirlpools?
262	How many hot tub/Jacuzzi/whirlpools indoor?
263	How many hot tub/Jacuzzi/whirlpool outdoor?
264	Do you have a sauna?
	BEGINNING OF APARTMENT SECTION
265	Approximately, what is the total heated living area of your apartment (sq. feet)?
266	Total number of heated rooms excluding bathroom?

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
267	What is the heating equipment that heats most of your apartment?
268	Fuel used by primary heating system?
269	Secondary fuel used by the primary heating system?
270	Do you have control over the temperature in your apartment?
271	At what temp do you usually maintain most of your home during the heating season (6AM-6PM)?
272	At what temp do you usually maintain most of your home during the heating season (6PM-10PM)?
273	At what temp do you usually maintain most of your home during the heating season (10PM-6AM)?
274	Do you have a wood burning fireplace in your apartment?
275	How many wood burning fireplaces in your apartment?
276	Does it have glass doors?
277	Does it have a fireplace insert?
278	How old is it?
279	About how often do you use the fireplace during the heating season?
280	Do you have a gas burning fireplace in your apartment?
281	How many gas burning fireplaces in your apartment?
282	Do you use a supplementary heating wood stove?
283	How old is the supplementary heating wood stove?
284	On average, how often do you use your supplementary Wood stove during the heating season?
285	Do you use supplementary electric baseboards?
286	Do you use supplementary portable heaters?
287	What fuel does the supplementary portable heater use?
288	Do you use other supplementary heating?
289	What fuel does the other supplementary heater use?
290	Use of supplementary heating?
291	During the last heating season, would you say you used your supplementary heating system?
292	Use of wood for heating?
293	How many cords of wood do you use in an average year?
294	What type of cord is it?
END OF APARTMENT SECTION	

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
295	Do you have central air conditioning?
296	Do you have central air conditioning?
297	Heat pump?
298	What is its cooling capacity (BTU/hr)?
299	How old is it?
300	How often did you use it last summer?
301	Do you use window or room air conditioners?
302	How many window or room air conditioners?
303	What is the cooling capacity of your first window or room unit?
304	What is the cooling capacity of your second window or room unit?
305	What is the cooling capacity of your third window or room unit?
306	For air-conditioning unit: make and model flag?
307	Second air-conditioning unit: make and model flag?
308	Third air-conditioning unit make and model flag?
309	How old is your first window or room unit?
310	How old is your second window or room unit?
311	How old is your third window or room unit?
312	How often did you use your window or room air conditioner last summer?
313	Do you use ceiling fans?
314	How many ceiling fans?
315	Do you use portable electric fans?
316	How many portable electric fans?
317	What fuel is used to heat the running water?
318	Does the water heating system serve your dwelling only or is it shared with other dwellings?
319	Do you use a how water tank (separate from furnace)?
320	How many hot water heaters?
321	How water heater: make and model flag?
322	How old is your hot water heater?
323	What size is the hot water tank?
324	Does your hot water system have an add-on insulation blanket around the outside of the hot water tank?
325	Does your hot water system have insulation around the pipes?
326	Do you use a low flow shower head in your house/apartment?
327	How many low flow shower heads?
328	Do you use an attachment on hot water faucet to reduce water flow (aerator)?

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
329	How many aerators?
330	Do you use any halogen light bulbs indoors or outdoors?
331	How many halogen light bulbs indoors?
332	How many halogen light bulbs outdoors?
333	Do you use any fluorescent lighting indoors or outdoors?
334	How many fluorescent light bulbs indoors?
335	How many fluorescent light bulbs outdoors?
336	How many ordinary (incandescent) light bulbs in your kitchen?
337	How many ordinary (incandescent) light bulbs in your living/dining area?
338	How many ordinary (incandescent) light bulbs in your bedrooms/closets?
339	How many ordinary (incandescent) light bulbs in your family room
340	How many ordinary (incandescent) light bulbs in your bathrooms?
341	How many ordinary (incandescent) light bulbs in your hallways?
342	How many ordinary (incandescent) light bulbs in your basement?
343	How many ordinary (incandescent) light bulbs in your attic?
344	How many ordinary (incandescent) light bulbs in your in other areas inside the house?
345	Total number of incandescent light bulbs indoors
346	How many incandescent light bulbs do you have in your garage?
347	How many incandescent light bulbs do you have outdoors (include spot lights)?
348	In what year was your dwelling built?
349	In what year did you or your household move in?
350	If 1992, what month did you move in?
351	To better understand the energy use in your home, please tell how many people living here are actually home during the day, on an average weekday, and please include children?
352	Do you own and use a vacation home (cottage, chalet, trailer home) in Canada?
353	How often do you usually heat it during the heating season?
354	Do you use a refrigerator?
355	What is your best estimate of the total income of all household members from all sources in 1992 before taxes and deductions?
356	Can you please tell me if you pay the bills for electricity?
357	Can you please tell me if you pay the bills for the heating oil?
358	Can you please tell me if you pay the bills for the natural gas?
359	Is natural gas available in your neighborhood?

Table A.1 Continued: Data available in SHEU

Inquiry Field	Description
360	Utility payment status
361	May we have permission to ask your energy suppliers about how much energy was used by this household in the past year?
362	Hydro supplier
363	Natural gas supplier
364	Heating oil supplier
365	Renter only, on which floor do you live
366	Renter only, how many bedrooms in your dwelling
367	Renter only, is heat included in the rent
368	Renter only, is hot water included in the rent
369	Renter only, is hot water included in the rent
370	Renter only, is cold water included in the rent
371	Renter only, is a fridge included
372	Renter only, is a stove included
373	Renter only, is a washing machine included
374	Renter only, is a clothes dryer included
375	Renter only, are other major appliances included in the rent
376	Renter only, total monthly rent

Table A.2 lists the data available in the EGH database.

Table A.2: Data available in EGH

Inquiry Field	Description
1	Year of Construction
2	City
3	Region of Country for house
4	Weather data location
5	Floor area of house [m2]
6	Footprint of house
7	Type of furnace
8	Primary heating equipment efficiency
9	Primary heating equipment fuel type
10	Heat pump source of supply
11	Heat pump coefficient of performance
12	Domestic hot water equipment type
13	Domestic hot water equipment efficiency
14	Domestic hot water equipment fuel type
15	Domestic hot water heat pump system type
16	Domestic hot water heat pump coefficient of performance
17	Canadian solar industry association rating for solar DHW systems (MJ/yr)
18	Type of house
19	Ceiling insulation RSI value
20	Foundation insulation RSI value
21	Main walls insulation RSI value
22	Number of floors
23	Total number of occupants
24	House shape
25	Temperature of the basement in degrees Celsius
26	Temperature of main floor in degrees Celsius
27	House volume in m3
28	Air leakage at 50 Pa
29	Equivalent leakage area at 10 Pa
30	Ventilation type installed
31	Consumption of electricity in kWh
32	Consumption of gas in m3
33	Consumption of oil in L
34	Consumption of propane in L
35	Total energy consumption in MJ
36	Estimated annual space heating energy consumption and ventilator electrical consumption (heating hour) heating energy in MJ

Table A.2 Continued: Data available in EGH

Inquiry Field	Description
37	Cost for consumption of electricity in CAD
38	Cost for consumption of gas in CAD
39	Cost for consumption of oil in CAD
40	Cost for consumption of propane in CAD
41	Total cost of energy consumption in CAD
42	Critical natural air change per hour
43	Critical total air change per hour
44	Heat loss to air leakage in MJ
45	Heat loss through foundation in MJ
46	Heat loss through ceilings in MJ
47	Heat loss through walls in MJ
48	Heat loss through windows and doors in MJ
49	Actual rating
50	Proposed primary heating equipment type
51	Proposed primary heating equipment efficiency
52	Proposed primary heating equipment fuel type
53	Proposed heat pump type
54	Proposed heat pump coefficient of performance
55	Proposed domestic hot water equipment type
56	Proposed domestic hot water equipment efficiency
57	Proposed domestic hot water fuel type
58	Proposed domestic hot water heat pump system type
59	Proposed domestic hot water heat pump system coefficient of performance
60	Proposed Canadian solar industry association rating for solar domestic hot water systems
61	Proposed ceiling RSI value
62	Proposed insulation foundation RSI value
63	Proposed insulation walls RSI value
64	Proposed consumption of electricity in kWh
65	Proposed consumption of gas in m3
66	Proposed consumption of oil in L
67	Proposed consumption of propane in L
68	Proposed total energy consumption in MJ
69	Proposed cost for consumption of electricity in CAD
70	Proposed cost for consumption of gas in CAD
71	Proposed cost for consumption of oil in CAD

Table A.2 Continued: Data available in EGH

Inquiry Field	Description
72	Proposed cost for consumption of propane in CAD
73	Proposed total energy cost in CAD
74	Proposed air at 50 Pa
75	Proposed heat loss to air leakage in MJ
76	Proposed heat loss to foundation in MJ
77	Proposed heat loss to ceiling in MJ
78	Proposed heat loss to walls in MJ
79	Proposed heat loss to windows and doors in MJ
80	Proposed rating
81	Year of Construction
82	City
83	Region of Country for house
84	Weather data location
85	Floor area of house [m2]
86	Footprint of house
87	Type of furnace
88	Primary heating equipment efficiency
89	Primary heating equipment fuel type
90	Heat pump source of supply
91	Heat pump coefficient of performance
92	Domestic hot water equipment type
93	Domestic hot water equipment efficiency
94	Domestic hot water equipment fuel type
95	Domestic hot water heat pump system type
96	Domestic hot water heat pump coefficient of performance
97	Canadian solar industry association rating for solar DHW systems (MJ/yr)
98	Type of house
99	Ceiling insulation RSI value
100	Foundation insulation RSI value
101	Main walls insulation RSI value
102	Number of floors
103	Total number of occupants
104	House shape
105	Temperature of the basement in degrees Celsius
106	Temperature of main floor in degrees Celsius
107	House volume in m3

Table A.2 Continued: Data available in EGH

Inquiry Field	Description
108	Air leakage at 50 Pa
109	Equivalent leakage area at 10 Pa
110	Ventilation type installed
111	Consumption of electricity in kWh
112	Consumption of gas in m3
113	Consumption of oil in L
114	Consumption of propane in L
115	Total energy consumption in MJ
116	Estimated annual space heating energy consumption and ventilator electrical consumption heating energy in MJ
117	Cost for consumption of electricity in CAD
118	Cost for consumption of gas in CAD
119	Cost for consumption of oil in CAD
120	Cost for consumption of propane in CAD
121	Total cost of energy consumption in CAD
122	Critical natural air change per hour
123	Critical total air change per hour
124	Heat loss to air leakage in MJ
125	Heat loss through foundation in MJ
126	Heat loss through ceilings in MJ
127	Heat loss through walls in MJ
128	Heat loss through windows and doors in MJ
129	Actual EGH rating
130	Decade house was built in
131	Province
132	Postal code of client
133	Previous file ID
134	Date file was created
135	Date file was modified
136	Annual energy consumption for the furnace in MJ
137	Proposed annual energy consumption for the furnace in MJ
138	Design heat loss in MJ
139	Proposed design heat loss in MJ
140	Furnace seasonal efficiency
141	Proposed furnace seasonal efficiency
142	Proposed ventilation system
143	Proposed critical natural air change per hour

Table A.2 Continued: Data available in EGH

Inquiry Field	Description
144	Heat loss to exposed floor in MJ
145	Exposed floor insulation RSI value
146	Proposed exposed floor insulation RSI value
147	Annual energy consumption for furnace in MJ
148	Design heat loss in MJ
149	Furnace seasonal efficiency
150	Heat loss to exposed floor in MJ
151	Exposed floor insulation RSI values
152	Proposed heat loss to exposed floor in MJ
153	Proposed total critical air change per hour
154	Proposed furnace seasonal efficiency
155	Furnace seasonal efficiency
156	Furnace seasonal efficiency
157	Consumption of wood in tonnes
158	Cost for consumption of wood in CAD
159	Proposed consumption of wood in tonnes
160	Proposed cost for consumption of wood in CAD
161	Consumption of wood in tonnes
162	Cost for consumption of wood in CAD
163	Proposed consumption of wood in tonnes
164	Proposed cost for consumption of wood in CAD
165	Homeowner mailing city for incentive
166	Homeowner mailing province for incentive
167	Type of housing

Table A.3 list the data available in the NHS database.

Table A.3: Data available in NHS

Inquiry Field	Description
1	What is the heating equipment that heats most of the house?
2	What is the efficiency rating of the heating equipment?
3	Do you have a heat pump?
4	Is your heat pump air source or ground source?
5	Does your house use a back-up furnace with your heat pump?
6	What fuel does the back-up furnace use?
7	Some heating systems have additional features, does yours have?
7a	Central electronic air filter
7b	Central humidifier
7c	Central dehumidifier
8	Do you have a wood burning fireplace in your home?
9	Does it have glass doors?
10	Does it have a fireplace insert?
11	About how often do you use the wood burning fireplace during the heating season?
12	Do you have a fireplace(s) in your home other than a wood burning fireplace?
12a	What area(s) is it heating?
12b	What fuel is used?
13	Do you use a wood stove?
13a	What area is it heating?
14	How many cords of wood do you use in an average year?
15	What type of cord is it?
16	Aside from your main heating system, do you use any of the following?
16a	Electric baseboard heaters
16b	Portable heaters
16c	Wood stove
16d	Fireplace (not wood burning)
16e	Other supplementary heaters
17	During the last heating season, would you say you used your supplementary heaters?
18	Do you use a programmable thermostat with at timer to change the temperature in your house?
19	During the heating season, at what temperature do you maintain most of your home?
19a	Daytime (6am-6pm)
19b	Evening (6pm-10pm)

Table A.3 Continued: Data available in NHS

Inquiry Field	Description
19c	Over night (10pm-6am)
20	How many storeys, excluding the basement, does your house have?
21	What are most of the exterior walls of your house made of?
22	What percentage of your exterior walls are covered with the surface mentioned in question 21?
23	What other material, if any, is used on the exterior walls?
24	Looking at the main structure of your home, is it mainly?
25	What is the r value of the insulation in your outside walls?
25a	What is the overall thickness of a typical outside wall in your house?
25b	If your house is primarily a wood or steel frame house, what is the size of framing in the outside walls?
26	What type of insulation do you have in your outside walls?
27	Approximately, what is the total heated living area of your house excluding basement and garage?
28	What is the combined square footage of your basement and/or crawl space?
29	Looking at the layout of your house, about what percentage of the ground floor living area is over?
29a	If any of your living area is slab on grade, does it have?
30	How are the basement and exterior basement walls insulated?
31	What percentage of the basement wall area is insulated?
32	What type of insulation, if any, is in the basement walls?
33	And, on average, how thick is the insulation in your basement walls?
34	About what percentage of the basement wall area is above grade?
35	Is the basement usually heated?
36	About what percentage of the basement area is heated?
37	About what percentage of your basement is finished?
38	Do you have a separate thermostat in your basement?
39	During the heating season, what would you say is the average temperature of the heated portion of your basement and the unheated portion?
40	Do you have the crawl space?
41	About what percentage of the crawl space area is heated?
42	Do you have a separate thermostat in your crawl space?
43	How is the crawl space insulated?
44	What percentage of the wall area of the crawl space is insulated?
45	What type of insulation, if any, is in the crawl space walls?
46	On average, how thick is the insulation, if any, in the crawl space?

Table A.3 Continued: Data available in NHS

Inquiry Field	Description
47	What type of insulation, if any, is in the crawl space ceiling?
48	On average, how thick is the insulation, if any, in the crawl space ceiling?
49	About what percentage of the crawl space area is above grade?
50	Does your house have a garage?
51	Is the garage heated?
52	Is the garage attached to your home?
53	Is the garage under a heated room or part of your basement?
54	In some garages the vehicle entry door is insulated with fibreglass or foam board attached to the inside of the door. Does your garage have an insulated vehicle entry door?
55	Does your house have an attic?
56	What type of insulation do you have over the ceilings in your home?
57	And on average, how thick is the insulation above your ceilings?
58	What direction the front of your house faces?
59	How many windows on the front of your house?
60	How many patio doors, skylights, or bay windows on the front of your house?
61	Not including any patio doors, skylights, or bay windows, how many windows of each of the following size categories are on the front of your house?
61a	In the basement
61b	In the main floors
62	How many windows on the back of your house?
63	How many patio doors, skylights, or bay windows on the back of your house?
64	Not including any patio doors, skylights, or bay windows, how many windows of each of the following size categories are on the back of your house?
64a	In the basement
64b	In the main floors
65	How many windows on the left of your house?
66	How many patio doors, skylights, or bay windows on the left of your house?
67	Not including any patio doors, skylights, or bay windows, how many windows of each of the following size categories are on the left of your house?
67a	In the basement
67b	In the main floors
68	How many windows on the right of your house?
69	How many patio doors, skylights, or bay windows on the right of your house?
70	Not including any patio doors, skylights, or bay windows, how many windows of each of the following size categories are on the right of your house?

Table A.3 Continued: Data available in NHS

Inquiry Field	Description
70a	In the basement?
70b	In the main floors?
71	In the main floors, how many windows of each of the following types do you have?
72	In the basement area, how many windows of each of the following types do you have?
73	Do you feel there are any air leaks or drafts around your windows?
74	Do you have a heated solarium or sunroom?
75	Do you have a central ventilation system, also known as an air heat exchanger?
76	Do you have central air conditioning in your house?
77	How often did you use your central air conditioner last summer?
78	Do you use window or room air conditioners?
79	Last summer, how often did you use your first window or room air conditioner?
80	What fuel is used to heat the running water in your home?
81	Is your space heating shared with other dwellings?
81a	Is your water heating system shared with other dwellings?
82	Do you use hot water tank separate from the furnace?
83	What size is the hot water tank?
84	Does your hot water system have?
85	Are any of the following energy savings devices used in your home?
86	If your house lot has a pool, do you use a pool heater?
87	Do you have a hot tub/Jacuzzi/whirlpool?
88	Do you have a sauna?
89	Is your home classified as an R2000 home?
90	Billing information?
91	Builder information?
92	Which category best describes your total household income?
93	What is the highest level of formal education attained by any of the adults in your household?
94	How many people live in your house who are?
95	In what month and year did you move into your house?
96	Is this your only home or do you also have another residence?
97	How many weeks during each season is the house usually vacant?
98	And during the weekdays, throughout the year, is someone usually home during the daytime?

Appendix B

Averaging Techniques

Although the SHEU database is very comprehensive, there were cases where data was missing or out of the range expected making it invalid. In this case, the sum of the weights had to be adjusted to reflect missing or invalid data. Calculating the average value of an incomplete dataset is illustrated below.

Table B.1: Sample Data Set for Averaging Example

House #	Weighting Factor	Efficiency	Area (ft^2)
1	70	0.9	300
2	200	0.8	700
3	4700	0.85	**data missing**
4	850	0.77	600
5	962	0.69	1100
6	1011	0.92	1300

In the above sample dataset, the sum of the weights is:

$$\sum W_{SHEU} = 7793$$

The weighted average for efficiency, or a complete dataset is calculated using the following equation:

$$\bar{\eta} = \frac{(70\times0.9)+(200\times0.8)+(4700\times0.85)+(850\times0.77)+(962\times0.69)+(1011\times0.92)}{7793}$$

$$\bar{\eta} = 0.83$$

In order to calculate the average area – an incomplete dataset, the following equation is used:

$$\bar{A} = \frac{(70\times300)+(200\times700)+(850\times600)+(962\times1100)+(1011\times1300)}{(7793-4700)}$$

Total W_i Sum → (7793) ; ← W_i of missing or invalid data point (4700)

$$\bar{A} = 984\ \text{ft}^2$$

There were several variables in the SHEU database that could not be handled using a weighted average approach. The average of indicator variables, variables that represented qualitative rather than quantitative characteristics, had to be determined by using the method explained below. First is an example of a case where the standard weighted averaged approach does not yield a meaningful result.

Assume that Table B.2 is the part of the SHEU database that describes the domestic hot water fuel type. Where the indicator variable 1 represents electricity, 2 represents oil, 3 represents natural gas and 4 represents propane.

Table B.2: Example Data Set for Indicator Variable Example

House #	DHW Fuel	Weights	Individual weighted value
1	1	1023	0.075
2	3	998	0.219
3	1	566	0.041
4	1	3902	0.285
5	1	1408	0.103
6	3	924	0.203
7	3	1789	0.392
8	3	1968	0.432
9	1	1098	0.080
Sum	-	13676	-
Weighted Average			**2**

Notice that although not one house uses oil (2) as the DHW fuel, the results of the weighted averaging procedure yield oil (2) as the DHW fuel.

In cases where indicator variables were used to define the test case house characteristics, a different method was employed. Rather than taking a weighted average, the data was sorted into individual categories, in this example, into the 4 fuel categories and then their associated weights were summed to see which fuel was most representative. This fuel then became the DHW fuel in the test case house. Below is a brief example illustrating the procedure.

The data in Table B.2 was sorted into categories and the sum of the respective weights calculated as shown in Table B.3.

Table B.3: Example Data Set for Indicator Variable Example

DHW Fuel	Weight	Electricity	Weight	Oil	Weight	Natural Gas	Weight	Propane	Weight
1	1023	1	1023	-	-	3	998	-	-
1	566	1	566			3	924		
1	3902	1	3902			3	1789		
1	1408	1	1408			3	1968		
1	1098	1	1098						
3	998								
3	924								
3	1789								
3	1968								
Sum of weights			**7997**		0		5679		0

From the sum of weights, it can be concluded that the most representative DHW fuel is electricity (1). This approach was used for averaging all indicator variables, as listed in Tables 5.15 – 5.17.

For the number of doors and windows in each test case house, one further step was employed. The sum of the individual weights for each category (e.g. the number of 2 pane windows) was divided by the total sum of the weights in the group. In order for a specific type of window or door to be included in the test case house, more than 50% (based on weights) of the houses had to have this type of window or door. This limit was imposed to avoid getting a cumulative effect rather than an averaged representation.

Appendix C

Test Case House Descriptions

Tables C.1 – C.31 list the construction, equipment, infiltration, and temperature set point data for the 30 test case houses.

Table C.1: Test Case House 1 – Specifications

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	3 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.75
Foundation RSI (Km^2/W)	1.82
Ceiling RSI (Km^2/W)	3.91
Roof RSI (Km^2/W)	0.26
Attic	full attic
External Wall Material	wood
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	77.3
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	51.1
Basement Heating	whole basement heated
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	8.07

Table C.2: Test Case House 1 – Window Data

Number of 3 Pane Large	0
Number of 3 Pane Regular	0
Number of 2 Pane Large	1
Number of 2 Pane Regular	7
Number of 1 Pane Large	3
Number of 1 Pane Regular	11
Number of Front Basement	0
Number of Back Basement	1
Number of Left Basement	1
Number of Right Basement	1
Number of Front Main	6
Number of Back Main	7
Number of Left Main	3
Number of Right Main	3
Number of Windows in Basement	3
Number of Windows in Main	19

Table C.3: Test Case House 2 – Specifications and Window Data

House Orientation	South
House Size (m^2)	163
Number of Storeys	2
Number and Construction of Doors	2 - metal, 2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	2.06
Foundation RSI (Km^2/W)	3.49
Ceiling RSI (Km^2/W)	4.76
Roof RSI (Km^2/W)	0.26
Attic	full attic
External Wall Material	vinyl siding
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	77.7
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	50.6
Basement Heating	whole basement heated
Number of Occupants	4
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	6.76
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	13
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	1
Number of Front Main Windows	4
Number of Back Main Windows	5
Number of Left Main Windows	2
Number of Right Main Windows	2
Number of Windows in Basement	2
Number of Windows in Main	13

Table C.4: Test Case House 3 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.55
Foundation RSI (Km^2/W)	2.37
Ceiling RSI (Km^2/W)	3.45
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	stucco
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	76.4
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	0.55
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	19
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	10.18
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	3
Number of 2 Pane Regular Windows	7
Number of 1 Pane Large Windows	1
Number of 1 Pane Regular Windows	5
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	4
Number of Back Main Windows	5
Number of Left Main Windows	2
Number of Right Main Windows	2
Number of Windows in Basement	3
Number of Windows in Main	13

Table C.5: Test Case House 4 – Specifications and Window Data

House Orientation	North
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.91
Foundation RSI (Km^2/W)	1.25
Ceiling RSI (Km^2/W)	4.23
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	stucco
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	74.9
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	55
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	4.32
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	6
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	1
Number of Front Main Windows	2
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	6

Table C.6: Test Case House 5 – Specifications and Window Data

House Orientation	North
House Size (m^2)	163
Number of Storeys	1
Number and Construction of Doors	2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	2.35
Foundation RSI (Km^2/W)	1.86
Ceiling RSI (Km^2/W)	5.01
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	vinyl siding
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	76.2
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	55.1
Basement Heating	whole basement
Number of Occupants	4
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	4.28
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	9
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	3
Number of Back Main Windows	3
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	3
Number of Windows in Main	8

Table C.7: Test Case House 6 – Specifications and Window Data

House Orientation	North
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.69
Foundation RSI (Km^2/W)	0.95
Ceiling RSI (Km^2/W)	4.19
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	stucco
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	74.9
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	54.8
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	6.04
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	5
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	1
Number of Front Main Windows	1
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	5

Table C.8: Test Case House 7 – Specifications and Window Data

House Orientation	East
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.89
Foundation RSI (Km^2/W)	1.4
Ceiling RSI (Km^2/W)	4.67
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	73.1
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	54.6
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	4.09
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	6
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	0
Number of Front Main Windows	1
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	5

Table C.9: Test Case House 8 – Specifications and Window Data

House Orientation	East
House Size (m^2)	163
Number of Storeys	1
Number and Construction of Doors	2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	2.66
Foundation RSI (Km^2/W)	2.13
Ceiling RSI (Km^2/W)	6
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	75
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	54.8
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	3.21
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	9
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	0
Number of Front Main Windows	2
Number of Back Main Windows	4
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	8

Table C.10: Test Case House 9 – Specifications and Window Data

House Orientation	East
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.76
Foundation RSI (Km^2/W)	1.2
Ceiling RSI (Km^2/W)	4.18
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	73.1
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	54.6
Basement Heating	whole basement
Number of Occupants	2
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	5.57
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	6
Number of 1 Pane Large Windows	1
Number of 1 Pane Regular Windows	7
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	3
Number of Back Main Windows	6
Number of Left Main Windows	1
Number of Right Main Windows	2
Number of Windows in Basement	3
Number of Windows in Main	12

Table C.11: Test Case House 10 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood, 2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	1.84
Foundation RSI (Km^2/W)	1.27
Ceiling RSI (Km^2/W)	4.64
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	stucco
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	78
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	54.3
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (ºC)	20
Temperature Set 2: 6PM-10PM (ºC)	21
Temperature Set 3: 10PM-6AM (ºC)	19
ACH @ 50 PA	3.5
Number of 3 Pane Large Windows	1
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	5
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	0
Number of Front Main Windows	2
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	6

Table C.12: Test Case House 11 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 -wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.43
Foundation RSI (Km^2/W)	1.13
Ceiling RSI (Km^2/W)	4.04
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	stucco
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	78
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	58.2
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	21
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	20
ACH @ 50 PA	5.34
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	5
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	7
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	3
Number of Back Main Windows	4
Number of Left Main Windows	2
Number of Right Main Windows	1
Number of Windows in Basement	3
Number of Windows in Main	10

Table C.13: Test Case House 12 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	3 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.41
Foundation RSI (Km^2/W)	0.85
Ceiling RSI (Km^2/W)	3.29
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	78
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	59.2
Basement Heating	whole basement
Number of Occupants	2
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	9
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	5
Number of 1 Pane Large Windows	1
Number of 1 Pane Regular Windows	7
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	4
Number of Back Main Windows	4
Number of Left Main Windows	2
Number of Right Main Windows	1
Number of Windows in Basement	3
Number of Windows in Main	11

Table C.14: Test Case House 13 – Specifications and Window Data

House Orientation	South
House Size (m^2)	163
Number of Storeys	2
Number and Construction of Doors	2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	2.28
Foundation RSI (Km^2/W)	1.79
Ceiling RSI (Km^2/W)	5.06
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	brick
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	82.4
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	55.6
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	4.56
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	9
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	0
Number of Front Main Windows	4
Number of Back Main Windows	3
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	9

Table C.15: Test Case House 14 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	2
Number and Construction of Doors	3 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.13
Foundation RSI (Km^2/W)	0.97
Ceiling RSI (Km^2/W)	2.86
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	brick
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	81.6
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	57.4
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	11.48
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	6
Number of 1 Pane Large Windows	1
Number of 1 Pane Regular Windows	12
Number of Front Basement Windows	1
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	6
Number of Back Main Windows	6
Number of Left Main Windows	2
Number of Right Main Windows	2
Number of Windows in Basement	4
Number of Windows in Main	16

Table C.16: Test Case House 15 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.4
Foundation RSI (Km^2/W)	1.1
Ceiling RSI (Km^2/W)	3.58
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	brick
Space Heating Equipment Type	furnace w/ cont. pilot
Space Heating Equipment Efficiency (%)	81.5
Space Heating Fuel Type	natural gas
DHW Tank Size (L)	180
DHW Equipment Type	conventional w/ pilot
DHW Fuel	natural gas
DHW Efficiency (%)	57.1
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	21
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	8.33
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	5
Number of 1 Pane Large Windows	1
Number of 1 Pane Regular Windows	7
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	5
Number of Back Main Windows	4
Number of Left Main Windows	2
Number of Right Main Windows	1
Number of Windows in Basement	3
Number of Windows in Main	12

Table C.17: Test Case House 16 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood, 1 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	1.97
Foundation RSI (Km^2/W)	1.3
Ceiling RSI (Km^2/W)	3.92
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	brick
Space Heating Equipment Type	furnace
Space Heating Equipment Efficiency (%)	73.9
Space Heating Fuel Type	oil
DHW Tank Size (L)	230
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	74.3
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	5.92
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	7
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	0
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	0
Number of Front Main Windows	2
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	6

Table C.18: Test Case House 17 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	2
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.59
Foundation RSI (Km^2/W)	0.74
Ceiling RSI (Km^2/W)	3.09
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	aluminium siding
Space Heating Equipment Type	furnace
Space Heating Equipment Efficiency (%)	74.5
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	77.3
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	21
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	20
ACH @ 50 PA	10.31
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	4
Number of 2 Pane Regular Windows	9
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	7
Number of Front Basement Windows	1
Number of Back Basement Windows	2
Number of Left Basement Windows	2
Number of Right Basement Windows	1
Number of Front Main Windows	6
Number of Back Main Windows	5
Number of Left Main Windows	2
Number of Right Main Windows	1
Number of Windows in Basement	6
Number of Windows in Main	14

Table C.19: Test Case House 18 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood, 2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	1.69
Foundation RSI (Km^2/W)	0.91
Ceiling RSI (Km^2/W)	3.47
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	brick
Space Heating Equipment Type	furnace
Space Heating Equipment Efficiency (%)	73.7
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	76.2
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	7.5
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	10
Number of 1 Pane Large Windows	2
Number of 1 Pane Regular Windows	9
Number of Front Basement Windows	1
Number of Back Basement Windows	2
Number of Left Basement Windows	2
Number of Right Basement Windows	1
Number of Front Main Windows	7
Number of Back Main Windows	5
Number of Left Main Windows	2
Number of Right Main Windows	2
Number of Windows in Basement	6
Number of Windows in Main	16

Table C.20: Test Case House 19 – Specifications and Window Data

House Orientation	East
House Size (m^2)	116
Number of Storeys	1.5
Number and Construction of Doors	3 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.22
Foundation RSI (Km^2/W)	0.33
Ceiling RSI (Km^2/W)	2.28
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace
Space Heating Equipment Efficiency (%)	73.8
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	78.3
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	21
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	11.72
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	7
Number of 1 Pane Large Windows	2
Number of 1 Pane Regular Windows	10
Number of Front Basement Windows	1
Number of Back Basement Windows	2
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	6
Number of Back Main Windows	5
Number of Left Main Windows	2
Number of Right Main Windows	2
Number of Windows in Basement	5
Number of Windows in Main	15

Table C.21: Test Case House 20 – Specifications and Window Data

House Orientation	East
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.83
Foundation RSI (Km^2/W)	0.53
Ceiling RSI (Km^2/W)	3.62
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace
Space Heating Equipment Efficiency (%)	73.1
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	76.9
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	6.31
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	8
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	1
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	0
Number of Front Main Windows	3
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	3
Number of Windows in Main	7

Table C.22: Test Case House 21 – Specifications and Window Data

House Orientation	East
House Size (m^2)	116
Number of Storeys	1.5
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.52
Foundation RSI (Km^2/W)	1
Ceiling RSI (Km^2/W)	2.84
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	vinyl siding
Space Heating Equipment Type	furnace
Space Heating Equipment Efficiency (%)	73.7
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	78
Basement Heating	whole basement
Number of Occupants	2
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	19
ACH @ 50 PA	7.97
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	3
Number of 2 Pane Regular Windows	6
Number of 1 Pane Large Windows	1
Number of 1 Pane Regular Windows	8
Number of Front Basement Windows	1
Number of Back Basement Windows	2
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	5
Number of Back Main Windows	5
Number of Left Main Windows	1
Number of Right Main Windows	2
Number of Windows in Basement	5
Number of Windows in Main	13

Table C.23: Test Case House 22 – Specifications and Window Data

House Orientation	North
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood, 2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	1.84
Foundation RSI (Km^2/W)	0.83
Ceiling RSI (Km^2/W)	3.19
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ flame ret. Head
Space Heating Equipment Efficiency (%)	78.7
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	Oil
DHW Efficiency (%)	56
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	6.84
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	8
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	1
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	1
Number of Front Main Windows	3
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	3
Number of Windows in Main	7

Table C.24: Test Case House 23 – Specifications and Window Data

House Orientation	North
House Size (m^2)	116
Number of Storeys	1.5
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.19
Foundation RSI (Km^2/W)	0.3
Ceiling RSI (Km^2/W)	1.82
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ flame ret. Head
Space Heating Equipment Efficiency (%)	78.5
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	Oil
DHW Efficiency (%)	61.2
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	12.01
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	6
Number of 1 Pane Large Windows	1
Number of 1 Pane Regular Windows	9
Number of Front Basement Windows	2
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	6
Number of Back Main Windows	4
Number of Left Main Windows	2
Number of Right Main Windows	1
Number of Windows in Basement	5
Number of Windows in Main	13

Table C.25: Test Case House 24 – Specifications and Window Data

House Orientation	North
House Size (m^2)	116
Number of Storeys	1.5
Number and Construction of Doors	2 -wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.36
Foundation RSI (Km^2/W)	0.63
Ceiling RSI (Km^2/W)	2.38
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ flame ret. Head
Space Heating Equipment Efficiency (%)	78.7
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	59.9
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	8.77
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	7
Number of 1 Pane Large Windows	1
Number of 1 Pane Regular Windows	10
Number of Front Basement Windows	2
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	6
Number of Back Main Windows	5
Number of Left Main Windows	2
Number of Right Main Windows	1
Number of Windows in Basement	5
Number of Windows in Main	14

Table C.26: Test Case House 25 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	2.49
Foundation RSI (Km^2/W)	0.81
Ceiling RSI (Km^2/W)	4.57
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	vinyl siding
Space Heating Equipment Type	furnace with flame ret. Head
Space Heating Equipment Efficiency (%)	79
Space Heating Fuel Type	Oil
DHW Tank Size (L)	NA
DHW Equipment Type	Tankless Coil
DHW Fuel	Oil
DHW Efficiency (%)	46.1
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	19
Temperature Set 2: 6PM-10PM (°C)	20
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	5.28
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	10
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	1
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	1
Number of Front Main Windows	3
Number of Back Main Windows	3
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	3
Number of Windows in Main	8

Table C.27: Test Case House 26 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	2.03
Foundation RSI (Km^2/W)	0.597
Ceiling RSI (Km^2/W)	3.58
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	vinyl siding
Space Heating Equipment Type	furnace w/ flame ret. Head
Space Heating Equipment Efficiency (%)	78.7
Space Heating Fuel Type	Oil
DHW Tank Size (L)	NA
DHW Equipment Type	tankless coil
DHW Fuel	Oil
DHW Efficiency (%)	49.2
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (ºC)	20
Temperature Set 2: 6PM-10PM (ºC)	20
Temperature Set 3: 10PM-6AM (ºC)	18
ACH @ 50 PA	5.69
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	7
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	1
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	0
Number of Front Main Windows	3
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	0
Number of Windows in Basement	2
Number of Windows in Main	6

Table C.28: Test Case House 27 – Specifications and Window Data

House Orientation	South
House Size (m^2)	116
Number of Storeys	1.5
Number and Construction of Doors	2 - wood
Basement	full basement
Main Wall RSI (Km^2/W)	1.53
Foundation RSI (Km^2/W)	0.22
Ceiling RSI (Km^2/W)	1.91
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ flame ret. Head
Space Heating Equipment Efficiency (%)	77.7
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	Conventional
DHW Fuel	Oil
DHW Efficiency (%)	54.3
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	11.76
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	6
Number of 1 Pane Large Windows	2
Number of 1 Pane Regular Windows	9
Number of Front Basement Windows	2
Number of Back Basement Windows	1
Number of Left Basement Windows	1
Number of Right Basement Windows	1
Number of Front Main Windows	6
Number of Back Main Windows	5
Number of Left Main Windows	2
Number of Right Main Windows	1
Number of Windows in Basement	5
Number of Windows in Main	14

Table C.29: Test Case House 28 – Specifications and Window Data

House Orientation	East
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood, 2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	1.9
Foundation RSI (Km^2/W)	3.83
Ceiling RSI (Km^2/W)	3.24
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ flame ret. Head
Space Heating Equipment Efficiency (%)	78.4
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	67.4
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	20
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	17
ACH @ 50 PA	6.51
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	7
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	1
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	0
Number of Front Main Windows	2
Number of Back Main Windows	2
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	6

Table C.30: Test Case House 29 – Specifications and Window Data

House Orientation	East
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	1 - wood, 2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	1.59
Foundation RSI (Km^2/W)	3.85
Ceiling RSI (Km^2/W)	2.94
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	vinyl siding
Space Heating Equipment Type	furnace w/ flame ret. Head
Space Heating Equipment Efficiency (%)	78.6
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	68.8
Basement Heating	whole basement
Number of Occupants	3
Temperature Set 1: 6AM-6PM (°C)	21
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	8.43
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	1
Number of 2 Pane Regular Windows	6
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	1
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	0
Number of Front Main Windows	2
Number of Back Main Windows	2
Number of Left Main Windows	0
Number of Right Main Windows	1
Number of Windows in Basement	2
Number of Windows in Main	5

Table C.31: Test Case House 30 – Specifications and Window Data

House Orientation	East
House Size (m^2)	116
Number of Storeys	1
Number and Construction of Doors	2 - wood, 2 - metal
Basement	full basement
Main Wall RSI (Km^2/W)	2.47
Foundation RSI (Km^2/W)	4.66
Ceiling RSI (Km^2/W)	4.36
Roof RSI (Km^2/W)	0.26
Attic	yes
External Wall Material	wood
Space Heating Equipment Type	furnace w/ flame ret. Head
Space Heating Equipment Efficiency (%)	80.3
Space Heating Fuel Type	Oil
DHW Tank Size (L)	180
DHW Equipment Type	conventional
DHW Fuel	electricity
DHW Efficiency (%)	67.9
Basement Heating	whole basement
Number of Occupants	4
Temperature Set 1: 6AM-6PM (°C)	21
Temperature Set 2: 6PM-10PM (°C)	21
Temperature Set 3: 10PM-6AM (°C)	18
ACH @ 50 PA	5.42
Number of 3 Pane Large Windows	0
Number of 3 Pane Regular Windows	0
Number of 2 Pane Large Windows	2
Number of 2 Pane Regular Windows	9
Number of 1 Pane Large Windows	0
Number of 1 Pane Regular Windows	0
Number of Front Basement Windows	1
Number of Back Basement Windows	1
Number of Left Basement Windows	0
Number of Right Basement Windows	1
Number of Front Main Windows	3
Number of Back Main Windows	3
Number of Left Main Windows	1
Number of Right Main Windows	1
Number of Windows in Basement	3
Number of Windows in Main	8

Appendix D

ESP-r Multi-Layer Construction Database

Test Case House Multi-Layer Construction Database:

MLC Description: External Wall
MLC Name: Ex_Wall
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	4	0.1	Outer Leaf Brick
2	0	0.025	Air (0.17 0.17 0.17)
3	67	0.011	Chipboard
4	281	0.14	Glass Fibre Quilt
5	72	0.012	Plywood

MLC Description: Single Pane Window
MLC Name: 1_Pane
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	242	0.003	Plate Glass

MLC Description: Double Pane Window
MLC Name: 2_Pane
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	242	0.003	Plate Glass
2	0	0.013	Air (0.17 0.17 0.17)
3	242	0.003	Plate Glass

MLC Description: Triple Pane Window
MLC Name: 3_Pane
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	242	0.003	Plate Glass
2	0	0.013	Air (0.17 0.17 0.17)
3	242	0.003	Plate Glass
4	0	0.013	Air (0.17 0.17 0.17)
5	242	0.003	Plate Glass

MLC Description: Ceiling
MLC Name: Ceiling
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	107	0.0127	Gypsum Plasterboard
2	219	0.25	Thermalite Turbo Block
3	72	0.025	Plywood

MLC Description: Inverted Ceiling
MLC Name: Ceiling_inv
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	72	0.025	Plywood
2	219	0.25	Thermalite Turbo Block
3	107	0.0127	Gypsum Plasterboard

MLC Description: Floor
MLC Name: Floor
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	225	0.015	Synthetic Carpet
2	65	0.025	Flooring
3	0	0.01	Air (0.17 0.17 0.17)
4	70	0.017	Plywood

MLC Description: Inverted Floor
MLC Name: Floor_inv
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	70	0.017	Plywood
2	0	0.01	Air (0.17 0.17 0.17)
3	65	0.025	Flooring
4	225	0.015	Synthetic Carpet

MLC Description: Steel Door
MLC Name: External Steel Door
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	283	0.005	Light Steel Door
2	205	0.025	Polyurethane Foam Board
3	283	0.005	Light Steel Door

MLC Description: Wood
MLC Name: Wood Door
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	69	0.025	Oak (radial)

MLC Description: Slab Floor
MLC Name: Slab
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	263	0.1	Common Earth
2	82	0.1	Red Granite
3	32	0.05	Heavy Mix Concrete
4	124	0.05	Cement Screed

MLC Description: Roof
MLC Name: Roof

MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	163	0.05	Asphalt Mastic Roof
2	72	0.012	Plywood

MLC Description: Foundation
MLC Name: Foundation
MLC Details:

Layer #	Reference #	Thickness (m)	Material Name
1	21	0.2	Light Mix Concrete
2	107	0.0135	Gypsum Plasterboard

Appendix E
DHW Heat Injector Rate Calculations

Table E.1 details the heat injector input based on fuel type and tank size as well as the number of bathrooms and bedrooms (ASHRAE, 1999).

Table E.1: DHW Data

Number of Baths	1 to 1.5			2 to 2.5				3 to 3.5			
Number of Bedrooms	1	2	3	2	3	4	5	3	4	5	6
GAS[a]											
Storage, L	76	114	114	114	150	150	190	150	190	190	190
kW input	7.9	10.5	10.5	10.5	10.5	11.1	13.8	11.1	11.1	13.8	14.6
1-h draw, L	163	227	227	227	265	273	341	273	311	341	350
Recovery, mL/s	24	32	32	32	32	36	42	34	34	42	44
ELECTRIC[a]											
Storage, L	76	114	150	150	190	190	250	190	250	250	300
kW input	2.5	3.5	4.5	4.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
1-h draw, L	114	167	220	220	273	273	334	273	334	334	387
Recovery, mL/s	10	15	19	19	23	23	23	23	23	23	23
OIL[a]											
Storage, L	114	114	114	114	114	114	114	114	114	114	114
kW input	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5
1-h draw, L	337	337	337	337	337	337	337	337	337	337	337
Recovery, mL/s	62	62	62	62	62	62	62	62	62	62	62
TANK-TYPE INDIRECT[b,c]											
I-W-H-rated draw, L in 3 h, 55 K rise		150	150		250	250[e]	250	250	250	250	250
Manufacturer-rated draw, L in 3 h, 55 K rise		186	186		284	284[e]	284	284	284	284	284
Tank capacity, L		250	250		250	250[e]	310	250	310	310	310
TANKLESS-TYPE INDIRECT[c,d]											
I-W-H-rated draw, mL/s, 55 K rise		170	170		200	200[e]	240	200	240	240	240
Manufacturer-rated draw, L in 5 min, 55 K rise		57	57		95	95[e]	133	95	133	133	133

The data from Table E.1 was used to determine the DHW heat injector rate based on fuel type and tank size, as these two variables were available in the SHEU database.

Table E.2 summarizes the data available for natural gas fired DHW tanks.

Table E.2: DHW Data – Natural Gas

Tank Size (L)	kW Input (kW)	Average kW Input
76	7.9	7.9
114	10.5	10.5
150	10.5	10.8
150	11.1	
190	13.8	13.17
190	11.1	
190	14.6	

Figure E.1 was generated using the data in Table E.2, and the resulting trend line equation used to determine the heat injector rate for the tank sizes used in the test case houses, namely 140L, 180L, and 230L.

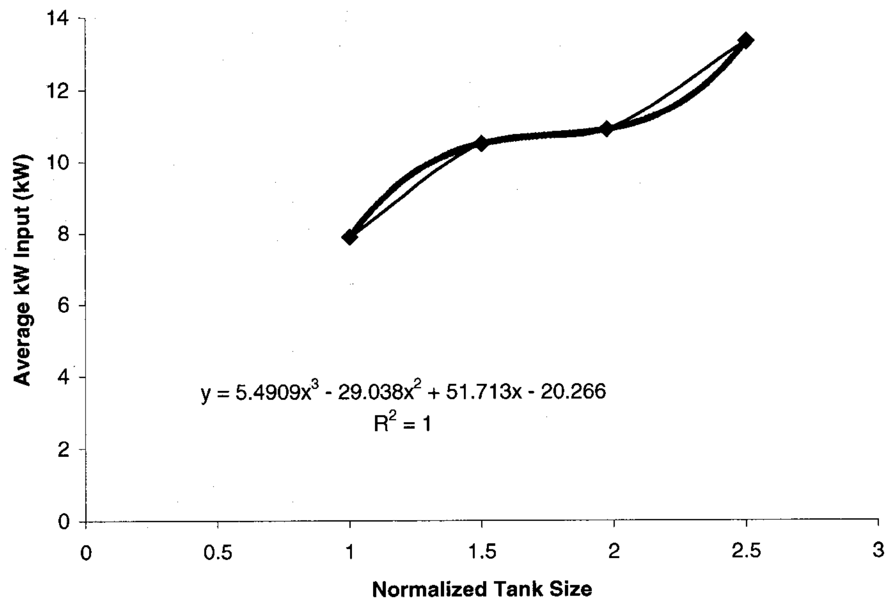

Figure E.1: Normalized Tank Size vs. Average kW Input – Natural Gas

Table E.3 details the heat injector rates used for different tank sizes. The bolded values are the values used for the test case house tank sizes.

Table E.3: Heat Injector Rate – Natural Gas

Tank Size (L)	Normalized Tank Size	Average kW Input
76	1.00	7.90
140	**1.84**	**10.78**
180	**2.37**	**12.28**
190	2.50	13.32
230	**3.03**	**22.48**
270	3.55	43.16

The same approach was used to determine the heat injector rate for oil and electric DHW tanks. Table E.4 summarizes the data available for oil fired DHW tanks.

Table E.4: DHW Data - Oil

Tank Size (L)	kW Input (kW)	Average kW Input
114	20.5	20.5

According to Table E.1, all oil fired DHW tanks have the same heat injector rate; therefore for all oil fired DHW tanks use 20.5 kW input.

Table E.5 summarizes the data for electric DHW tanks.

Table E.5: DHW Data - Electricity

Tank Size (L)	kW Input	Average kW Input
76	2.5	2.5
114	3.5	3.5
150	4.5	4.5
190	5.5	5.5
250	5.5	5.5
300	5.5	5.5

Figure E.2 was generated using the data in Table E.5, and the equation used to determine the heat injector rate for the tank sizes used in the test case houses, namely 140L, 180L, and 230L.

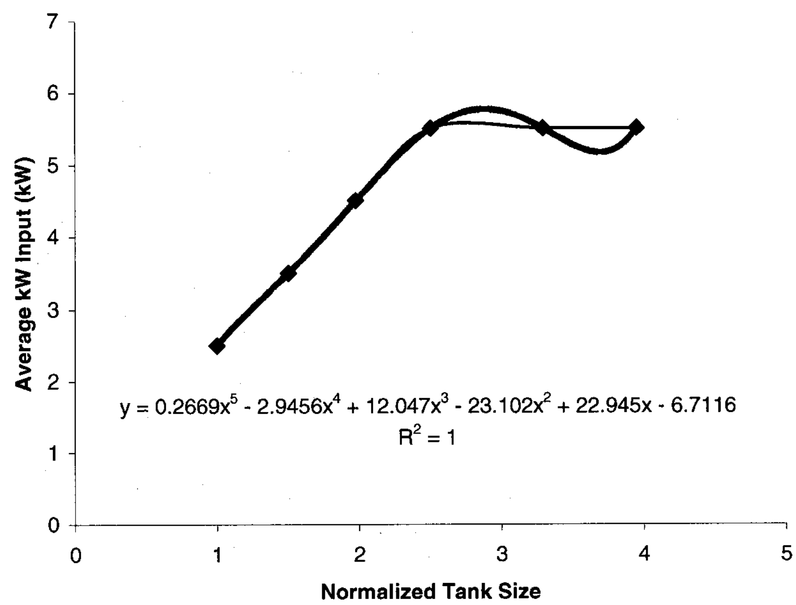

Figure E.2: Normalized Tank Size vs. Average kW Input - Electricity

Table E.6 details the heat injector rates used for different tank sizes. The bolded values are the values used for the test case house tank sizes.

Table E.6: Heat Injector Rate - Electricity

Tank Size (L)	Normalized Tank Size	Average kW Input
76	1.00	2.50
140	**1.84**	**4.21**
180	**2.37**	**5.30**
190	2.50	5.50
230	**3.03**	**5.73**
250	3.29	5.50

Appendix F
Flat Rate and Time-of-Use Electricity Pricing

In most provinces in Canada, electricity consumption at the residential level is charged using a flat rate based on the number of kilowatt-hours (kWh) consumed. Nova Scotia and recently, Ontario have moved to a time-of-use (TOU) pricing scenario, assigning different prices depending on the time of day the electricity is used (Nova Scotia Power, 2006, Ontario Energy Board, 2006). In this work, understanding how the pricing scheme (i.e.: flat rate versus TOU pricing) affects the economic viability of ICE based cogeneration is under investigation. For provinces in which there is not currently a TOU pricing scenario, namely British Columbia, Alberta, Saskatchewan, Manitoba, Quebec, New Brunswick, Prince Edward Island, and Newfoundland, TOU pricing schemes were generated. The methodology used is discussed in detail below.

F.1 Time-of-Use Pricing Scheme in Ontario

The TOU scenario implemented in Ontario as of May 1, 2006 is detailed in Figure F.1, illustrating the wholesale electricity prices.

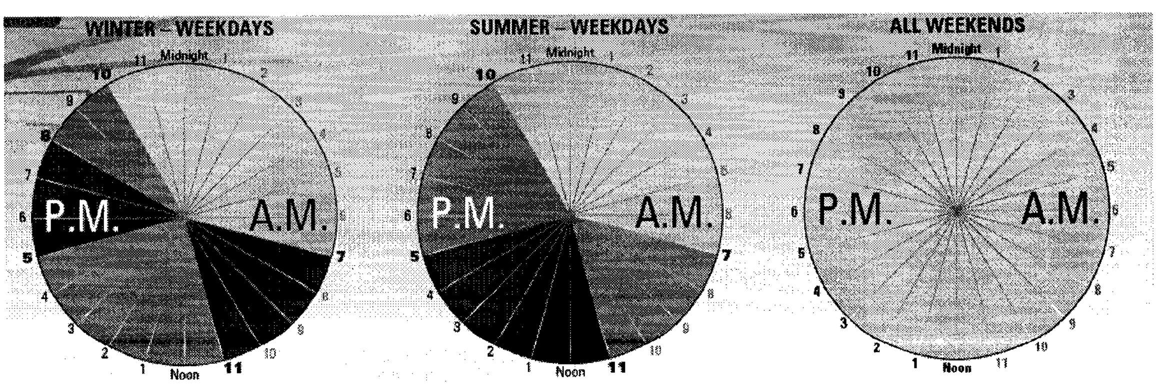

Figure F.1 Time-of-use Pricing in Ontario (Ontario Energy Board, 2006)

Where:

- On-peak price = 10.5 ¢/kWh
- Mid-peak price = 7.5 ¢/kWh
- Off-peak price = 3.5 ¢/kWh

F.2 Provincial Flat Rate Electricity Prices

The determination of a retail flat rate price for Ontario is detailed in Table F.1.

Table F.1: Ontario Flat Rate Price

Duration	Whole-sale Rate (¢/kWh)	Trans. (¢/kWh)	Distribution Charge (¢/kWh)	Wholesale Market Operation (¢/kWh)	Debt Retirement Charge (¢/kWh)	Regulated Price Plan Admin. Charge (¢/kWh)	Retail Price (¢/kWh)
1-24	5.8	1.02	1.86	0.62	0.7	0.000347	10.0

Thus, the flat rate price for Ontario is 10 ¢/kWh (Ontario Energy Board, 2006).

Manitoba, Quebec, New Brunswick and Prince Edward Island have tiered flat rate pricing schemes, thus determining a single flat rate price required some analysis. Each of these provinces is discussed below.

F.2.1 Manitoba Flat Rate Price Determination

The pricing scheme defined by Manitoba Hydro is (Manitoba Hydro, 2006):

First 175 kWh/month @ 5.78 ¢/kWh

Remaining @ 5.654 ¢/kWh

In order to determine a single flat rate price, it is necessary to determine the number of kWh/month consumed by each of the three test case houses in Manitoba. Using the Neural Network estimates for annual electricity consumption, discussed in Section 6.2, the average monthly consumption was calculated, and the results are tabulated in Table F.2.

Table F.2: Manitoba - Annual and Monthly Electricity Consumption

Test Case House	Annual Electricity Consumption (kWh)	Monthly Electricity Consumption (kWh)
A10	9697	808
A11	8276	690
A12	7344	612

The flat rate was determined using a weighed average according to Equation F.1.

$$P_F = \frac{[(h_I \times P_I) + (h_{II} \times P_{II})]}{h_{TOTAL}} \quad \text{[F.1]}$$

Where:

P_F = flat rate electricity price (¢/kWh)

h_I = number of kWh in first price tier

P_I = flat rate electricity price for first tier (¢/kWh)

h_{II} = number of kWh in second price tier

P_{II} = flat rate electricity price for second tier (¢/kWh)

h_{TOTAL} = total number of kWh

Using the weighted average, Table F.3 details the flat rate prices for each of the test case houses in Manitoba.

Table F.3: Flat Rate Prices for Manitoba Test Case Houses

Test Case House	Number of kWh in Tier I	Number of kWh in Tier II	Flat Rate Price (¢/kWh)
10	175	633	5.681
11	175	515	5.686
12	175	437	5.69

To simplify the analysis, the average flat rate price of 5.69 ¢/kWh was used for all three test case houses in Manitoba.

F.2.2 Quebec Flat Rate Determination

The pricing scheme as defined by Hydro Quebec is defined as (Hydro Quebec, 2006):

First 30 kWh/day @ 5.22 ¢/kWh

Remaining @ 6.83 ¢/kWh

In order to determine a single flat rate price, it is necessary to determine the number of kWh/day consumed by each of the three test case houses in Quebec. Using the Neural Network estimates for annual electricity consumption as discussed in Section 6.2, the average daily consumption was calculated, and the results are tabulated in Table F.4.

Table F.4: Quebec – Annual and Daily Electricity Consumption

Test Case House	Annual Electricity Consumption (kWh)	Daily Electricity Consumption (kWh)
A16	8537	23
A17	7625	21
A18	6078	17

According to Table F.4, no test case house consumes more than 30kWh per day, therefore the flat rate price of 5.22 ¢/kWh was used for all three test case houses in Quebec.

F.2.3 New Brunswick Flat Rate Determination

The pricing scheme as defined by New Brunswick Power is defined as (NB Power, 2006):

First 1300 kWh/month @ 9.04 ¢/kWh
Remaining @ 7.16 ¢/kWh

In order to determine a single flat rate price, it is necessary to determine the number of kWh/month consumed by each of the three test case houses in New Brunswick. Using the Neural Network estimates for annual electricity consumption as discussed in Section 6.2, the average monthly consumption was calculated, and the results are tabulated in Table F.5.

Table F.5: New Brunswick – Annual and Monthly Electricity Consumption

Test Case House	Annual Electricity Consumption (kWh)	Monthly Electricity Consumption (kWh)
A19	7439	620
A20	9013	751
A21	7450	621

According to Table F.5, no test case house consumes more than 1300kWh per month, therefore the flat rate price of 9.04 ¢/kWh was used for all three test case houses in New Brunswick.

F.2.4 Prince Edward Island Flat Rate Determination

The pricing scheme as defined by The Maritime Electric Company, the main utility in P.E.I., is defined as (Maritime Electric, 2006):

First 1200 kWh/month @ 10.68 ¢/kWh

Remaining @ 8.28 ¢/kWh

In order to determine a single flat rate price, it is necessary to determine the number of kWh/month consumed by each of the three test case houses in Prince Edward Island. Using the Neural Network estimates for annual electricity consumption as discussed in Section 6.2, the average monthly consumption was calculated, and the results are tabulated in Table F.6.

Table F.6: Prince Edward Island – Annual and Monthly Electricity Consumption

Test Case House	Annual Electricity Consumption (kWh)	Monthly Electricity Consumption (kWh)
A25	7143	595
A26	7527	627
A27	6774	565

According to Table F.6, no test case house consumes more than 1200kWh per month, therefore the therefore the flat rate price of 10.68 ¢/kWh was used for all three test case houses in Prince Edward Island.

The remaining provinces namely, British Columbia, Alberta, Saskatchewan and Newfoundland have only one flat rate price, which was used to determine the TOU pricing. Table F.7 details the flat rate prices for all ten provinces that were used to determine the TOU structure. While a TOU structure is in place in Ontario, a flat rate price of 10 ¢/kWh is also available, and this is the flat rate price used to generate the provincial TOU scenarios as discussed in Section F.3. In addition, Nova Scotia offers both a flat rate price and a TOU pricing scheme, both are detailed below.

Table F.7: Flat Rate Electricity Prices by Province[7]

Province	Flat Rate Electricity Price (¢/kWh)
British Columbia	6.33
Alberta	7.71
Saskatchewan	8.99
Manitoba	5.69
Ontario	10.00
Quebec	5.22
New Brunswick	9.04
Nova Scotia	10.13
Prince Edward Island	10.68
Newfoundland	8.92

F.3 TOU Schemes by Province

Using the TOU pricing scheme for Ontario, the flat rate price for Ontario, and the flat rate price for each province, a TOU scheme was developed for each province. Tables F.8 – F.10 detail the TOU scheme for Ontario according to Figure F.1.

[7] All prices are retail prices

Table F.8: Ontario TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)	Trans. (¢/kWh)	Distribution Charge (¢/kWh)	Wholesale Market Operation (¢/kWh)	Debt Retirement Charge (¢/kWh)	Regulated Price Plan Admin. Charge (¢/kWh)	Final Price (¢/kWh)
1-6	Off-Peak	3.5	1.02	1.86	0.62	0.7	0.000347	7.7
7-10	On-Peak	10.5	1.02	1.86	0.62	0.7	0.000347	14.7
11-16	Mid-Peak	7.5	1.02	1.86	0.62	0.7	0.000347	11.7
17-19	On-Peak	10.5	1.02	1.86	0.62	0.7	0.000347	14.7
20-21	Mid-Peak	7.5	1.02	1.86	0.62	0.7	0.000347	11.7
22-24	Off-Peak	3.5	1.02	1.86	0.62	0.7	0.000347	7.7

Table F.9: Ontario TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)	Trans. (¢/kWh)	Distribution Charge (¢/kWh)	Wholesale Market Operation (¢/kWh)	Debt Retirement Charge (¢/kWh)	Regulated Price Plan Admin. Charge (¢/kWh)	Final Price (¢/kWh)
1-6	Off-Peak	3.5	1.02	1.86	0.62	0.7	0.000347	7.7
7-10	Mid-Peak	7.5	1.02	1.86	0.62	0.7	0.000347	11.7
11-16	On-Peak	10.5	1.02	1.86	0.62	0.7	0.000347	14.7
17-21	Mid-Peak	7.5	1.02	1.86	0.62	0.7	0.000347	11.7
22-24	Off-Peak	3.5	1.02	1.86	0.62	0.7	0.000347	7.7

Table F.10: Ontario TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)	Trans. (¢/kWh)	Distribution Charge (¢/kWh)	Wholesale Market Operation (¢/kWh)	Debt Retirement Charge (¢/kWh)	Regulated Price Plan Admin. Charge (¢/kWh)	Final Price (¢/kWh)
1-24	Off-Peak	3.5	1.02	1.86	0.62	0.7	0.000347	7.7

Using the flat rate price and TOU prices for Ontario as well as the flat rate prices for each province, a TOU scheme was developed. At each hour, the price in ¢/kWh was determined using Equation F.2.

$$P_{TOU} = O_{TOU} \times \left(\frac{P_F}{O_F} \right) \quad [F.2]$$

Where:

P_{TOU} = provincial time-of-use electricity price (¢/kWh)

O_{TOU} = Ontario time-of-use electricity price (¢/kWh)

P_F = provincial flat rate electricity price (¢/kWh)

O_F = Ontario flat rate electricity price (¢/kWh)

F.3.1 Provincial TOU Pricing Results

The results for each province are presented in Tables F.11 - F.37.

Table F.11: British Columbia TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	4.9
7-10	On-Peak	9.3
11-16	Mid-Peak	7.4
17-19	On-Peak	9.3
20-21	Mid-Peak	7.4
22-24	Off-Peak	4.9

Table F.12: British Columbia TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	4.9
7-10	Mid-Peak	7.4
11-16	On-Peak	9.3
17-21	Mid-Peak	7.4
22-24	Off-Peak	4.9

Table F.13: British Columbia TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	4.9

Table F.14: Alberta TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	5.9
7-10	On-Peak	11.3
11-16	Mid-Peak	9.0
17-19	On-Peak	11.3
20-21	Mid-Peak	9.0
22-24	Off-Peak	5.9

Table F.15: Alberta TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	5.9
7-10	Mid-Peak	9.0
11-16	On-Peak	11.3
17-21	Mid-Peak	9.0
22-24	Off-Peak	5.9

Table F.16: Alberta TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	5.9

Table F.17: Saskatchewan TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	6.9
7-10	On-Peak	13.2
11-16	Mid-Peak	10.5
17-19	On-Peak	13.2
20-21	Mid-Peak	10.5
22-24	Off-Peak	6.9

Table F.18: Saskatchewan TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	5.9
7-10	Mid-Peak	9.0
11-16	On-Peak	11.3
17-21	Mid-Peak	9.0
22-24	Off-Peak	5.9

Table F.19: Saskatchewan TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	5.9

Table F.20: Manitoba TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	4.4
7-10	On-Peak	8.4
11-16	Mid-Peak	6.6
17-19	On-Peak	8.4
20-21	Mid-Peak	6.6
22-24	Off-Peak	4.4

Table F.21: Manitoba TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	4.4
7-10	Mid-Peak	6.6
11-16	On-Peak	8.4
17-21	Mid-Peak	6.6
22-24	Off-Peak	4.4

Table F.22: Manitoba TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	4.4

Table F.23: Quebec TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	4.0
7-10	On-Peak	7.7
11-16	Mid-Peak	6.1
17-19	On-Peak	7.7
20-21	Mid-Peak	6.1
22-24	Off-Peak	4.0

Table F.24: Quebec TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	4.0
7-10	Mid-Peak	6.1
11-16	On-Peak	7.7
17-21	Mid-Peak	6.1
22-24	Off-Peak	4.0

Table F.25: Quebec TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	4.0

Table F.26: New Brunswick TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	7.0
7-10	On-Peak	13.3
11-16	Mid-Peak	10.6
17-19	On-Peak	13.3
20-21	Mid-Peak	10.6
22-24	Off-Peak	7.0

Table F.27: New Brunswick TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	7.0
7-10	Mid-Peak	10.6
11-16	On-Peak	13.3
17-21	Mid-Peak	10.6
22-24	Off-Peak	7.0

Table F.28: New Brunswick TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	7.0

Table F.29: Prince Edward Island TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	8.2
7-10	On-Peak	15.7
11-16	Mid-Peak	12.5
17-19	On-Peak	15.7
20-21	Mid-Peak	12.5
22-24	Off-Peak	8.2

Table F.30: Prince Edward Island TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	8.2
7-10	Mid-Peak	12.5
11-16	On-Peak	15.7
17-21	Mid-Peak	12.5
22-24	Off-Peak	8.2

Table F.31: Prince Edward Island TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	8.2

Table F.32: Newfoundland TOU Pricing – Winter Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	6.9
7-10	On-Peak	13.1
11-16	Mid-Peak	10.4
17-19	On-Peak	13.1
20-21	Mid-Peak	10.4
22-24	Off-Peak	6.9

Table F.33: Newfoundland TOU Pricing – Summer Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	6.9
7-10	Mid-Peak	10.4
11-16	On-Peak	13.1
17-21	Mid-Peak	10.4
22-24	Off-Peak	6.9

Table F.34: Newfoundland TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	6.9

Nova Scotia currently has a TOU pricing scheme and is presented in Tables F.35 – F.37 (Nova Scotia Power, 2006).

Table F.35: Nova Scotia TOU Pricing – Winter (Dec. – Feb.) Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	5.1
7-11	On-Peak	14.6
11-17	Mid-Peak	10.1
18-22	On-Peak	14.6
23-24	Off-Peak	5.1

Table F.36: Nova Scotia TOU Pricing – Non-Winter (Mar. – Nov) Weekdays

Duration (hour)	Time Period	Rate (¢/kWh)
1-6	Off-Peak	5.1
7-10	Mid-Peak	10.1
11-24	Off-Peak	5.1

Table F.37: Nova Scotia TOU Pricing – All Weekends

Duration (hour)	Time Period	Rate (¢/kWh)
1-24	Off-Peak	5.1

Appendix G

Electricity Greenhouse Gas Emissions Data

Tables G.1 – G.30 detail the GHG emissions, electricity generation, and the GHG intensity for each province (Environment Canada, 2006)

Table G.1: British Columbia - GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	333	532	236	243	118	91	135	77	76	70	88	108	60	82	85
Natural Gas	841	507	1030	2100	2060	2610	632	1110	1770	1200	1360	2920	1120	1250	1380
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1170	1040	1270	2340	2180	2700	770	1190	1840	1270	2450	3030	1180	1330	1460

Table G.2: British Columbia – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	510	688	391	433	213	169	373	2232508	141	154	157	204	140	165	180
Natural Gas	1647	1040	1999	4012	4523	5728	1675	0	3795	3190	5106	6454	3126	3440	4065
Nuclear	0	0	0	0	0	0	0	63332	0	0	0	0	0	0	0
Hydro	57308	60197	60663	53174	54305	50181	67668	2383	60860	61582	60208	49162	58878	56929	54653
Biomass	1549	1458	1778	2030	2630	2540	2583	438	2402	2893	2921	2660	2775	2766	2948
Others	0	0	0	103	401	436	374	68884	573	362	293	283	416	82	105
Total	61015	63383	64831	59753	62071	59054	72673		67771	68182	68684	58763	65335	63382	61951

Table G.3: British Columbia – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	653	773	605	562	555	536	363	346	538	450	560	530	430	500	470
Natural Gas	510	488	516	523	465	456	378	442	466	463	463	453	359	363	339
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average Intensity	19	16	20	39	35	46	11	17	27	19	36	52	18	21	24

Table G.4: Alberta - GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	37300	39400	41700	42600	46000	46300	44900	46700	46200	44300	44000	45200	46000	45600	45200
Refined Petroleum Products	12	14	15	18	18	16	43	8	31	30	40	30	30	40	40
Natural Gas	2290	2040	2850	2810	2790	2220	2900	3350	4360	4480	6550	6210	5060	5260	4640
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	334	345	425	392	543	443	260	770	840	970	1040	1190	1190	3200	2220
Total	40000	41800	45000	45800	49300	49000	48100	50800	51400	49800	51700	52600	52300	54100	52100

Table G.5: Alberta – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	34672	36391	38373	39066	42467	43069	41596	43134	42332	41814	42199	45943	47189	43368	44586
Refined Petroleum Products	14	16	18	21	21	20	52	10	39	33	41	39	37	2508	1507
Natural Gas	4971	4484	5960	5911	6000	5111	6273	6817	8816	8516	12141	11969	9998	9971	8944
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	2060	2030	1563	1808	1806	2190	1990	1837	2098	2239	1845	1568	1884	2162	2497
Biomass	446	557	565	717	771	756	725	828	821	829	778	1216	1220	1236	1246
Others	999	1001	1139	1141	1295	1308	1316	535	315	1716	1530	1303	1313	1069	1663
Total	43162	44480	47617	48663	52361	52453	51951	53161	54421	55147	58534	62038	61641	60314	60443

Table G.6: Alberta – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	1080	1080	1090	1090	1080	1070	1080	1080	1090	1060	1040	980	980	1050	1010
Refined Petroleum Products	857	841	851	847	845	835	832	792	793	830	850	790	690	20	30
Natural Gas	461	455	478	475	465	435	463	492	495	526	539	519	506	528	519
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	334	345	373	343	419	339	198	1450	2680	564	677	915	904	2991	1332
Average Intensity	926	940	946	941	942	934	927	956	944	902	882	848	849	898	861

Table G.7: Saskatchewan - GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	10100	10300	11600	12100	13100	13400	13500	14000	14100	14000	13200	X	X	X	X
Refined Petroleum Products	22	21	21	19	28	57	63	82	50	50	40	X	X	X	X
Natural Gas	260	306	571	268	129	412	419	759	989	880	1440	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Total	10400	10600	12100	12400	13300	13900	14000	14900	15100	14900	14700	X	X	X	X

Table G.8: Saskatchewan – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	8634	8617	9889	10433	11544	11258	11175	11290	11622	11644	11819	11756	11848	11576	12157
Refined Petroleum Products	47	43	46	41	64	95	95	98	58	59	50	40	37	34	30
Natural Gas	545	622	1048	579	374	816	813	1337	1725	1483	2448	2678	2839	4440	4152
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	4215	4214	3059	4051	3393	4118	4376	3987	3442	3689	3046	2393	2879	3475	2820
Biomass	100	102	94	98	103	107	96	126	114	115	125	349	367	265	277
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	13541	13598	14137	15212	15479	16394	16554	16837	16961	16988	17488	17215	17970	19790	19437

Table G.9: Saskatchewan – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	1170	1190	1170	1160	1140	1190	1210	1240	1210	1200	1120	X	X	X	X
Refined Petroleum Products	478	480	459	473	433	594	666	841	853	850	810	X	X	X	X
Natural Gas	476	492	545	464	345	506	516	568	573	594	590	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Average Intensity	765	780	859	815	857	846	847	882	891	878	840	X	X	X	X

Table G.10: Manitoba - GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	455	352	351	252	276	180	282	224	944	522	971	X	X	X	X
Refined Petroleum Products	66	64	61	30	45	35	56	20	18	24	22	X	X	X	X
Natural Gas	3	2	5	2	2	4	2	0	0	0	0	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Total	525	418	417	284	323	219	340	244	962	546	993	X	X	X	X

Table G.11: Manitoba – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	322	233	237	188	195	128	200	178	844	461	869	443	365	611	296
Refined Petroleum Products	61	65	51	31	54	57	61	27	25	36	36	45	46	33	32
Natural Gas	13	9	14	9	8	14	11	1	0	0	0	0	134	184	63
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	19827	22554	26434	26891	28146	29013	30866	33391	30781	28138	31536	32899	28821	20246	27219
Biomass	31	30	43	40	42	26	45	64	74	56	60	61	72	67	75
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	12	18
Total	20254	22891		27159	28445	29238	31184	33661	31724	28691	32501	33448	29438	21152	27703

Table G.12: Manitoba – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	1410	1510	1480	1340	1420	1410	1410	1260	1120	1130	1120	X	X	X	X
Refined Petroleum Products	1080	999	1080	970	828	616	911	741	733	650	600	X	X	X	X
Natural Gas	236	248	371	257	238	258	225	272	-	-	-	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Average Intensity	26	18	16	11	11	7	11	7	30	19	31	X	X	X	X

Table G.13: Ontario - GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	24800	26200	25400	16500	13500	14300	16400	20600	27200	28200	36200	33300	33100	37300	27700
Refined Petroleum Products	1130	934	710	139	278	348	308	356	1210	1060	400	690	500	1110	720
Natural Gas	528	554	1270	1550	1900	3750	3650	4290	4500	5620	5460	6040	6160	6600	5860
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	26	56	61	70	78	79	86	329	235	264	223	186	283	252	273
Total	26400	27700	27400	18300	15800	18500	20500	25600	33100	35200	42300	40200	40100	45300	34600

Table G.14: Ontario – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	26121	30298	27221	19452	16377	16677	19515	26310	34096	34809	42442	38236	37951	37511	27593
Refined Petroleum Products	1377	1238	894	169	378	508	519	547	1657	1525	583	982	762	1289	826
Natural Gas	1597	1683	2996	3545	4302	7750	7892	8874	9838	12143	11283	12216	12959	12073	10644
Nuclear	59353	70773	66586	78509	91066	86216	77676	70209	59879	61473	59829	63128	62965	62003	76063
Hydro	40561	37647	40151	40753	39311	38809	41662	39963	35416	37294	37908	37136	38438	36062	39500
Biomass	657	611	761	687	792	860	790	918	947	922	972	964	1020	881	954
Others	108	194	180	195	203	199	219	221	262	228	204	194	240	232	266
Total	129773	142444	139788	143310	152430	151018	148271	147041	142094	148392	153221	152856	154336	150051	155847

Table G.15: Ontario – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	948	865	899	848	826	859	841	762	797	811	852	871	872	995	1004
Refined Petroleum Products	842	754	794	822	735	686	594	652	728	690	690	700	660	860	870
Natural Gas	330	329	424	438	442	484	463	483	458	463	484	495	475	547	550
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	238	287	342	359	384	399	393	1490	899	1160	1090	957	1180	1090	1030
Average Intensity	204	195	196	127	104	123	138	174	233	237	276	263	259	302	222

Table G.16: Quebec - GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	1360	374	794	144	310	188	184	215	1330	910	310	340	240	1500	1280
Natural Gas	75	75	75	75	82	80	81	81	76	63	72	68	72	76	74
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1430	448	869	219	392	268	265	296	1400	980	380	410	310	1580	1350

Table G.17: Quebec – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	1707	415	1015	166	247	370	556	695	2329	1753	869	1047	894	2972	2472
Natural Gas	156	123	145	140	105	268	385	392	252	244	332	358	428	214	209
Nuclear	4070	3910	4600	4807	5406	4511	5243	4204	3814	3775	4886	4705	4530	3548	4878
Hydro	129939	138550	141983	150048	157851	167946	165016	160686	148148	162890	173179	164529	170713	170498	166759
Biomass	0	0	0	0	0	0	185	273	403	506	478	485	584	617	634
Others	11	0	0	0	0	4	1	5	4	8	13	7	0	0	0
Total	135883	142998	147743	155160	163609	173099	171386	166255	154950	169176	179757	171131	177150	177849	174951

Table G.18: Quebec – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Refined Petroleum Products	795	900	782	869	1257	508	331	309	569	520	360	330	270	510	520
Natural Gas	482	607	519	538	776	300	210	206	302	259	217	189	168	344	353
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydro	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Average Intensity	11	3	6	1	2	2	2	2	9	6	2	2	2	9	8

Table G.19: New Brunswick - GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	1140	940	1030	1190	2680	3040	3150	3030	3240	3130	2820	X	X	X	X
Refined Petroleum Products	4700	4320	4950	3830	3280	3560	2670	5090	5970	4820	5550	X	X	X	X
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Total	5840	5270	5980	5010	5960	6600	5820	8120	9210	7950	8360	X	X	X	X

Table G.20: New Brunswick – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	1285	1120	1226	1377	3118	3445	3551	3625	3901	3885	3607	3849	3462	4296	2999
Refined Petroleum Products	6092	5718	6477	4931	4249	4538	3308	6564	7687	6415	7586	8455	7184	6443	8384
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	245	1331	1137
Nuclear	5338	5440	4833	5323	5239	1579	4591	3444	3773	4083	3959	4487	3757	4742	4299
Hydro	3533	3003	3011	3057	2773	2706	3532	2373	2862	3380	3293	2059	2251	3233	3013
Biomass	505	527	462	471	516	520	507	779	815	910	847	871	974	914	931
Others	0	0	0	0	0	0	0	0	0	2	3	8	10	9	9
Total	16752	15808	16009	15158	15895	12788	15488	16784	19038	18676	19295	19728	17883	20968	20772

Table G.21: New Brunswick – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	880	840	840	860	860	880	890	840	830	810	780	X	X	X	X
Refined Petroleum Products	772	756	764	776	772	784	806	775	777	750	730	X	X	X	X
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Average Intensity	348	333	374	331	375	516	376	484	484	426	433	X	X	X	X

Table G.22: Nova Scotia – GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	5050	5280	5390	5530	6100	5840	6510	6860	5890	6530	7590	X	X	X	X
Refined Petroleum Products	1790	1720	1990	1770	1020	1050	600	680	1920	1520	1230	X	X	X	X
Natural Gas	0		0	0	0	0	0	0	0	0	0	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Total	6830	7000	7380	7310	7120	6900	7100	7530	7800	8060	8820	X	X	X	X

Table G.23: Nova Scotia – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	5760	5933	6079	6337	7136	6987	7944	8367	7119	7916	8959	9801	8576	7335	7567
Refined Petroleum Products	2233	2113	2447	2201	1290	1407	791	887	2475	1978	1547	1106	424	3618	3813
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	1930	127	101
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	1181	1071	905	916	1054	937	1156	978	932	1018	924	748	1082	1142	961
Biomass	259	277	290	260	287	240	302	281	235	158	191	189	127	161	155
Others	0	0	0	0	0	0	0	0	19	6	4	5	8	8	0
Total	9432	9394	9720	9714	9767	9571	10193	10513	10780	11076	11624	11849	12146	12391	12597

Table G.24: Nova Scotia – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	88	890	890	870	860	840	820	820	830	830	850	X	X	X	X
Refined Petroleum Products	800	813	813	805	788	749	753	761	775	770	790	X	X	X	X
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Average Intensity	724	745	759	752	729	721	697	717	724	727	759	X	X	X	X

Table G.25: Prince Edward Island – GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Refined Petroleum Products	101	91	50	73	57	38	24	31	10	19	55	X	X	X	X
Natural Gas	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Total	101	91	50	73	57	38	24	31	10	19	55	X	X	X	X

Table G.26: Prince Edward Island – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	81	72	34	59	41	23	11	22	4	10	49	43	20	43	13
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	81	72	34	59	41	23	11	22	4	10	49	43	20	43	13

Table G.27: Prince Edward Island – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Refined Petroleum Products	1250	1270	1480	1250	1410	1660	2320	1390	2910	1890	1120	X	X	X	X
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Nuclear	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Hydro	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Biomass	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Others	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Average Intensity	1250	1270	1480	1250	141	1660	2320	1390	2910	1890	1120	X	X	X	X

Table G.28: Newfoundland – GHG Emissions (kt CO_2eq)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Refined Petroleum Products	1610	1280	1480	1340	720	1250	1160	1210	1020	810	800	X	X	X	X
Natural Gas	0	0	0	0	0	0	0	0	0	124	115	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X
Total	1610	1280	1480	1340	720	1250	1160	1210	1020	940	920	X	X	X	X

Table G.29: Newfoundland – Electricity Generation (GWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refined Petroleum Products	1978	1534	1784	1659	879	1626	1484	1573	1317	971	1025	2155	2436	2008	1706
Natural Gas	0	0	0	0	0	0	0	0	164	283	261	273	273	284	264
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	34687	35410	34875	39194	37606	36287	35292	40177	43640	41382	42313	38824	41416	39801	39589
Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	36665	36944	36659	40853	38485	37913	36776	41750	45121	42636	43599	41252	44125	42093	41559

Table G.30: Newfoundland – GHG Intensity (gCO_2eq/kWh)

Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Coal	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Refined Petroleum Products	816	835	829	809	815	770	782	770	772	836	785	X	X	X	X
Natural Gas	-	-	-	-	-	-	-	-	0	440	440	X	X	X	X
Nuclear	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Hydro	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Biomass	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Others	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X
Average Intensity	44	35	40	33	19	33	32	29	23	22	21	X	X	X	X

Appendix H
ICE Based Cogeneration Annual Simulation Results

The annual base case simulation results are presented in Tables H.1 – H.10. Summary results for the ICE based cogeneration case are presented in Tables H.11 – H.21 and the detailed cogeneration results are presented in Tables H.22 – H.79.

H.1 Simulation Results

Table H.1: Annual Base Case Simulation Results – British Columbia

	Test Case House 1		Test Case House 2		Test Case House 3	
	Prince George	Vancouver	Prince George	Vancouver	Prince George	Vancouver
$Demand_{el}$ (kWh/yr)	17937	17659	17630	17469	15605	15342
$Demand_{SH}$ (GJ/yr)	107.9	62.2	48.9	19.0	76.6	33.3
Fuel for SH (GJ/yr)	152.8	86.0	65.7	27.2	110.7	47.0
$\eta_{Furnace}$ (%)	77.3	77.3	77.7	77.7	76.4	76.4
Fuel for SH (m^3/yr)	3998	2251	1720	711	2897	1230
$Demand_{DHW}$ (GJ/yr)	11.7	11.7	13.9	13.9	11.8	11.8
Fuel for DHW (GJ/yr)	26.0	25.9	30.3	30.1	24.0	23.9
η_{DHW} (%)	51.1	51.1	50.6	50.6	55.0	55.0
Fuel for DHW (m^3/yr)	681	678	792	787	628	624
Total Fuel (m^3/yr)	4678	2929	2512	1498	3525	1854
$Cost_{el,flat}$ (CAD/yr)	1135	1118	1116	1106	988	971
$Cost_{el,TOU}$ (CAD/yr)	1198	1180	1181	1171	1042	1026
$Cost_{NG}$ (CAD/yr)	1907	1194	1024	611	1437	756
$Cost_{tot,flat}$ (CAD/yr)	3043	2312	2140	1717	2425	1727
$Cost_{tot,TOU}$ (CAD/yr)	3105	2374	2205	1782	2480	1781
$GHG_{el,avg}$ (tonnes/yr)	0.43	0.42	0.42	0.42	0.37	0.37
$GHG_{el,high}$ (tonnes/yr)	6.73	6.62	6.61	6.55	5.85	5.75
GHG_{th} (tonnes/yr)	8.68	5.44	4.66	2.78	6.54	3.44
$GHG_{tot,avg}$ (tonnes/yr)	9.12	5.86	5.09	3.20	6.92	3.81
$GHG_{tot,high}$ (tonnes/yr)	15.41	12.06	11.27	9.33	12.40	9.19

Table H.2: Annual Base Case Simulation Results – Alberta

	Test Case House 4		Test Case House 5		Test Case House 6	
	Calgary	Edmonton	Calgary	Edmonton	Calgary	Edmonton
$Demand_{el}$ (kWh/yr)	10867	10911	11036	11084	9940	9988
$Demand_{SH}$ (GJ/yr)	61.3	68.1	65.5	73.2	69.6	76.9
Fuel for SH (GJ/yr)	88.5	99.3	92.9	104.8	100.6	112.5
$\eta_{Furnace}$ (%)	74.9	74.9	76.2	76.2	74.9	74.9
Fuel for SH (m^3/yr)	2317	2599	2432	2742	2633	2944
$Demand_{DHW}$ (GJ/yr)	11.8	11.8	13.9	13.9	11.8	11.8
Fuel for DHW (GJ/yr)	24.0	24.0	27.8	27.9	24.1	24.1
η_{DHW} (%)	55.0	55.0	55.1	55.1	54.8	54.8
Fuel for DHW (m^3/yr)	627	628	728	729	630	631
Total Fuel (m^3/yr)	2944	3227	3160	3471	3263	3575
$Cost_{el,flat}$ (CAD/yr)	838	841	851	855	766	770
$Cost_{el,TOU}$ (CAD/yr)	878	876	893	894	809	807
$Cost_{NG}$ (CAD/yr)	1139	1248	1222	1343	1262	1383
$Cost_{tot,flat}$ (CAD/yr)	1976	2089	2073	2197	2028	2153
$Cost_{tot,TOU}$ (CAD/yr)	2017	2124	2116	2236	2071	2189
$GHG_{el,avg}$ (tonnes/yr)	9.36	9.39	9.50	9.54	8.56	8.60
$GHG_{el,high}$ (tonnes/yr)	10.70	10.75	10.87	10.92	9.79	9.84
GHG_{th} (tonnes/yr)	5.46	5.99	5.87	6.44	6.06	6.64
$GHG_{tot,avg}$ (tonnes/yr)	14.82	15.38	15.37	15.99	14.62	15.24
$GHG_{tot,high}$ (tonnes/yr)	16.17	16.74	16.74	17.36	15.85	16.47

Table H.3: Annual Base Case Simulation Results – Saskatchewan

	Test Case House 7		Test Case House 8		Test Case House 9	
	North Battleford	Regina	North Battleford	Regina	North Battleford	Regina
$Demand_{el}$ (kWh/yr)	8974	8928	10020	9975	8457	8393
$Demand_{SH}$ (GJ/yr)	79.0	70.7	78.1	70.0	95.9	84.6
Fuel for SH (GJ/yr)	116.0	104.3	111.6	100.5	140.7	124.3
$\eta_{Furnace}$ (%)	73.1	73.1	75.0	75.0	73.1	73.1
Fuel for SH (m^3/yr)	3037	2729	2921	2629	3682	3253
$Demand_{DHW}$ (GJ/yr)	11.8	11.8	11.8	11.8	9.6	9.6
Fuel for DHW (GJ/yr)	24.2	24.1	24.1	24.0	20.2	20.2
η_{DHW} (%)	54.6	54.6	54.8	54.8	54.6	54.6
Fuel for DHW (m^3/yr)	633	632	630	629	530	529
Total Fuel (m^3/yr)	3669	3361	3551	3258	4212	3782
$Cost_{el,flat}$ (CAD/yr)	807	803	901	897	760	755
$Cost_{el,TOU}$ (CAD/yr)	852	848	950	946	809	803
$Cost_{NG}$ (CAD/yr)	1245	1141	1205	1106	1429	1283
$Cost_{tot,flat}$ (CAD/yr)	2052	1943	2106	2002	2189	2038
$Cost_{tot,TOU}$ (CAD/yr)	2097	1988	2155	2052	2239	2086
$GHG_{el,avg}$ (tonnes/yr)	7.54	7.50	8.42	8.38	7.10	7.05
$GHG_{el,high}$ (tonnes/yr)	10.22	10.17	11.41	11.36	9.63	9.56
GHG_{th} (tonnes/yr)	6.81	6.24	6.59	6.05	7.82	7.02
$GHG_{tot,avg}$ (tonnes/yr)	14.35	13.74	15.01	14.43	14.92	14.07
$GHG_{tot,high}$ (tonnes/yr)	17.03	16.41	18.00	17.41	17.45	16.58

Table H.4: Annual Base Case Simulation Results – Manitoba

	Test Case House 10		Test Case House 11		Test Case House 12	
	Le Pas	Winnipeg	Le Pas	Winnipeg	Le Pas	Winnipeg
$Demand_{el}$ (kWh/yr)	10211	10108	8936	8816	8111	7978
$Demand_{SH}$ (GJ/yr)	88.9	71.4	114.0	93.8	132.6	110.0
Fuel for SH (GJ/yr)	122.3	97.9	156.9	128.6	182.5	150.8
$\eta_{Furnace}$ (%)	78.0	78.0	78.0	78.0	78.0	78.0
Fuel for SH (m^3/yr)	3200	2561	4107	3364	4776	3947
$Demand_{DHW}$ (GJ/yr)	11.8	11.8	11.8	11.8	9.6	9.6
Fuel for DHW (GJ/yr)	24.3	24.2	22.7	22.7	18.8	18.7
η_{DHW} (%)	54.3	54.3	58.2	58.2	59.2	59.2
Fuel for DHW (m^3/yr)	637	634	595	593	492	490
Total Fuel (m^3/yr)	3837	3196	4702	3957	5269	4437
$Cost_{el,flat}$ (CAD/yr)	581	575	508	502	462	454
$Cost_{el,TOU}$ (CAD/yr)	615	609	538	531	492	484
$Cost_{NG}$ (CAD/yr)	1968	1639	2412	2030	2703	2276
$Cost_{tot,flat}$ (CAD/yr)	2549	2215	2921	2532	3164	2730
$Cost_{tot,TOU}$ (CAD/yr)	2584	2249	2950	2561	3194	2760
$GHG_{el,avg}$ (tonnes/yr)	0.32	0.31	0.28	0.27	0.25	0.25
$GHG_{el,high}$ (tonnes/yr)	12.18	12.06	10.66	10.52	9.68	9.52
GHG_{th} (tonnes/yr)	7.12	5.93	8.73	7.35	9.78	8.24
$GHG_{tot,avg}$ (tonnes/yr)	7.44	6.25	9.01	7.62	10.03	8.48
$GHG_{tot,high}$ (tonnes/yr)	19.30	17.99	19.39	17.86	19.46	17.75

Table H.5: Annual Base Case Simulation Results – Ontario

	Test Case House 13		Test Case House 14		Test Case House 15	
	Ottawa	Toronto	Ottawa	Toronto	Ottawa	Toronto
$Demand_{el}$ (kWh/yr)	9822	9793	8887	8814	7775	7719
$Demand_{SH}$ (GJ/yr)	36.0	30.9	79.7	67.2	59.4	49.7
Fuel for SH (GJ/yr)	47.1	40.5	104.2	87.7	77.8	65.0
$\eta_{Furnace}$ (%)	82.4	82.4	81.5	81.5	81.6	81.6
Fuel for SH (m^3/yr)	1232	1060	2728	2294	2035	1700
$Demand_{DHW}$ (GJ/yr)	11.8	11.8	11.8	11.8	11.8	11.8
Fuel for DHW (GJ/yr)	23.7	23.6	23.0	23.0	23.0	22.9
η_{DHW} (%)	55.6	55.6	57.1	57.1	57.4	57.4
Fuel for DHW (m^3/yr)	619	618	603	602	602	601
Total Fuel (m^3/yr)	1852	1678	3331	2896	2637	2301
$Cost_{el,flat}$ (CAD/yr)	982	979	889	881	777	772
$Cost_{el,TOU}$ (CAD/yr)	1046	1043	945	938	827	821
$Cost_{NG}$ (CAD/yr)	912	827	1641	1427	1299	1134
$Cost_{tot,flat}$ (CAD/yr)	1894	1806	2530	2308	2077	1906
$Cost_{tot,TOU}$ (CAD/yr)	1959	1870	2586	2365	2126	1955
$GHG_{el,avg}$ (tonnes/yr)	2.18	2.17	1.97	1.96	1.73	1.71
$GHG_{el,high}$ (tonnes/yr)	9.37	9.34	8.48	8.41	7.42	7.36
GHG_{th} (tonnes/yr)	3.44	3.11	6.18	5.38	4.90	4.27
$GHG_{tot,avg}$ (tonnes/yr)	5.62	5.29	8.16	7.33	6.62	5.99
$GHG_{tot,high}$ (tonnes/yr)	12.81	12.46	14.66	13.78	12.31	11.64

Table H.6: Annual Base Case Simulation Results – Quebec

	Test Case House 16		Test Case House 17		Test Case House 18	
	Montreal	Quebec	Montreal	Quebec	Montreal	Quebec
$Demand_{el}$ (kWh/yr)	8772	7958	6501	6511	7946	8910
$Demand_{SH}$ (GJ/yr)	41.9	59.4	75.6	77.2	57.3	66.7
Fuel for SH (GJ/yr)	59.1	82.4	106.4	109.1	80.0	93.6
$\eta_{Furnace}$ (%)	73.9	74.5	73.7	73.7	74.5	73.9
Fuel for SH (litres/yr)	1539	2147	2773	2843	2083	2439
$Demand_{DHW}$ (GJ/yr)	11.8	11.8	11.8	11.8	11.8	11.8
Fuel for DHW (GJ/yr)	17.7	17.1	17.3	17.4	17.1	17.8
η_{DHW} (%)	74.3	77.3	76.2	76.2	77.3	74.3
Fuel for DHW (kWh/yr)	4918	4762	4816	4822	4758	4935
Total Fuel (litres/yr)	1539	2147	2773	2843	2083	2439
$Cost_{el,flat}$ (CAD/yr)	715	664	591	592	663	723
$Cost_{el,TOU}$ (CAD/yr)	760	709	630	630	708	769
$Cost_{NG}$ (CAD/yr)	1108	1383	1997	1831	1500	1571
$Cost_{tot,flat}$ (CAD/yr)	1822	2047	2588	2423	2163	2294
$Cost_{tot,TOU}$ (CAD/yr)	1868	2092	2626	2461	2208	2340
$GHG_{el,avg}$ (tonnes/yr)	0.11	0.10	0.09	0.09	0.10	0.11
$GHG_{el,high}$ (tonnes/yr)	7.52	6.98	6.21	6.22	6.97	7.60
GHG_{th} (tonnes/yr)	4.36	6.09	7.86	8.06	5.90	6.91
$GHG_{tot,avg}$ (tonnes/yr)	4.47	6.19	7.95	8.15	6.01	7.03
$GHG_{tot,high}$ (tonnes/yr)	11.88	13.07	14.07	14.28	12.88	14.52

Table H.7: Annual Base Case Simulation Results – New Brunswick

	Test Case House 19		Test Case House 20		Test Case House 21	
	Fredericton	Saint John	Fredericton	Saint John	Fredericton	Saint John
$Demand_{el}$ (kWh/yr)	8259	8249	9407	9399	8071	8132
$Demand_{SH}$ (GJ/yr)	114.7	143.5	69.6	68.2	109.6	120.7
Fuel for SH (GJ/yr)	206.1	203.8	99.9	97.9	156.2	171.8
$\eta_{Furnace}$ (%)	73.8	73.8	73.1	73.1	73.7	73.7
Fuel for SH (litres/yr)	5370	5310	2604	2552	4071	4476
$Demand_{DHW}$ (GJ/yr)	11.8	11.8	11.8	11.8	9.7	9.7
Fuel for DHW (GJ/yr)	16.9	16.9	17.2	17.2	14.2	14.2
η_{DHW} (%)	78.3	78.3	76.9	76.9	78.0	78.0
Fuel for DHW (kWh/yr)	4702	4708	4786	4791	3949	3957
Total Fuel (litres/yr)	5370	5310	2604	2552	4071	4476
$Cost_{el,flat}$ (CAD/yr)	1172	1171	1283	1283	1087	1093
$Cost_{el,TOU}$ (CAD/yr)	1250	1250	1370	1369	1163	1169
$Cost_{NG}$ (CAD/yr)	3952	3839	1917	1845	2996	3236
$Cost_{tot,flat}$ (CAD/yr)	5124	5010	3200	3128	4083	4329
$Cost_{tot,TOU}$ (CAD/yr)	5202	5089	3287	3214	4159	4405
$GHG_{el,avg}$ (tonnes/yr)	5.61	5.61	6.15	6.14	5.20	5.23
$GHG_{el,high}$ (tonnes/yr)	10.46	10.46	11.45	11.45	9.70	9.76
GHG_{th} (tonnes/yr)	15.22	15.05	7.38	7.23	11.54	12.69
$GHG_{tot,avg}$ (tonnes/yr)	20.83	20.66	13.53	13.38	16.74	17.92
$GHG_{tot,high}$ (tonnes/yr)	25.68	25.51	18.84	18.68	21.24	22.44

Table H.8: Annual Base Case Simulation Results – Nova Scotia

	Test Case House 22		Test Case House 23		Test Case House 24	
	Halifax	Sydney	Halifax	Sydney	Halifax	Sydney
$Demand_{el}$ (kWh/yr)	10127	10200	8027	8173	8703	8828
$Demand_{SH}$ (GJ/yr)	54.8	68.5	107.7	135.0	89.4	113.0
Fuel for SH (GJ/yr)	72.8	90.0	144.0	178.4	119.0	148.6
$\eta_{Furnace}$ (%)	78.7	78.7	78.5	78.5	78.7	78.7
Fuel for SH (litres/yr)	1897	2345	3751	4648	3100	3873
$Demand_{DHW}$ (GJ/yr)	11.8	11.8	11.8	11.7	11.8	11.8
Fuel for DHW (GJ/yr)	23.5	23.6	21.6	21.6	22.0	22.0
η_{DHW} (%)	56.0	56.0	61.2	61.2	59.9	59.9
Fuel for DHW (litres/yr)	613	614	562	563	6110*	6125*
Total Fuel (litres/yr)	2510	2959	4312	5211	3100	3873
$Cost_{el,flat}$ (CAD/yr)	1026	1033	813	828	1501	1515
$Cost_{el,TOU}$ (CAD/yr)	678	683	541	550	1004	1013
$Cost_{NG}$ (CAD/yr)	1792	2110	3079	3715	2213	2761
$Cost_{tot,flat}$ (CAD/yr)	2818	3143	3892	4543	3714	4276
$Cost_{tot,TOU}$ (CAD/yr)	2470	2793	3620	4266	3218	3774
$GHG_{el,avg}$ (tonnes/yr)	7.69	7.74	6.09	6.20	11.24	11.35
$GHG_{el,high}$ (tonnes/yr)	9.28	9.34	7.35	7.49	13.57	13.70
GHG_{th} (tonnes/yr)	7.11	8.39	12.22	14.77	8.79	10.98
$GHG_{tot,avg}$ (tonnes/yr)	14.80	16.13	18.32	20.97	20.03	22.33
$GHG_{tot,high}$ (tonnes/yr)	16.39	17.73	19.58	22.26	22.36	24.67

* in kWh since test case house 24 uses electricity as the DHW fuel, while the remaining Nova Scotia test case houses use oil as the DHW fuel.

Table H.9: Annual Base Case Simulation Results – Prince Edward Island

	Test Case House 25	Test Case House 26	Test Case House 27
	Charlottetown	Charlottetown	Charlottetown
$Demand_{el}$ (kWh/yr)	7426	7857	7463
$Demand_{SH}$ (GJ/yr)	50.8	59.0	122.8
Fuel for SH (GJ/yr)	66.5	77.9	164.7
$\eta_{Furnace}$ (%)	79.0	78.7	77.7
Fuel for SH (litres/yr)	1733	2029	4291
$Demand_{DHW}$ (GJ/yr)	11.7	11.7	11.8
Fuel for DHW (GJ/yr)	28.4	26.7	24.3
η_{DHW} (%)	46.1	49.2	54.3
Fuel for DHW (litres/yr)	741	696	634
Total Fuel (litres/yr)	2474	2725	4925
$Cost_{el,flat}$ (CAD/yr)	793	839	797
$Cost_{el,TOU}$ (CAD/yr)	843	892	844
$Cost_{NG}$ (CAD/yr)	1724	1900	3432
$Cost_{tot,flat}$ (CAD/yr)	2517	2739	4230
$Cost_{tot,TOU}$ (CAD/yr)	2567	2791	4277
$GHG_{el,avg}$ (tonnes/yr)	8.32	8.80	8.36
$GHG_{el,high}$ (tonnes/yr)	8.99	9.52	9.04
GHG_{th} (tonnes/yr)	7.01	7.73	13.96
$GHG_{tot,avg}$ (tonnes/yr)	15.33	16.53	22.32
$GHG_{tot,high}$ (tonnes/yr)	16.00	17.24	23.00

Table H.10: Annual Base Case Simulation Results – Newfoundland

	Test Case House 28		Test Case House 29		Test Case House 30	
	Goose Bay	St. John's	Goose Bay	St. John's	Goose Bay	St. John's
$Demand_{el}$ (kWh/yr)	9917	9764	8984	8810	9582	9449
$Demand_{SH}$ (GJ/yr)	94.4	66.6	107.9	76.3	84.9	60.8
Fuel for SH (GJ/yr)	124.8	88.5	142.2	101.0	109.2	78.6
$\eta_{Furnace}$ (%)	78.4	78.4	78.6	78.6	80.3	80.3
Fuel for SH (litres/yr)	3252	2305	3705	2631	2846	2049
$Demand_{DHW}$ (GJ/yr)	11.8	11.8	11.8	11.8	13.9	13.9
Fuel for DHW (GJ/yr)	19.6	19.6	19.2	19.2	22.6	22.6
η_{DHW} (%)	67.4	67.4	68.8	68.8	67.9	67.9
Fuel for DHW (kWh/yr)	5452	5439	5343	5328	6276	6267
Total Fuel (litres/yr)	3252	2305	3705	2631	2846	2049
$Cost_{el,flat}$ (CAD/yr)	1371	1356	1278	1261	1415	1402
$Cost_{el,TOU}$ (CAD/yr)	1456	1442	1357	1342	1507	1494
$Cost_{NG}$ (CAD/yr)	2267	1607	2582	1834	1984	1428
$Cost_{tot,flat}$ (CAD/yr)	3638	2963	3860	3095	3398	2830
$Cost_{tot,TOU}$ (CAD/yr)	3723	3049	3939	3176	3491	2922
$GHG_{el,avg}$ (tonnes/yr)	0.32	0.32	0.30	0.30	0.33	0.33
$GHG_{el,high}$ (tonnes/yr)	11.97	11.84	11.16	11.01	12.35	12.24
GHG_{th} (tonnes/yr)	9.22	6.53	10.50	7.46	8.07	5.81
$GHG_{tot,avg}$ (tonnes/yr)	9.54	6.85	10.80	7.76	8.40	6.14
$GHG_{tot,high}$ (tonnes/yr)	21.19	18.38	21.66	18.47	20.42	18.05

The change in total fuel cost (natural gas/propane and electricity) compared to the base case is calculated according to Equation H.1 where a positive value indicates a reduction in fuel cost.

$$\Delta \cos t = \frac{\cos t_{BC} - \cos t_{ICE}}{\cos t_{BC}} \times 100\% \qquad \text{[H.1]}$$

Where:

Δcost = change in fuel cost relative to base case cost (%)

$cost_{BC}$ = total fuel cost in base case simulation (CAD/yr)

$cost_{ICE}$ = total fuel cost in ICE based cogeneration simulation (CAD/yr)

Similarly, the total GHG emissions (from electricity and fuel) compared to the base case is calculated according to Equation H.2 where a positive value indicates a reduction in GHG emissions. Two estimates of the total GHG emissions are given using the average and high intensity electricity GHG emissions as discussed in Section 9.2.

$$\Delta GHG = \frac{GHG_{BC} - GHG_{ICE}}{GHG_{BC}} \times 100\% \qquad \text{[H.2]}$$

Where:

ΔGHG = change in GHG emissions relative to base case GHG emissions (%)

GHG_{BC} = total GHG emissions in base case simulation (tonnes/yr)

GHG_{ICE} = total GHG emissions in ICE based cogeneration simulation (tonnes/yr)

A summary of the ICE based cogeneration results are presented in Tables H.11 – H.21.

Table H.11: Summary of Annual ICE Based Cogeneration Simulation Results – British Columbia

System	Indicator (%)	Test Case House 1		Test Case House 2		Test Case House 3	
		Prince George	Vancouver	Prince George	Vancouver	Prince George	Vancouver
1.0 kW, 300 kg	Δ Cost	-3.9	-13.9	-15.2	-30.9	-15.2	-29.8
	Δ GHG_{avg}	-25.4	-56.4	-62.4	-130.4	-49.3	-107.5
	Δ GHG_{max}	0.3	-7.2	-8.2	-19.7	-8.9	-19.3
1.0 kW, 450 kg	Δ Cost	-5.5	-14.4	-16.0	-31.0	-16.9	-30.2
	Δ GHG_{avg}	-27.8	-56.9	-63.4	-129.8	-52.0	-108.3
	Δ GHG_{max}	-1.2	-7.6	-9.0	-19.8	-10.4	-19.5
2.0 kW, 300 kg	Δ Cost	-10.8	-36.2	-42.5	-80.8	-33.8	-71.6
	Δ GHG_{avg}	-52.3	-122.0	-141.6	-296.9	-98.4	-230.4
	Δ GHG_{max}	-2.7	-22.4	-27.8	-56.4	-21.9	-50.0
2.0 kW, 450 kg	Δ Cost	-13.0	-36.2	-42.6	-81.0	-34.5	-71.9
	Δ GHG_{avg}	-55.6	-122.1	-141.8	-297.3	-99.5	-230.6
	Δ GHG_{max}	-4.8	-22.5	-27.9	-56.7	-22.6	-50.3

Table H.12: Summary of Annual ICE Based Cogeneration Simulation Results – Alberta

System	Indicator (%)	Test Case House 4		Test Case House 5		Test Case House 6	
		Calgary	Edmonton	Calgary	Edmonton	Calgary	Edmonton
1.0 kW, 300 kg	Δ Cost	-14.0	-11.1	-10.9	-8.2	-7.7	-9.0
	Δ GHG_{avg}	10.4	12.2	11.1	12.8	13.8	12.9
	Δ GHG_{max}	14.0	15.7	14.4	16.0	17.1	16.3
1.0 kW, 450 kg	Δ Cost	-14.8	-10.9	-10.8	-9.5	-10.3	-9.0
	Δ GHG_{avg}	9.9	12.4	11.1	12.0	12.1	12.9
	Δ GHG_{max}	13.6	15.9	14.4	15.3	15.6	16.4
2.0 kW, 300 kg	Δ Cost	-30.7	-27.5	-27.6	-25.3	-23.1	-24.2
	Δ GHG_{avg}	11.4	12.7	11.6	12.3	13.9	12.4
	Δ GHG_{max}	17.6	18.7	17.5	18.0	19.7	18.2
2.0 kW, 450 kg	Δ Cost	-32.1	-29.7	-29.8	-27.0	-30.9	-26.2
	Δ GHG_{avg}	10.5	11.2	10.1	11.1	8.7	11.0
	Δ GHG_{max}	16.8	17.4	16.1	17.0	14.8	16.9

Table H.13: Summary of Annual ICE Based Cogeneration Simulation Results – Saskatchewan

System	Indicator (%)	Test Case House 7		Test Case House 8		Test Case House 9	
		North Battleford	Regina	North Battleford	Regina	North Battleford	Regina
1.0 kW, 300 kg	Δ Cost	-5.0	-6.5	-4.9	-7.1	-3.3	-5.5
	Δ GHG_{avg}	10.3	9.6	10.0	8.8	10.3	9.3
	Δ GHG_{max}	18.9	18.6	18.2	17.4	18.4	17.9
1.0 kW, 450 kg	Δ Cost	-6.0	-7.9	-5.7	-8.1	-4.2	-6.7
	Δ GHG_{avg}	9.5	8.5	9.4	8.0	9.7	8.4
	Δ GHG_{max}	18.3	17.7	17.7	16.8	17.8	17.1
2.0 kW, 300 kg	Δ Cost	-18.5	-23.0	-17.9	-22.6	-15.0	-20.5
	Δ GHG_{avg}	5.9	3.3	7.3	4.6	6.5	3.3
	Δ GHG_{max}	19.7	18.0	21.1	19.2	19.2	17.0
2.0 kW, 450 kg	Δ Cost	-19.6	-24.0	-18.7	-23.2	-15.9	-21.1
	Δ GHG_{avg}	5.0	2.5	6.6	4.1	5.8	2.8
	Δ GHG_{max}	18.9	17.2	20.6	18.8	18.6	16.6

Table H.14: Summary of Annual ICE Based Cogeneration Simulation Results – Manitoba

System	Indicator (%)	Test Case House 10		Test Case House 11		Test Case House 12	
		Le Pas	Winnipeg	Le Pas	Winnipeg	Le Pas	Winnipeg
1.0 kW, 300 kg	Δ Cost	-23.1	-35.0	-20.3	-28.1	-22.2	-28.7
	Δ GHG_{avg}	-43.1	-61.6	-35.3	-47.5	-35.1	-45.1
	Δ GHG_{max}	20.4	17.4	19.2	18.6	15.2	15.3
1.0 kW, 450 kg	Δ Cost	-23.1	-35.9	-21.9	-30.1	-22.6	-29.8
	Δ GHG_{avg}	-43.1	-63.0	-37.2	-50.0	-35.5	-46.3
	Δ GHG_{max}	20.5	17.0	18.4	17.6	15.1	14.7
2.0 kW, 300 kg	Δ Cost	-44.4	-66.4	-38.1	-54.3	-36.5	-49.9
	Δ GHG_{avg}	-76.7	-110.7	-61.1	-84.5	-55.2	-73.9
	Δ GHG_{max}	25.9	20.5	22.1	18.3	17.9	14.9
2.0 kW, 450 kg	Δ Cost	-47.8	-69.3	-39.7	-56.0	-37.6	-51.0
	Δ GHG_{avg}	-80.9	-114.4	-63.0	-86.5	-56.5	-75.2
	Δ GHG_{max}	24.2	19.2	21.2	17.4	17.2	14.3

Table H.15: Summary of Annual ICE Based Cogeneration Simulation Results – Ontario

System	Indicator (%)	Test Case House 13		Test Case House 14		Test Case House 15	
		Ottawa	Toronto	Ottawa	Toronto	Ottawa	Toronto
1.0 kW, 300 kg	Δ Cost	-24.5	-26.4	-9.4	-11.4	-23.8	-28.6
	Δ GHG_{avg}	-46.5	-50.2	-21.7	-25.3	-40.9	-48.3
	Δ GHG_{max}	11.6	11.4	16.1	16.1	10.6	9.2
1.0 kW, 450 kg	Δ Cost	-24.4	-25.6	-8.1	-10.0	-25.6	-29.7
	Δ GHG_{avg}	-46.5	-49.2	-20.1	-23.6	-43.0	-49.6
	Δ GHG_{max}	11.7	11.8	16.9	17.0	9.3	8.3
2.0 kW, 300 kg	Δ Cost	-58.9	-66.1	-26.8	-34.8	-44.8	-52.1
	Δ GHG_{avg}	-98.8	-110.5	-46.9	-58.4	-70.2	-81.6
	Δ GHG_{max}	6.6	4.3	14.9	12.1	6.3	4.3
2.0 kW, 450 kg	Δ Cost	-58.9	-66.3	-26.1	-33.8	-46.7	-52.6
	Δ GHG_{avg}	-98.9	-110.7	-46.0	-57.3	-72.6	-82.1
	Δ GHG_{max}	6.5	4.1	15.4	12.7	5.1	4.1

Table H.16: Summary of Annual ICE Based Cogeneration Simulation Results – Quebec

System	Indicator (%)	Test Case House 16		Test Case House 17		Test Case House 18	
		Montreal	Quebec	Montreal	Quebec	Montreal	Quebec
1.0 kW, 300 kg	Δ Cost	-120.5	-110.8	-90.8	-105.6	-98.1	-108.9
	Δ GHG_{avg}	-113.4	-67.1	-50.8	-48.5	-70.9	-62.7
	Δ GHG_{max}	5.9	10.8	9.3	9.8	10.1	9.7
1.0 kW, 450 kg	Δ Cost	-132.5	-114.7	-94.1	-109.3	-103.5	-109.7
	Δ GHG_{avg}	-125.4	-70.2	-53.5	-51.2	-75.7	-63.4
	Δ GHG_{max}	1.3	9.2	7.8	8.3	7.8	9.4
2.0 kW, 300 kg	Δ Cost	-199.9	-170.2	-132.0	-153.4	-150.5	-162.3
	Δ GHG_{avg}	-198.4	-118.2	-83.5	-82.9	-120.4	-108.1
	Δ GHG_{max}	-15.4	-5.1	-4.2	-4.9	-4.6	-3.3
2.0 kW, 450 kg	Δ Cost	-201.6	-170.0	-135.8	-155.8	-152.3	-166.2
	Δ GHG_{avg}	-201.2	-119.2	-88.9	-87.2	-123.0	-113.0
	Δ GHG_{max}	-16.5	-5.6	-7.2	-7.3	-5.8	-5.7

Table H.17: Summary of Annual ICE Based Cogeneration Simulation Results – New Brunswick

System	Indicator (%)	Test Case House 19		Test Case House 20		Test Case House 21	
		Fredericton	Saint John	Fredericton	Saint John	Fredericton	Saint John
1.0 kW, 300 kg	Δ Cost	-104.3	-106.7	-118.1	-118.1	-113.6	-109.6
	Δ GHG_{avg}	10.4	10.3	5.5	5.5	6.4	9.0
	Δ GHG_{max}	23.6	23.2	25.4	25.4	21.5	22.8
1.0 kW, 450 kg	Δ Cost	-105.3	-107.4	-119.6	-119.6	-115.6	-110.3
	Δ GHG_{avg}	10.0	10.0	4.9	4.9	5.5	8.8
	Δ GHG_{max}	23.2	23.0	25.0	25.0	20.9	22.6
2.0 kW, 300 kg	Δ Cost	-137.8	-131.8	-172.2	-172.2	-153.9	-143.0
	Δ GHG_{avg}	1.6	5.2	-10.0	-10.0	-4.9	0.6
	Δ GHG_{max}	19.7	22.6	19.6	19.6	16.6	19.9
2.0 kW, 450 kg	Δ Cost	-131.7	-126.9	-172.2	-172.2	-150.8	-139.0
	Δ GHG_{avg}	1.9	5.2	-10.7	-10.7	-5.5	0.4
	Δ GHG_{max}	19.9	22.7	19.1	19.1	16.1	19.8

Table H.18: Summary of Annual ICE Based Cogeneration Simulation Results – Nova Scotia

System	Indicator (%)	Test Case House 22		Test Case House 23		Test Case House 24	
		Halifax	Sydney	Halifax	Sydney	Halifax	Sydney
1.0 kW, 300 kg	Δ Cost	-133.5	-122.0	-128.2	-121.4	-117.7	-106.9
	Δ GHG_{avg}	10.1	13.3	12.0	13.6	24.6	26.5
	Δ GHG_{max}	14.9	17.5	15.8	16.9	30.5	31.7
1.0 kW, 450 kg	Δ Cost	-135.6	-124.6	-131.7	-123.5	-119.9	-108.4
	Δ GHG_{avg}	9.2	12.3	10.8	12.9	23.9	26.1
	Δ GHG_{max}	14.1	16.5	14.7	16.2	29.9	31.2
2.0 kW, 300 kg	Δ Cost	-201.8	-181.1	-174.0	-152.4	-167.6	-144.9
	Δ GHG_{avg}	0.5	5.4	3.9	10.1	17.2	21.9
	Δ GHG_{max}	9.1	12.9	9.9	15.0	25.4	29.0
2.0 kW, 450 kg	Δ Cost	-202.6	-180.3	-172.1	-149.3	-168.0	-143.8
	Δ GHG_{avg}	-0.1	5.2	2.9	9.4	15.9	21.1
	Δ GHG_{max}	8.6	12.7	8.9	14.3	24.3	28.2

Table H.19: Summary of Annual ICE Based Cogeneration Simulation Results – Prince Edward Island

System	Indicator (%)	Test Case House 25	Test Case House 26	Test Case House 27
		Charlottetown	Charlottetown	Charlottetown
1.0 kW, 300 kg	Δ Cost	-51.6	-47.4	-41.3
	Δ GHG_{avg}	21.4	22.1	20.0
	Δ GHG_{max}	23.6	24.1	21.6
1.0 kW, 450 kg	Δ Cost	-53.5	-48.2	-41.8
	Δ GHG_{avg}	20.4	21.5	19.8
	Δ GHG_{max}	22.6	23.5	21.4
2.0 kW, 300 kg	Δ Cost	-90.5	-81.9	-62.2
	Δ GHG_{avg}	13.9	16.8	17.4
	Δ GHG_{max}	17.4	20.0	19.8
2.0 kW, 450 kg	Δ Cost	-90.9	-82.1	-60.0
	Δ GHG_{avg}	13.4	16.3	16.9
	Δ GHG_{max}	16.9	19.5	19.2

Table H.20: Summary of Annual ICE Based Cogeneration Simulation Results – Newfoundland

System	Indicator (%)	Test Case House 28		Test Case House 29		Test Case House 30	
		Goose Bay	St. John's	Goose Bay	St. John's	Goose Bay	St. John's
1.0 kW, 300 kg	Δ Cost	-82.2	-81.8	-79.9	-77.6	-79.3	-81.8
	Δ GHG_{avg}	-36.0	-52.3	-27.3	-39.1	-41.7	-62.2
	Δ GHG_{max}	25.2	27.7	25.9	29.3	28.1	29.4
1.0 kW, 450 kg	Δ Cost	-85.7	-82.1	-80.9	-81.1	-84.1	-82.6
	Δ GHG_{avg}	-38.8	-52.4	-28.0	-41.9	-45.7	-62.9
	Δ GHG_{max}	23.9	27.3	25.6	28.0	26.5	29.0
2.0 kW, 300 kg	Δ Cost	-114.7	-127.4	-105.2	-116.6	-119.7	-131.8
	Δ GHG_{avg}	-64.5	-98.9	-47.6	-75.3	-79.0	-116.5
	Δ GHG_{max}	22.4	21.8	24.2	23.8	23.0	22.6
2.0 kW, 450 kg	Δ Cost	-116.1	-126.0	-107.4	-115.9	-117.9	-130.8
	Δ GHG_{avg}	-67.3	-98.1	-51.1	-75.4	-79.1	-115.9
	Δ GHG_{max}	21.2	22.1	22.5	23.8	23.0	22.8

Table H.21: Summary of Annual ICE Base Cogeneration Simulation Results – Prince George, 3.0 kW ICE, 1000 kg Thermal Storage

Indicator (%)	Test Case House 1	Test Case House 2	Test Case House 3
	Prince George	Prince George	Prince George
Δ Cost	-28.4	-75.2	-47.8
Δ GHG_{avg}	-88.0	-220.4	-130.2
Δ GHG_{max}	-16.8	-53.7	-32.7

The results of the simulations using a 3.0 kW ICE and a 1000 kg thermal storage tank in the Prince George test case houses illustrate several important points:

- Due to the high electrical demand of test case house 1 and test case house 2 (>19,000 kWh/year), the 3.0 kW ICE is able to meet more of the electrical demand compared to the 1.0 kW and 2.0 kW systems.

- Due to the high space heating demand of test case house 1 and test case house 3 and the higher thermal output of the ICE based cogeneration system, relative to the 1.0 kW and 2.0 kW systems, the larger thermal storage tank is beneficial in that it can store more of the thermal energy generated by the ICE based cogeneration.

- Depending on the test case house specific electrical and thermal demands, different combinations of ICE capacity and thermal storage capacity affect the cost and GHG emissions profile.

- Because the range of electrical and thermal demands of the test case houses is large (10,000 kWh/year to 20,000 kWh/year and 20 GJ to 145 GJ) the performance of the systems tested is variable because in some cases, the combinations of ICE and thermal storage capacities are either over or under sized. The results of these Prince George simulation highlight the need for further optimization studies to be performed to determine the most suitable ICE and thermal storage capacities based on the test case house specific electrical and thermal demands.

The detailed simulation results for the ICE based cogeneration case are presented in Tables H.22 – H.79.

Table H.22: Test Case House 1, Prince George – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	19246	19233	19286	19343
$Demand_{el,grid}$ (kWh/yr)	11229	11218	5551	5604
$ICE_{Output,el}$ (kWh/yr)	8016	8015	13735	13740
$ICE_{Output,th}$ (GJ/yr)	76.5	76.5	137.1	137.2
BB_{Output} (GJ/yr)	73.5	77.2	24.4	29.2
Heat Dump (GJ/yr)	32.1	36.1	44.2	49.2
$Demand_{SH}$ (GJ/yr)	107.0	106.8	106.4	106.3
$Demand_{DHW}$ (GJ/yr)	12.1	12.1	12.2	12.2
η_{el} (%)	23.2	23.2	21.3	21.3
η_{CHP} (%)	62.3	62.3	44.5	44.6
$Cost_{el,flat}$ (CAD/yr)	711	710	351	355
$Cost_{el,TOU}$ (CAD/yr)	771	770	393	397
Total Fuel (m^3/yr)	6012	6131	7407	7566
$Cost_{fuel}$ (CAD/yr)	2451	2500	3020	3085
$Cost_{tot,flat}$ (CAD/yr)	3162	3210	3371	3440
$Cost_{tot,TOU}$ (CAD/yr)	3222	3270	3413	3482
$GHG_{el,avg}$ (tonnes/yr)	0.27	0.27	0.13	0.13
$GHG_{el,high}$ (tonnes/yr)	4.21	4.21	2.08	2.10
GHG_{th} (tonnes/yr)	11.16	11.38	13.75	14.05
$GHG_{tot,avg}$ (tonnes/yr)	11.43	11.65	13.88	14.18
$GHG_{tot,high}$ (tonnes/yr)	15.37	15.59	15.83	16.15

Table H.23: Test Case House 1, Vancouver – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	19202	19273	19256	19266
$Demand_{el,grid}$ (kWh/yr)	10710	10774	4998	5004
$ICE_{Output,el}$ (kWh/yr)	8492	8498	14258	14262
$ICE_{Output,th}$ (GJ/yr)	80.4	80.5	141.3	141.4
BB_{Output} (GJ/yr)	29.6	30.0	0.0	0.0
Heat Dump (GJ/yr)	37.3	38.4	68.3	68.5
$Demand_{SH}$ (GJ/yr)	61.6	60.9	61.7	61.5
$Demand_{DHW}$ (GJ/yr)	12.4	12.4	12.7	12.7
η_{el} (%)	23.2	23.2	21.0	21.0
η_{CHP} (%)	60.5	60.7	42.7	42.7
$Cost_{el,flat}$ (CAD/yr)	678	682	316	317
$Cost_{el,TOU}$ (CAD/yr)	736	740	355	356
Total Fuel (m^3/yr)	4798	4813	6945	6946
$Cost_{fuel}$ (CAD/yr)	1956	1962	2831	2832
$Cost_{tot,flat}$ (CAD/yr)	2634	2644	3148	3149
$Cost_{tot,TOU}$ (CAD/yr)	2692	2702	3187	3188
$GHG_{el,avg}$ (tonnes/yr)	0.26	0.26	0.12	0.12
$GHG_{el,high}$ (tonnes/yr)	4.02	4.04	1.87	1.88
GHG_{th} (tonnes/yr)	8.91	8.94	12.89	12.89
$GHG_{tot,avg}$ (tonnes/yr)	9.16	9.19	13.01	13.01
$GHG_{tot,high}$ (tonnes/yr)	12.92	12.98	14.77	14.77

Table H.24: Test Case House 2, Prince George – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	19093	19198	19197	19206
$Demand_{el,grid}$ (kWh/yr)	11234	11331	6043	6045
$ICE_{Output,el}$ (kWh/yr)	7858	7867	13153	13160
$ICE_{Output,th}$ (GJ/yr)	74.8	74.9	131.5	131.4
BB_{Output} (GJ/yr)	22.6	23.3	2.5	2.7
Heat Dump (GJ/yr)	38.5	39.7	75.4	75.6
$Demand_{SH}$ (GJ/yr)	45.4	45.0	44.8	44.6
$Demand_{DHW}$ (GJ/yr)	14.8	14.8	15.2	15.2
η_{el} (%)	23.0	23.0	20.7	20.7
η_{CHP} (%)	60.6	60.8	44.3	44.3
$Cost_{el,flat}$ (CAD/yr)	711	717	383	383
$Cost_{el,TOU}$ (CAD/yr)	772	778	425	425
Total Fuel (m^3/yr)	4305	4331	6542	6547
$Cost_{fuel}$ (CAD/yr)	1755	1766	2667	2669
$Cost_{tot,flat}$ (CAD/yr)	2466	2483	3050	3052
$Cost_{tot,TOU}$ (CAD/yr)	2527	2544	3092	3094
$GHG_{el,avg}$ (tonnes/yr)	0.27	0.27	0.15	0.15
$GHG_{el,high}$ (tonnes/yr)	4.21	4.25	2.27	2.27
GHG_{th} (tonnes/yr)	7.99	8.04	12.14	12.16
$GHG_{tot,avg}$ (tonnes/yr)	8.26	8.31	12.29	12.30
$GHG_{tot,high}$ (tonnes/yr)	12.20	12.29	14.41	14.42

Table H.25: Test Case House 2, Vancouver – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	19093	19190	18990	19047
$Demand_{el,grid}$ (kWh/yr)	10807	10903	5397	5432
$ICE_{Output,el}$ (kWh/yr)	8285	8287	13593	13615
$ICE_{Output,th}$ (GJ/yr)	77.6	77.6	130.4	130.5
BB_{Output} (GJ/yr)	1.7	1.3	0.0	0.0
Heat Dump (GJ/yr)	46.5	46.2	96.7	97.1
$Demand_{SH}$ (GJ/yr)	18.7	18.6	18.4	18.2
$Demand_{DHW}$ (GJ/yr)	15.5	15.5	16.6	16.6
η_{el} (%)	22.9	22.9	20.3	20.4
η_{CHP} (%)	59.1	59.1	41.8	41.9
$Cost_{el,flat}$ (CAD/yr)	684	690	342	344
$Cost_{el,TOU}$ (CAD/yr)	744	750	380	383
Total Fuel (m^3/yr)	3832	3821	6772	6778
$Cost_{fuel}$ (CAD/yr)	1562	1558	2761	2764
$Cost_{tot,flat}$ (CAD/yr)	2246	2248	3103	3107
$Cost_{tot,TOU}$ (CAD/yr)	2306	2308	3141	3146
$GHG_{el,avg}$ (tonnes/yr)	0.26	0.26	0.13	0.13
$GHG_{el,high}$ (tonnes/yr)	4.05	4.09	2.02	2.04
GHG_{th} (tonnes/yr)	7.11	7.09	12.57	12.58
$GHG_{tot,avg}$ (tonnes/yr)	7.37	7.35	12.70	12.71
$GHG_{tot,high}$ (tonnes/yr)	11.17	11.18	14.60	14.62

Table H.26: Test Case House 3, Prince George – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	16942	16928	16993	17027
$Demand_{el,grid}$ (kWh/yr)	9037	9024	3948	3970
$ICE_{Output,el}$ (kWh/yr)	7906	7904	13045	13057
$ICE_{Output,th}$ (GJ/yr)	75.6	75.6	132.4	132.6
BB_{Output} (GJ/yr)	57.1	60.3	28.0	29.2
Heat Dump (GJ/yr)	44.5	47.7	72.4	74.2
$Demand_{SH}$ (GJ/yr)	77.1	77.0	76.8	76.3
$Demand_{DHW}$ (GJ/yr)	12.4	12.5	12.6	12.5
η_{el} (%)	23.1	23.1	20.7	20.7
η_{CHP} (%)	59.1	59.1	41.6	41.7
$Cost_{el,flat}$ (CAD/yr)	572	571	250	251
$Cost_{el,TOU}$ (CAD/yr)	5446	5550	7344	7386
Total Fuel (m^3/yr)	622	622	282	284
$Cost_{fuel}$ (CAD/yr)	2220	2263	2994	3011
$Cost_{tot,flat}$ (CAD/yr)	2792	2834	3244	3263
$Cost_{tot,TOU}$ (CAD/yr)	2843	2884	3276	3295
$GHG_{el,avg}$ (tonnes/yr)	0.22	0.22	0.09	0.10
$GHG_{el,high}$ (tonnes/yr)	3.39	3.38	1.48	1.49
GHG_{th} (tonnes/yr)	10.11	10.30	13.63	13.71
$GHG_{tot,avg}$ (tonnes/yr)	10.33	10.52	13.73	13.81
$GHG_{tot,high}$ (tonnes/yr)	13.50	13.69	15.11	15.20

Table H.27: Test Case House 3, Vancouver – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	17071	17069	16911	16975
$Demand_{el,grid}$ (kWh/yr)	8714	8710	3444	3495
$ICE_{Output,el}$ (kWh/yr)	8357	8359	13467	13480
$ICE_{Output,th}$ (GJ/yr)	79.4	79.5	131.0	130.9
BB_{Output} (GJ/yr)	10.7	11.2	0.0	0.0
Heat Dump (GJ/yr)	46.7	47.2	86.6	86.7
$Demand_{SH}$ (GJ/yr)	32.0	31.9	31.9	31.7
$Demand_{DHW}$ (GJ/yr)	12.8	12.8	13.8	13.8
η_{el} (%)	23.0	23.0	20.3	20.3
η_{CHP} (%)	57.6	57.5	39.4	39.4
$Cost_{el,flat}$ (CAD/yr)	552	551	218	221
$Cost_{el,TOU}$ (CAD/yr)	601	601	247	251
Total Fuel (m^3/yr)	4147	4161	6736	6739
$Cost_{fuel}$ (CAD/yr)	1691	1697	2746	2748
$Cost_{tot,flat}$ (CAD/yr)	2242	2248	2964	2969
$Cost_{tot,TOU}$ (CAD/yr)	2291	2297	2993	2998
$GHG_{el,avg}$ (tonnes/yr)	0.21	0.21	0.08	0.08
$GHG_{el,high}$ (tonnes/yr)	3.27	3.27	1.29	1.31
GHG_{th} (tonnes/yr)	7.70	7.73	12.50	12.51
$GHG_{tot,avg}$ (tonnes/yr)	7.91	7.93	12.59	12.60
$GHG_{tot,high}$ (tonnes/yr)	10.97	10.99	13.80	13.82

Table H.28: Test Case House 4, Calgary – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	12191	12181	12206	12237
$Demand_{el,grid}$ (kWh/yr)	5029	5021	1494	1510
$ICE_{Output,el}$ (kWh/yr)	7161	7161	10712	10728
$ICE_{Output,th}$ (GJ/yr)	69.7	69.7	116.5	116.6
BB_{Output} (GJ/yr)	46.2	47.5	21.9	23.7
Heat Dump (GJ/yr)	44.4	45.8	67.4	70.0
$Demand_{SH}$ (GJ/yr)	60.2	60.1	59.6	59.0
$Demand_{DHW}$ (GJ/yr)	12.6	12.6	12.7	12.7
η_{el} (%)	22.4	22.4	19.0	19.0
η_{CHP} (%)	53.4	53.3	36.5	36.5
$Cost_{el,flat}$ (CAD/yr)	388	387	115	116
$Cost_{el,TOU}$ (CAD/yr)	422	421	130	131
Total Fuel (m^3/yr)	4821	4863	6381	6447
$Cost_{fuel}$ (CAD/yr)	1865	1881	2468	2494
$Cost_{tot,flat}$ (CAD/yr)	2253	2268	2584	2610
$Cost_{tot,TOU}$ (CAD/yr)	2287	2302	2598	2625
$GHG_{el,avg}$ (tonnes/yr)	4.33	4.32	1.29	1.30
$GHG_{el,high}$ (tonnes/yr)	4.95	4.95	1.47	1.49
GHG_{th} (tonnes/yr)	8.95	9.03	11.85	11.97
$GHG_{tot,avg}$ (tonnes/yr)	13.28	13.35	13.13	13.27
$GHG_{tot,high}$ (tonnes/yr)	13.90	13.97	13.32	13.45

Table H.29: Test Case House 4, Edmonton – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	12219	12211	12224	12241
$Demand_{el,grid}$ (kWh/yr)	4808	4802	1324	1340
$ICE_{Output,el}$ (kWh/yr)	7411	7410	10900	10901
$ICE_{Output,th}$ (GJ/yr)	72.4	72.5	120.4	120.3
BB_{Output} (GJ/yr)	49.0	48.7	23.7	27.3
Heat Dump (GJ/yr)	42.4	42.4	65.4	68.9
$Demand_{SH}$ (GJ/yr)	67.8	67.6	67.4	67.3
$Demand_{DHW}$ (GJ/yr)	12.5	12.5	12.6	12.6
η_{el} (%)	22.3	22.3	18.7	18.7
η_{CHP} (%)	51.9	51.9	35.9	35.9
$Cost_{el,flat}$ (CAD/yr)	371	370	102	103
$Cost_{el,TOU}$ (CAD/yr)	399	399	113	115
Total Fuel (m^3/yr)	5045	5036	6624	6740
$Cost_{fuel}$ (CAD/yr)	1951	1948	2562	2607
$Cost_{tot,flat}$ (CAD/yr)	2322	2318	2664	2710
$Cost_{tot,TOU}$ (CAD/yr)	2351	2347	2675	2722
$GHG_{el,avg}$ (tonnes/yr)	4.14	4.13	1.14	1.15
$GHG_{el,high}$ (tonnes/yr)	4.74	4.73	1.30	1.32
GHG_{th} (tonnes/yr)	9.37	9.35	12.30	12.51
$GHG_{tot,avg}$ (tonnes/yr)	13.51	13.48	13.44	13.67
$GHG_{tot,high}$ (tonnes/yr)	14.10	14.08	13.60	13.83

Table H.30: Test Case House 5, Calgary – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	12343	12338	12338	12346
$Demand_{el,grid}$ (kWh/yr)	5356	5352	1820	1831
$ICE_{Output,el}$ (kWh/yr)	6987	6986	10519	10515
$ICE_{Output,th}$ (GJ/yr)	68.6	68.7	115.5	115.4
BB_{Output} (GJ/yr)	49.3	49.2	26.3	29.8
Heat Dump (GJ/yr)	39.8	40.1	63.9	67.5
$Demand_{SH}$ (GJ/yr)	64.5	64.2	64.1	64.0
$Demand_{DHW}$ (GJ/yr)	14.9	14.9	15.0	15.1
η_{el} (%)	22.1	22.1	18.7	18.7
η_{CHP} (%)	54.0	54.0	36.7	36.7
$Cost_{el,flat}$ (CAD/yr)	413	413	140	141
$Cost_{el,TOU}$ (CAD/yr)	448	448	155	156
Total Fuel (m^3/yr)	4877	4874	6476	6590
$Cost_{fuel}$ (CAD/yr)	1887	1885	2505	2549
$Cost_{tot,flat}$ (CAD/yr)	2299	2298	2645	2690
$Cost_{tot,TOU}$ (CAD/yr)	2335	2333	2660	2705
$GHG_{el,avg}$ (tonnes/yr)	4.61	4.61	1.57	1.58
$GHG_{el,high}$ (tonnes/yr)	5.28	5.27	1.79	1.80
GHG_{th} (tonnes/yr)	9.05	9.05	12.02	12.23
$GHG_{tot,avg}$ (tonnes/yr)	13.67	13.66	13.59	13.81
$GHG_{tot,high}$ (tonnes/yr)	14.33	14.32	13.81	14.04

Table H.31: Test Case House 5, Edmonton – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	12380	12379	12377	12379
$Demand_{el,grid}$ (kWh/yr)	5155	5153	1646	1651
$ICE_{Output,el}$ (kWh/yr)	7225	7225	10731	10729
$ICE_{Output,th}$ (GJ/yr)	71.2	71.4	119.4	119.3
BB_{Output} (GJ/yr)	52.8	55.0	30.3	33.2
Heat Dump (GJ/yr)	38.4	41.4	64.9	67.9
$Demand_{SH}$ (GJ/yr)	72.0	71.4	71.2	70.9
$Demand_{DHW}$ (GJ/yr)	14.9	14.9	15.0	15.0
η_{el} (%)	22.0	22.0	18.4	18.4
η_{CHP} (%)	52.5	52.5	36.1	36.0
$Cost_{el,flat}$ (CAD/yr)	397	397	127	127
$Cost_{el,TOU}$ (CAD/yr)	429	429	139	139
Total Fuel (m^3/yr)	5121	5192	6793	6887
$Cost_{fuel}$ (CAD/yr)	1981	2008	2627	2664
$Cost_{tot,flat}$ (CAD/yr)	2378	2406	2754	2791
$Cost_{tot,TOU}$ (CAD/yr)	2410	2437	2766	2803
$GHG_{el,avg}$ (tonnes/yr)	4.44	4.44	1.42	1.42
$GHG_{el,high}$ (tonnes/yr)	5.08	5.07	1.62	1.63
GHG_{th} (tonnes/yr)	9.51	9.64	12.61	12.79
$GHG_{tot,avg}$ (tonnes/yr)	13.94	14.07	14.03	14.21
$GHG_{tot,high}$ (tonnes/yr)	14.58	14.71	14.23	14.41

Table H.32: Test Case House 6, Calgary – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11295	11283	11326	11364
$Demand_{el,grid}$ (kWh/yr)	4320	4309	1211	1223
$ICE_{Output,el}$ (kWh/yr)	6976	6974	10115	10141
$ICE_{Output,th}$ (GJ/yr)	69.2	69.1	114.4	114.6
BB_{Output} (GJ/yr)	46.6	50.8	21.6	23.7
Heat Dump (GJ/yr)	35.9	40.2	56.5	59.3
$Demand_{SH}$ (GJ/yr)	68.9	68.6	68.3	67.8
$Demand_{DHW}$ (GJ/yr)	12.4	12.4	12.5	12.5
η_{el} (%)	22.1	22.1	18.3	18.36421
η_{CHP} (%)	51.0	51.0	35.6	35.7
$Cost_{el,flat}$ (CAD/yr)	333	332	93	94
$Cost_{el,TOU}$ (CAD/yr)	367	366	106	108
Total Fuel (m^3/yr)	4786	4923	6215	6622
$Cost_{fuel}$ (CAD/yr)	1851	1904	2404	2561
$Cost_{tot,flat}$ (CAD/yr)	2184	2236	2497	2656
$Cost_{tot,TOU}$ (CAD/yr)	2218	2270	2510	2669
$GHG_{el,avg}$ (tonnes/yr)	3.72	3.71	1.04	1.05
$GHG_{el,high}$ (tonnes/yr)	4.25	4.24	1.19	1.20
GHG_{th} (tonnes/yr)	8.89	9.14	11.54	12.29
$GHG_{tot,avg}$ (tonnes/yr)	12.60	12.85	12.58	13.35
$GHG_{tot,high}$ (tonnes/yr)	13.14	13.38	12.73	13.50

Table H.33: Test Case House 6, Edmonton – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11298	11289	11299	11302
$Demand_{el,grid}$ (kWh/yr)	4106	4098	1052	1062
$ICE_{Output,el}$ (kWh/yr)	7192	7191	10247	10240
$ICE_{Output,th}$ (GJ/yr)	71.2	71.3	117.3	117.1
BB_{Output} (GJ/yr)	57.0	57.0	31.5	35.0
Heat Dump (GJ/yr)	41.6	42.3	62.8	66.1
$Demand_{SH}$ (GJ/yr)	75.5	74.8	74.8	74.7
$Demand_{DHW}$ (GJ/yr)	21.9	21.9	18.0	18.0
η_{el} (%)	49.6	49.6	34.9	34.9
η_{CHP} (%)	49.6	49.6	34.9	34.9
$Cost_{el,flat}$ (CAD/yr)	316	316	81	82
$Cost_{el,TOU}$ (CAD/yr)	345	344	91	92
Total Fuel (m^3/yr)	5248	5247	6703	6815
$Cost_{fuel}$ (CAD/yr)	2030	2029	2593	2636
$Cost_{tot,flat}$ (CAD/yr)	2346	2345	2674	2718
$Cost_{tot,TOU}$ (CAD/yr)	2375	2374	2683	2727
$GHG_{el,avg}$ (tonnes/yr)	3.53	3.53	0.91	0.91
$GHG_{el,high}$ (tonnes/yr)	4.04	4.04	1.04	1.05
GHG_{th} (tonnes/yr)	9.74	9.74	12.44	12.65
$GHG_{tot,avg}$ (tonnes/yr)	13.28	13.27	13.35	13.57
$GHG_{tot,high}$ (tonnes/yr)	13.79	13.78	13.48	13.70

Table H.34: Test Case House 7, North Battleford – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10281	10281	10275	10271
$Demand_{el,grid}$ (kWh/yr)	3136	3132	594	599
$ICE_{Output,el}$ (kWh/yr)	7145	7148	9681	9673
$ICE_{Output,th}$ (GJ/yr)	71.1	71.4	115.5	115.4
BB_{Output} (GJ/yr)	64.4	66.2	42.9	45.0
Heat Dump (GJ/yr)	45.4	48.6	69.9	72.0
$Demand_{SH}$ (GJ/yr)	78.8	77.8	77.2	77.1
$Demand_{DHW}$ (GJ/yr)	12.6	12.5	12.7	12.7
η_{el} (%)	21.5	21.5	17.1	17.1
η_{CHP} (%)	45.8	45.9	33.3	33.3
$Cost_{el,flat}$ (CAD/yr)	282	282	53	54
$Cost_{el,TOU}$ (CAD/yr)	314	313	62	62
Total Fuel (m^3/yr)	5518	5579	7006	7072
$Cost_{fuel}$ (CAD/yr)	1872	1893	2377	2400
$Cost_{tot,flat}$ (CAD/yr)	2154	2174	2431	2453
$Cost_{tot,TOU}$ (CAD/yr)	2186	2206	2439	2462
$GHG_{el,avg}$ (tonnes/yr)	2.63	2.63	0.50	0.50
$GHG_{el,high}$ (tonnes/yr)	3.57	3.57	0.68	0.68
GHG_{th} (tonnes/yr)	10.24	10.36	13.01	13.13
$GHG_{tot,avg}$ (tonnes/yr)	12.88	12.99	13.51	13.63
$GHG_{tot,high}$ (tonnes/yr)	13.82	13.92	13.68	13.81

Table H.35: Test Case House 7, Regina – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10231	10231	10231	10226
$Demand_{el,grid}$ (kWh/yr)	3133	3131	604	607
$ICE_{Output,el}$ (kWh/yr)	7098	7099	9626	9619
$ICE_{Output,th}$ (GJ/yr)	70.6	70.8	114.6	114.5
BB_{Output} (GJ/yr)	57.5	60.0	40.2	42.1
Heat Dump (GJ/yr)	46.7	50.2	74.2	76.0
$Demand_{SH}$ (GJ/yr)	70.0	69.3	69.1	69.1
$Demand_{DHW}$ (GJ/yr)	12.7	12.6	12.7	12.7
η_{el} (%)	21.5	21.5	17.1	17.1
η_{CHP} (%)	45.9	45.9	33.3	33.3
$Cost_{el,flat}$ (CAD/yr)	282	282	54	55
$Cost_{el,TOU}$ (CAD/yr)	313	313	63	63
Total Fuel (m^3/yr)	5270	5352	6881	6942
$Cost_{fuel}$ (CAD/yr)	1788	1816	2335	2355
$Cost_{tot,flat}$ (CAD/yr)	2070	2097	2389	2410
$Cost_{tot,TOU}$ (CAD/yr)	2101	2129	2397	2418
$GHG_{el,avg}$ (tonnes/yr)	2.63	2.63	0.51	0.51
$GHG_{el,high}$ (tonnes/yr)	3.57	3.57	0.69	0.69
GHG_{th} (tonnes/yr)	9.78	9.94	12.77	12.89
$GHG_{tot,avg}$ (tonnes/yr)	12.42	12.57	13.28	13.40
$GHG_{tot,high}$ (tonnes/yr)	13.35	13.50	13.46	13.58

Table H.36: Test Case House 8, North Battleford – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11333	11333	11325	11323
$Demand_{el,grid}$ (kWh/yr)	4084	4083	959	965
$ICE_{Output,el}$ (kWh/yr)	7249	7250	10366	10359
$ICE_{Output,th}$ (GJ/yr)	72.0	72.2	119.2	119.1
BB_{Output} (GJ/yr)	60.8	62.3	39.2	40.8
Heat Dump (GJ/yr)	45.0	47.4	71.4	73.0
$Demand_{SH}$ (GJ/yr)	76.6	75.9	75.6	75.6
$Demand_{DHW}$ (GJ/yr)	12.5	12.5	12.7	12.7
η_{el} (%)	21.7	21.7	17.7	17.7
η_{CHP} (%)	48.7	48.8	34.4	34.4
$Cost_{el,flat}$ (CAD/yr)	367	367	86	87
$Cost_{el,TOU}$ (CAD/yr)	404	404	97	98
Total Fuel (m^3/yr)	5430	5479	7061	7113
$Cost_{fuel}$ (CAD/yr)	1842	1859	2396	2413
$Cost_{tot,flat}$ (CAD/yr)	2209	2226	2482	2500
$Cost_{tot,TOU}$ (CAD/yr)	2246	2263	2493	2511
$GHG_{el,avg}$ (tonnes/yr)	3.43	3.43	0.80	0.81
$GHG_{el,high}$ (tonnes/yr)	4.65	4.65	1.09	1.10
GHG_{th} (tonnes/yr)	10.08	10.17	13.11	13.20
$GHG_{tot,avg}$ (tonnes/yr)	13.51	13.60	13.91	14.01
$GHG_{tot,high}$ (tonnes/yr)	14.73	14.82	14.20	14.30

Table H.37: Test Case House 8, Regina – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11290	11292	11286	11280
$Demand_{el,grid}$ (kWh/yr)	4088	4089	978	978
$ICE_{Output,el}$ (kWh/yr)	7202	7204	10308	10302
$ICE_{Output,th}$ (GJ/yr)	71.3	71.5	118.2	118.1
BB_{Output} (GJ/yr)	55.7	57.5	37.6	38.8
Heat Dump (GJ/yr)	46.4	49.1	75.9	77.2
$Demand_{SH}$ (GJ/yr)	69.2	68.6	68.4	68.2
$Demand_{DHW}$ (GJ/yr)	12.7	12.6	12.7	12.8
η_{el} (%)	21.7	21.7	17.7	17.7
η_{CHP} (%)	48.8	48.9	34.5	34.5
$Cost_{el,flat}$ (CAD/yr)	367	368	88	88
$Cost_{el,TOU}$ (CAD/yr)	404	404	99	99
Total Fuel (m^3/yr)	5239	5299	6974	7011
$Cost_{fuel}$ (CAD/yr)	1778	1798	2366	2379
$Cost_{tot,flat}$ (CAD/yr)	2145	2165	2454	2467
$Cost_{tot,TOU}$ (CAD/yr)	2182	2202	2465	2478
$GHG_{el,avg}$ (tonnes/yr)	3.43	3.43	0.82	0.82
$GHG_{el,high}$ (tonnes/yr)	4.66	4.66	1.11	1.11
GHG_{th} (tonnes/yr)	9.73	9.84	12.95	13.02
$GHG_{tot,avg}$ (tonnes/yr)	13.16	13.27	13.77	13.84
$GHG_{tot,high}$ (tonnes/yr)	14.38	14.49	14.06	14.13

Table H.38: Test Case House 9, North Battleford – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9789	9786	9775	9768
$Demand_{el,grid}$ (kWh/yr)	2873	2870	504	502
$ICE_{Output,el}$ (kWh/yr)	6916	6916	9272	9265
$ICE_{Output,th}$ (GJ/yr)	69.8	70.1	113.2	113.2
BB_{Output} (GJ/yr)	78.1	79.9	55.0	56.9
Heat Dump (GJ/yr)	45.4	48.0	66.6	68.7
$Demand_{SH}$ (GJ/yr)	93.6	93.0	92.6	92.4
$Demand_{DHW}$ (GJ/yr)	10.3	10.3	10.3	10.3
η_{el} (%)	21.1	21.1	16.6	16.6
η_{CHP} (%)	44.7	44.8	32.7	32.7
$Cost_{el,flat}$ (CAD/yr)	258	258	45	45
$Cost_{el,TOU}$ (CAD/yr)	291	290	52	52
Total Fuel (m^3/yr)	5908	5964	7288	7348
$Cost_{fuel}$ (CAD/yr)	2004	2024	2473	2493
$Cost_{tot,flat}$ (CAD/yr)	2263	2282	2518	2538
$Cost_{tot,TOU}$ (CAD/yr)	2295	2314	2525	2546
$GHG_{el,avg}$ (tonnes/yr)	2.41	2.41	0.42	0.42
$GHG_{el,high}$ (tonnes/yr)	3.27	3.27	0.57	0.57
GHG_{th} (tonnes/yr)	10.97	11.07	13.53	13.64
$GHG_{tot,avg}$ (tonnes/yr)	13.38	13.48	13.95	14.06
$GHG_{tot,high}$ (tonnes/yr)	14.24	14.34	14.10	14.21

Table H.39: Test Case House 9, Regina – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9711	9713	9704	9698
$Demand_{el,grid}$ (kWh/yr)	2854	2855	508	508
$ICE_{Output,el}$ (kWh/yr)	6857	6858	9196	9190
$ICE_{Output,th}$ (GJ/yr)	69.2	69.4	112.1	112.1
BB_{Output} (GJ/yr)	68.9	71.1	50.5	51.7
Heat Dump (GJ/yr)	46.2	49.2	71.9	73.3
$Demand_{SH}$ (GJ/yr)	82.8	82.2	81.6	81.3
$Demand_{DHW}$ (GJ/yr)	10.4	10.3	10.4	10.4
η_{el} (%)	21.1	21.1	16.6	16.6
η_{CHP} (%)	44.6	44.7	32.6	32.6
$Cost_{el,flat}$ (CAD/yr)	257	257	46	46
$Cost_{el,TOU}$ (CAD/yr)	288	288	53	53
Total Fuel (m^3/yr)	5581	5652	7103	7139
$Cost_{fuel}$ (CAD/yr)	1894	1918	2410	2422
$Cost_{tot,flat}$ (CAD/yr)	2150	2174	2456	2468
$Cost_{tot,TOU}$ (CAD/yr)	2182	2206	2463	2475
$GHG_{el,avg}$ (tonnes/yr)	2.40	2.40	0.43	0.43
$GHG_{el,high}$ (tonnes/yr)	3.25	3.25	0.58	0.58
GHG_{th} (tonnes/yr)	10.36	10.49	13.19	13.25
$GHG_{tot,avg}$ (tonnes/yr)	12.76	12.89	13.61	13.68
$GHG_{tot,high}$ (tonnes/yr)	13.61	13.74	13.76	13.83

Table H.40: Test Case House 10, Le Pas – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11493	11488	11506	11514
$Demand_{el,grid}$ (kWh/yr)	4054	4050	992	1006
$ICE_{Output,el}$ (kWh/yr)	7439	7438	10514	10508
$ICE_{Output,th}$ (GJ/yr)	73.6	73.7	121.2	121.0
BB_{Output} (GJ/yr)	66.0	66.1	36.9	42.0
Heat Dump (GJ/yr)	40.9	41.2	59.5	64.6
$Demand_{SH}$ (GJ/yr)	87.6	87.5	87.4	87.2
$Demand_{DHW}$ (GJ/yr)	12.4	12.4	12.5	12.5
η_{el} (%)	21.9	21.9	17.9	17.8
η_{CHP} (%)	48.8	48.8	34.6	34.6
$Cost_{el,flat}$ (CAD/yr)	231	230	56	57
$Cost_{el,TOU}$ (CAD/yr)	256	256	65	66
Total Fuel (m^3/yr)	5667	5668	7066	7232
$Cost_{fuel}$ (CAD/yr)	2907	2908	3625	3710
$Cost_{tot,flat}$ (CAD/yr)	3138	3138	3681	3767
$Cost_{tot,TOU}$ (CAD/yr)	3163	3164	3690	3776
$GHG_{el,avg}$ (tonnes/yr)	0.13	0.13	0.03	0.03
$GHG_{el,high}$ (tonnes/yr)	4.84	4.83	1.18	1.20
GHG_{th} (tonnes/yr)	10.52	10.52	13.12	13.43
$GHG_{tot,avg}$ (tonnes/yr)	10.65	10.65	13.15	13.46
$GHG_{tot,high}$ (tonnes/yr)	15.36	15.35	14.30	14.63

Table H.41: Test Case House 10, Winnipeg – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11683	11658	11684	11700
$Demand_{el,grid}$ (kWh/yr)	4108	4083	976	989
$ICE_{Output,el}$ (kWh/yr)	7575	7575	10708	10712
$ICE_{Output,th}$ (GJ/yr)	74.5	74.6	122.6	122.5
BB_{Output} (GJ/yr)	54.9	56.3	33.8	37.5
Heat Dump (GJ/yr)	47.9	49.6	75.2	79.1
$Demand_{SH}$ (GJ/yr)	70.1	69.9	69.7	69.5
$Demand_{DHW}$ (GJ/yr)	12.7	12.7	12.8	12.8
η_{el} (%)	21.8	21.8	17.8	17.8
η_{CHP} (%)	48.5	48.5	34.4	34.4
$Cost_{el,flat}$ (CAD/yr)	234	232	56	56
$Cost_{el,TOU}$ (CAD/yr)	259	258	64	65
Total Fuel (m^3/yr)	5370	5415	7074	7198
$Cost_{fuel}$ (CAD/yr)	2755	2778	3629	3693
$Cost_{tot,flat}$ (CAD/yr)	2989	3010	3684	3749
$Cost_{tot,TOU}$ (CAD/yr)	3014	3036	3693	3757
$GHG_{el,avg}$ (tonnes/yr)	0.13	0.13	0.03	0.03
$GHG_{el,high}$ (tonnes/yr)	4.90	4.87	1.16	1.18
GHG_{th} (tonnes/yr)	9.97	10.05	13.13	13.36
$GHG_{tot,avg}$ (tonnes/yr)	10.10	10.18	13.16	13.39
$GHG_{tot,high}$ (tonnes/yr)	14.87	14.92	14.30	14.54

Table H.42: Test Case House 11, Le Pas – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10212	10207	10205	10199
$Demand_{el,grid}$ (kWh/yr)	2993	2985	519	523
$ICE_{Output,el}$ (kWh/yr)	7220	7222	9687	9676
$ICE_{Output,th}$ (GJ/yr)	72.2	72.5	117.0	116.9
BB_{Output} (GJ/yr)	93.8	96.6	66.3	69.2
Heat Dump (GJ/yr)	42.9	47.7	62.3	65.3
$Demand_{SH}$ (GJ/yr)	112.0	110.2	109.8	109.6
$Demand_{DHW}$ (GJ/yr)	12.5	12.4	12.5	12.5
η_{el} (%)	21.5	21.5	17.0	17.0
η_{CHP} (%)	45.4	45.5	33.2	33.2
$Cost_{el,flat}$ (CAD/yr)	170	170	30	30
$Cost_{el,TOU}$ (CAD/yr)	190	189	34	34
Total Fuel (m^3/yr)	6516	6607	7805	7897
$Cost_{fuel}$ (CAD/yr)	3343	3390	4004	4051
$Cost_{tot,flat}$ (CAD/yr)	3513	3559	4033	4081
$Cost_{tot,TOU}$ (CAD/yr)	3533	3579	4038	4086
$GHG_{el,avg}$ (tonnes/yr)	0.09	0.09	0.02	0.02
$GHG_{el,high}$ (tonnes/yr)	3.57	3.56	0.62	0.62
GHG_{th} (tonnes/yr)	12.10	12.27	14.49	14.66
$GHG_{tot,avg}$ (tonnes/yr)	12.19	12.36	14.51	14.68
$GHG_{tot,high}$ (tonnes/yr)	15.67	15.83	15.11	15.28

Table H.43: Test Case House 11, Winnipeg – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10110	10107	10108	10106
$Demand_{el,grid}$ (kWh/yr)	2845	2842	467	472
$ICE_{Output,el}$ (kWh/yr)	7265	7265	9642	9634
$ICE_{Output,th}$ (GJ/yr)	72.8	73.0	117.5	117.5
BB_{Output} (GJ/yr)	76.8	80.0	57.5	60.0
Heat Dump (GJ/yr)	45.2	49.2	71.3	74.3
$Demand_{SH}$ (GJ/yr)	93.1	92.4	92.2	91.8
$Demand_{DHW}$ (GJ/yr)	12.7	12.6	12.7	12.7
η_{el} (%)	21.4	21.4	16.8	16.8
η_{CHP} (%)	44.7	44.7	32.8	32.8
$Cost_{el,flat}$ (CAD/yr)	162	162	27	27
$Cost_{el,TOU}$ (CAD/yr)	181	180	31	31
Total Fuel (m^3/yr)	6005	6107	7566	7648
$Cost_{fuel}$ (CAD/yr)	3081	3133	3881	3923
$Cost_{tot,flat}$ (CAD/yr)	3242	3295	3908	3950
$Cost_{tot,TOU}$ (CAD/yr)	3261	3314	3912	3954
$GHG_{el,avg}$ (tonnes/yr)	0.09	0.09	0.01	0.01
$GHG_{el,high}$ (tonnes/yr)	3.39	3.39	0.56	0.56
GHG_{th} (tonnes/yr)	11.15	11.34	14.04	14.20
$GHG_{tot,avg}$ (tonnes/yr)	11.24	11.43	14.06	14.21
$GHG_{tot,high}$ (tonnes/yr)	14.54	14.73	14.60	14.76

Table H.44: Test Case House 12, Le Pas – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9472	9455	9411	9400
$Demand_{el,grid}$ (kWh/yr)	2533	2522	353	350
$ICE_{Output,el}$ (kWh/yr)	6939	6934	9059	9050
$ICE_{Output,th}$ (GJ/yr)	70.5	70.7	113.1	113.2
BB_{Output} (GJ/yr)	118.7	119.4	89.2	91.3
Heat Dump (GJ/yr)	49.8	51.5	63.8	66.3
$Demand_{SH}$ (GJ/yr)	130.6	129.9	129.6	129.4
$Demand_{DHW}$ (GJ/yr)	10.1	10.1	10.2	10.2
η_{el} (%)	21.0	21.0	16.3	16.3
η_{CHP} (%)	43.6	43.6	32.2	32.2
$Cost_{el,flat}$ (CAD/yr)	144	143	20	20
$Cost_{el,TOU}$ (CAD/yr)	162	162	23	23
Total Fuel (m^3/yr)	7259	7281	8382	8451
$Cost_{fuel}$ (CAD/yr)	3724	3735	4300	4335
$Cost_{tot,flat}$ (CAD/yr)	3868	3879	4320	4355
$Cost_{tot,TOU}$ (CAD/yr)	3886	3897	4323	4358
$GHG_{el,avg}$ (tonnes/yr)	0.08	0.08	0.01	0.01
$GHG_{el,high}$ (tonnes/yr)	3.02	3.01	0.42	0.42
GHG_{th} (tonnes/yr)	13.48	13.52	15.56	15.69
$GHG_{tot,avg}$ (tonnes/yr)	13.55	13.59	15.57	15.70
$GHG_{tot,high}$ (tonnes/yr)	16.50	16.52	15.98	16.11

Table H.45: Test Case House 12, Winnipeg – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9261	9258	9247	9239
$Demand_{el,grid}$ (kWh/yr)	2346	2344	304	305
$ICE_{Output,el}$ (kWh/yr)	6914	6914	8943	8934
$ICE_{Output,th}$ (GJ/yr)	70.6	70.9	113.3	113.3
BB_{Output} (GJ/yr)	97.5	99.3	74.9	76.8
Heat Dump (GJ/yr)	50.9	53.6	72.4	74.6
$Demand_{SH}$ (GJ/yr)	108.3	107.6	106.7	106.4
$Demand_{DHW}$ (GJ/yr)	10.3	10.3	10.4	10.4
η_{el} (%)	20.8	20.8	16.0	16.0
η_{CHP} (%)	42.6	42.7	31.8	31.8
$Cost_{el,flat}$ (CAD/yr)	134	133	17	17
$Cost_{el,TOU}$ (CAD/yr)	151	151	20	20
Total Fuel (m^3/yr)	6591	6648	7942	8003
$Cost_{fuel}$ (CAD/yr)	3381	3410	4074	4105
$Cost_{tot,flat}$ (CAD/yr)	3515	3544	4091	4123
$Cost_{tot,TOU}$ (CAD/yr)	3532	3561	4094	4126
$GHG_{el,avg}$ (tonnes/yr)	0.07	0.07	0.01	0.01
$GHG_{el,high}$ (tonnes/yr)	2.80	2.80	0.36	0.36
GHG_{th} (tonnes/yr)	12.24	12.34	14.74	14.86
$GHG_{tot,avg}$ (tonnes/yr)	12.31	12.41	14.75	14.87
$GHG_{tot,high}$ (tonnes/yr)	15.03	15.14	15.11	15.22

Table H.46: Test Case House 13, Ottawa – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11516	11513	11418	11433
$Demand_{el,grid}$ (kWh/yr)	4215	4211	1089	1101
$ICE_{Output,el}$ (kWh/yr)	7301	7303	10328	10333
$ICE_{Output,th}$ (GJ/yr)	72.8	72.8	117.8	117.8
BB_{Output} (GJ/yr)	12.6	12.5	0.0	0.0
Heat Dump (GJ/yr)	38.2	38.4	70.5	70.7
$Demand_{SH}$ (GJ/yr)	35.6	35.3	35.2	35.1
$Demand_{DHW}$ (GJ/yr)	12.9	12.9	13.4	13.4
η_{el} (%)	21.2	21.2	17.2	17.18664
η_{CHP} (%)	48.0	48.0	33.6	33.7
$Cost_{el,flat}$ (CAD/yr)	422	421	109	110
$Cost_{el,TOU}$ (CAD/yr)	468	467	125	126
Total Fuel (m^3/yr)	3931	3929	5887	5888
$Cost_{fuel}$ (CAD/yr)	1937	1936	2901	2901
$Cost_{tot,flat}$ (CAD/yr)	2358	2357	3009	3011
$Cost_{tot,TOU}$ (CAD/yr)	2404	2403	3026	3028
$GHG_{el,avg}$ (tonnes/yr)	0.94	0.93	0.24	0.24
$GHG_{el,high}$ (tonnes/yr)	4.02	4.02	1.04	1.05
GHG_{th} (tonnes/yr)	7.30	7.29	10.93	10.93
$GHG_{tot,avg}$ (tonnes/yr)	8.23	8.23	11.17	11.18
$GHG_{tot,high}$ (tonnes/yr)	11.32	11.31	11.97	11.98

Table H.47: Test Case House 13, Toronto – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11524	11524	11374	11404
$Demand_{el,grid}$ (kWh/yr)	4224	4225	1081	1102
$ICE_{Output,el}$ (kWh/yr)	7300	7300	10293	10302
$ICE_{Output,th}$ (GJ/yr)	72.7	72.6	116.3	116.3
BB_{Output} (GJ/yr)	8.0	7.1	0.0	0.0
Heat Dump (GJ/yr)	38.4	37.6	73.8	73.8
$Demand_{SH}$ (GJ/yr)	30.7	30.4	30.3	30.1
$Demand_{DHW}$ (GJ/yr)	12.9	12.9	13.6	13.6
η_{el} (%)	21.2	21.2	17.2	17.2
η_{CHP} (%)	48.2	48.2	33.5	33.6
$Cost_{el,flat}$ (CAD/yr)	422	422	108	110
$Cost_{el,TOU}$ (CAD/yr)	469	469	124	127
Total Fuel (m^3/yr)	3775	3746	5869	5871
$Cost_{fuel}$ (CAD/yr)	1860	1846	2892	2893
$Cost_{tot,flat}$ (CAD/yr)	2282	2268	3000	3003
$Cost_{tot,TOU}$ (CAD/yr)	2329	2315	3016	3020
$GHG_{el,avg}$ (tonnes/yr)	0.94	0.94	0.24	0.24
$GHG_{el,high}$ (tonnes/yr)	4.03	4.03	1.03	1.05
GHG_{th} (tonnes/yr)	7.01	6.96	10.90	10.90
$GHG_{tot,avg}$ (tonnes/yr)	7.95	7.89	11.14	11.14
$GHG_{tot,high}$ (tonnes/yr)	11.04	10.99	11.93	11.95

Table H.48: Test Case House 14, Ottawa – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10548	10559	10541	10544
$Demand_{el,grid}$ (kWh/yr)	3248	3255	676	680
$ICE_{Output,el}$ (kWh/yr)	7300	7305	9864	9865
$ICE_{Output,th}$ (GJ/yr)	73.1	73.3	117.4	117.2
BB_{Output} (GJ/yr)	44.0	41.9	18.1	17.0
Heat Dump (GJ/yr)	26.5	24.7	45.3	43.8
$Demand_{SH}$ (GJ/yr)	79.5	79.3	78.8	79.0
$Demand_{DHW}$ (GJ/yr)	12.5	12.5	12.7	12.7
η_{el} (%)	21.3	21.3	16.9	16.9
η_{CHP} (%)	45.5	45.6	32.9	32.9
$Cost_{el,flat}$ (CAD/yr)	325	325	68	68
$Cost_{el,TOU}$ (CAD/yr)	363	364	79	80
Total Fuel (m^3/yr)	4957	4889	6371	6335
$Cost_{fuel}$ (CAD/yr)	2443	2409	3139	3121
$Cost_{tot,flat}$ (CAD/yr)	2767	2735	3207	3189
$Cost_{tot,TOU}$ (CAD/yr)	2806	2773	3219	3201
$GHG_{el,avg}$ (tonnes/yr)	0.72	0.72	0.15	0.15
$GHG_{el,high}$ (tonnes/yr)	3.10	3.10	0.65	0.65
GHG_{th} (tonnes/yr)	9.20	9.08	11.83	11.76
$GHG_{tot,avg}$ (tonnes/yr)	9.92	9.80	11.98	11.91
$GHG_{tot,high}$ (tonnes/yr)	12.30	12.18	12.47	12.41

Table H.49: Test Case House 14, Toronto – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10546	10554	10523	10525
$Demand_{el,grid}$ (kWh/yr)	3249	3255	675	678
$ICE_{Output,el}$ (kWh/yr)	7296	7299	9847	9847
$ICE_{Output,th}$ (GJ/yr)	73.2	73.3	116.9	116.7
BB_{Output} (GJ/yr)	32.0	29.9	12.6	11.2
Heat Dump (GJ/yr)	28.2	26.4	52.4	51.0
$Demand_{SH}$ (GJ/yr)	65.8	65.5	65.5	65.4
$Demand_{DHW}$ (GJ/yr)	12.5	12.5	12.8	12.8
η_{el} (%)	21.3	21.3	16.9	16.9
η_{CHP} (%)	45.6	45.6	32.8	32.8
$Cost_{el,flat}$ (CAD/yr)	325	326	68	68
$Cost_{el,TOU}$ (CAD/yr)	364	364	79	80
Total Fuel (m^3/yr)	4559	4491	6176	6131
$Cost_{fuel}$ (CAD/yr)	2246	2213	3043	3021
$Cost_{tot,flat}$ (CAD/yr)	2571	2538	3111	3089
$Cost_{tot,TOU}$ (CAD/yr)	2610	2577	3123	3101
$GHG_{el,avg}$ (tonnes/yr)	0.72	0.72	0.15	0.15
$GHG_{el,high}$ (tonnes/yr)	3.10	3.11	0.64	0.65
GHG_{th} (tonnes/yr)	8.46	8.34	11.47	11.38
$GHG_{tot,avg}$ (tonnes/yr)	9.19	9.06	11.62	11.53
$GHG_{tot,high}$ (tonnes/yr)	11.56	11.44	12.11	12.03

Table H.50: Test Case House 15, Ottawa – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9123	9160	9185	9201
$Demand_{el,grid}$ (kWh/yr)	2285	2311	361	360
$ICE_{Output,el}$ (kWh/yr)	6838	6849	8825	8841
$ICE_{Output,th}$ (GJ/yr)	70.2	70.4	113.5	113.6
BB_{Output} (GJ/yr)	41.4	43.6	16.6	19.0
Heat Dump (GJ/yr)	41.6	44.4	60.7	63.6
$Demand_{SH}$ (GJ/yr)	58.6	58.1	57.8	57.5
$Demand_{DHW}$ (GJ/yr)	12.8	12.7	12.8	12.8
η_{el} (%)	20.5	20.5	15.7	15.77004
η_{CHP} (%)	42.0	42.1	31.7	31.7
$Cost_{el,flat}$ (CAD/yr)	229	231	36	36
$Cost_{el,TOU}$ (CAD/yr)	259	261	43	43
Total Fuel (m^3/yr)	4753	4825	6029	6112
$Cost_{fuel}$ (CAD/yr)	2342	2377	2971	3011
$Cost_{tot,flat}$ (CAD/yr)	2570	2608	3007	3047
$Cost_{tot,TOU}$ (CAD/yr)	2600	2639	3014	3054
$GHG_{el,avg}$ (tonnes/yr)	0.51	0.51	0.08	0.08
$GHG_{el,high}$ (tonnes/yr)	2.18	2.20	0.34	0.34
GHG_{th} (tonnes/yr)	8.82	8.96	11.19	11.35
$GHG_{tot,avg}$ (tonnes/yr)	9.33	9.47	11.27	11.43
$GHG_{tot,high}$ (tonnes/yr)	11.00	11.16	11.54	11.69

Table H.51: Test Case House 15, Toronto – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9123	9188	9190	9199
$Demand_{el,grid}$ (kWh/yr)	2301	2341	363	363
$ICE_{Output,el}$ (kWh/yr)	6822	6848	8828	8836
$ICE_{Output,th}$ (GJ/yr)	70.2	70.5	113.4	113.5
BB_{Output} (GJ/yr)	34.2	35.1	10.1	10.6
Heat Dump (GJ/yr)	43.8	45.6	63.9	64.8
$Demand_{SH}$ (GJ/yr)	49.0	48.5	48.1	47.8
$Demand_{DHW}$ (GJ/yr)	12.8	12.8	12.9	12.8
η_{el} (%)	20.5	20.5	15.8	15.8
η_{CHP} (%)	42.1	42.3	31.7	31.8
$Cost_{el,flat}$ (CAD/yr)	230	234	36	36
$Cost_{el,TOU}$ (CAD/yr)	260	265	43	43
Total Fuel (m^3/yr)	4506	4542	5810	5827
$Cost_{fuel}$ (CAD/yr)	2220	2238	2863	2871
$Cost_{tot,flat}$ (CAD/yr)	2450	2472	2899	2907
$Cost_{tot,TOU}$ (CAD/yr)	2481	2503	2906	2914
$GHG_{el,avg}$ (tonnes/yr)	0.51	0.52	0.08	0.08
$GHG_{el,high}$ (tonnes/yr)	2.20	2.23	0.35	0.35
GHG_{th} (tonnes/yr)	8.37	8.43	10.79	10.82
$GHG_{tot,avg}$ (tonnes/yr)	8.88	8.95	10.87	10.90
$GHG_{tot,high}$ (tonnes/yr)	10.56	10.67	11.13	11.16

Table H.52: Test Case House 16, Montreal – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10114	10114	10138	10165
$Demand_{el,grid}$ (kWh/yr)	3037	3038	685	685
$ICE_{Output,el}$ (kWh/yr)	7077	7075	9453	9479
$ICE_{Output,th}$ (GJ/yr)	72.0	72.0	116.4	116.5
BB_{Output} (GJ/yr)	24.4	31.5	10.5	11.9
Heat Dump (GJ/yr)	43.2	50.7	74.2	76.2
$Demand_{SH}$ (GJ/yr)	41.7	41.2	40.9	40.5
$Demand_{DHW}$ (GJ/yr)	12.9	12.9	13.0	13.0
η_{el} (%)	20.9	20.9	16.4	16.4
η_{CHP} (%)	44.6	44.6	32.6	32.7
$Cost_{el,flat}$ (CAD/yr)	159	159	36	36
$Cost_{el,TOU}$ (CAD/yr)	179	180	42	42
Total Fuel (m^3/yr)	5939	6275	8354	8402
$Cost_{fuel}$ (CAD/yr)	3861	4079	5430	5461
$Cost_{tot,flat}$ (CAD/yr)	4019	4237	5466	5497
$Cost_{tot,TOU}$ (CAD/yr)	4040	4258	5472	5503
$GHG_{el,avg}$ (tonnes/yr)	0.02	0.02	0.01	0.01
$GHG_{el,high}$ (tonnes/yr)	1.67	1.67	0.38	0.38
GHG_{th} (tonnes/yr)	9.51	10.05	13.33	13.46
$GHG_{tot,avg}$ (tonnes/yr)	9.54	10.08	13.34	13.46
$GHG_{tot,high}$ (tonnes/yr)	11.18	11.72	13.71	13.84

Table H.53: Test Case House 16, Quebec – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9337	9379	9414	9434
$Demand_{el,grid}$ (kWh/yr)	2430	2460	441	441
$ICE_{Output,el}$ (kWh/yr)	6907	6919	8973	8993
$ICE_{Output,th}$ (GJ/yr)	71.4	71.6	114.9	115.1
BB_{Output} (GJ/yr)	36.4	38.7	16.3	17.0
Heat Dump (GJ/yr)	37.8	41.0	62.6	64.0
$Demand_{SH}$ (GJ/yr)	58.7	58.0	57.3	56.8
$Demand_{DHW}$ (GJ/yr)	12.6	12.6	12.7	12.7
η_{el} (%)	20.6	20.7	15.9	15.9
η_{CHP} (%)	42.7	42.9	32.0	32.0
$Cost_{el,flat}$ (CAD/yr)	127	128	23	23
$Cost_{el,TOU}$ (CAD/yr)	144	146	27	27
Total Fuel (m^3/yr)	6444	6562	8471	8467
$Cost_{fuel}$ (CAD/yr)	4189	4265	5506	5503
$Cost_{tot,flat}$ (CAD/yr)	4315	4393	5529	5526
$Cost_{tot,TOU}$ (CAD/yr)	4333	4411	5534	5531
$GHG_{el,avg}$ (tonnes/yr)	0.02	0.02	0.00	0.00
$GHG_{el,high}$ (tonnes/yr)	1.33	1.35	0.24	0.24
GHG_{th} (tonnes/yr)	10.32	10.51	13.50	13.56
$GHG_{tot,avg}$ (tonnes/yr)	10.34	10.53	13.50	13.57
$GHG_{tot,high}$ (tonnes/yr)	11.66	11.86	13.74	13.81

Table H.54: Test Case House 17, Montreal – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	7798	7799	7798	7792
$Demand_{el,grid}$ (kWh/yr)	1414	1414	127	127
$ICE_{Output,el}$ (kWh/yr)	6384	6385	7671	7665
$ICE_{Output,th}$ (GJ/yr)	68.0	68.2	108.5	108.5
BB_{Output} (GJ/yr)	62.2	65.0	41.4	47.1
Heat Dump (GJ/yr)	43.0	46.7	63.8	69.7
$Demand_{SH}$ (GJ/yr)	75.8	75.1	74.5	74.4
$Demand_{DHW}$ (GJ/yr)	12.8	12.8	12.9	12.8
η_{el} (%)	19.7	19.7	14.5	14.5
η_{CHP} (%)	39.0	39.0	30.4	30.4
$Cost_{el,flat}$ (CAD/yr)	74	74	7	7
$Cost_{el,TOU}$ (CAD/yr)	85	85	8	8
Total Fuel (m^3/yr)	7481	7613	9227	9378
$Cost_{fuel}$ (CAD/yr)	4863	4949	5997	6096
$Cost_{tot,flat}$ (CAD/yr)	4936	5023	6004	6102
$Cost_{tot,TOU}$ (CAD/yr)	4947	5033	6005	6104
$GHG_{el,avg}$ (tonnes/yr)	0.01	0.01	0.00	0.00
$GHG_{el,high}$ (tonnes/yr)	0.78	0.78	0.07	0.07
GHG_{th} (tonnes/yr)	11.98	12.20	14.59	15.02
$GHG_{tot,avg}$ (tonnes/yr)	12.00	12.21	14.59	15.02
$GHG_{tot,high}$ (tonnes/yr)	12.76	12.97	14.66	15.09

Table H.55: Test Case House 17, Quebec – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	7829	7827	7829	7825
$Demand_{el,grid}$ (kWh/yr)	1432	1430	133	134
$ICE_{Output,el}$ (kWh/yr)	6397	6397	7696	7691
$ICE_{Output,th}$ (GJ/yr)	68.2	68.4	108.8	108.8
BB_{Output} (GJ/yr)	63.5	66.5	45.3	50.0
Heat Dump (GJ/yr)	42.7	46.7	66.1	71.0
$Demand_{SH}$ (GJ/yr)	77.6	76.8	76.5	76.3
$Demand_{DHW}$ (GJ/yr)	12.8	12.7	12.8	12.8
η_{el} (%)	19.7	19.7	14.5	14.5
η_{CHP} (%)	39.0	39.0	30.4	30.4
$Cost_{el,flat}$ (CAD/yr)	75	75	7	7
$Cost_{el,TOU}$ (CAD/yr)	86	85	8	8
Total Fuel (m^3/yr)	7547	7688	9436	9524
$Cost_{fuel}$ (CAD/yr)	4905	4997	6133	6190
$Cost_{tot,flat}$ (CAD/yr)	4980	5072	6140	6197
$Cost_{tot,TOU}$ (CAD/yr)	4991	5082	6142	6199
$GHG_{el,avg}$ (tonnes/yr)	0.01	0.01	0.00	0.00
$GHG_{el,high}$ (tonnes/yr)	0.79	0.79	0.07	0.07
GHG_{th} (tonnes/yr)	12.09	12.32	14.91	15.26
$GHG_{tot,avg}$ (tonnes/yr)	12.10	12.33	14.91	15.26
$GHG_{tot,high}$ (tonnes/yr)	12.88	13.10	14.98	15.33

Table H.56: Test Case House 18, Montreal – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9313	9339	9373	9399
$Demand_{el,grid}$ (kWh/yr)	2416	2434	430	430
$ICE_{Output,el}$ (kWh/yr)	6897	6905	8944	8969
$ICE_{Output,th}$ (GJ/yr)	71.1	71.3	114.5	114.6
BB_{Output} (GJ/yr)	35.4	39.1	13.1	15.0
Heat Dump (GJ/yr)	38.7	43.1	61.0	63.6
$Demand_{SH}$ (GJ/yr)	56.4	55.9	55.1	54.5
$Demand_{DHW}$ (GJ/yr)	12.7	12.7	12.8	12.8
η_{el} (%)	20.6	20.6	15.9	15.9
η_{CHP} (%)	42.6	42.7	31.9	31.9
$Cost_{el,flat}$ (CAD/yr)	126	127	22	22
$Cost_{el,TOU}$ (CAD/yr)	143	144	27	27
Total Fuel (m^3/yr)	6397	6576	8300	8360
$Cost_{fuel}$ (CAD/yr)	4158	4274	5395	5434
$Cost_{tot,flat}$ (CAD/yr)	4284	4401	5417	5456
$Cost_{tot,TOU}$ (CAD/yr)	4301	4418	5421	5460
$GHG_{el,avg}$ (tonnes/yr)	0.02	0.02	0.00	0.00
$GHG_{el,high}$ (tonnes/yr)	1.33	1.34	0.24	0.24
GHG_{th} (tonnes/yr)	10.25	10.53	13.24	13.39
$GHG_{tot,avg}$ (tonnes/yr)	10.27	10.55	13.24	13.39
$GHG_{tot,high}$ (tonnes/yr)	11.57	11.87	13.47	13.63

Table H.57: Test Case House 18, Quebec – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10223	10218	10232	10242
$Demand_{el,grid}$ (kWh/yr)	3095	3091	696	703
$ICE_{Output,el}$ (kWh/yr)	7128	7127	9535	9539
$ICE_{Output,th}$ (GJ/yr)	72.7	72.8	118.0	117.9
BB_{Output} (GJ/yr)	49.0	49.6	26.6	31.1
Heat Dump (GJ/yr)	44.3	45.3	67.8	72.7
$Demand_{SH}$ (GJ/yr)	65.9	65.7	65.3	64.9
$Demand_{DHW}$ (GJ/yr)	12.7	12.7	12.7	12.7
η_{el} (%)	21.0	21.0	16.5	16.5
η_{CHP} (%)	44.9	45.0	32.9	32.9
$Cost_{el,flat}$ (CAD/yr)	162	161	36	37
$Cost_{el,TOU}$ (CAD/yr)	183	182	43	43
Total Fuel (m^3/yr)	7122	7152	9198	9337
$Cost_{fuel}$ (CAD/yr)	4629	4649	5979	6069
$Cost_{tot,flat}$ (CAD/yr)	4791	4810	6015	6106
$Cost_{tot,TOU}$ (CAD/yr)	4812	4831	6022	6112
$GHG_{el,avg}$ (tonnes/yr)	0.02	0.02	0.01	0.01
$GHG_{el,high}$ (tonnes/yr)	1.70	1.70	0.38	0.39
GHG_{th} (tonnes/yr)	11.41	11.46	14.61	14.96
$GHG_{tot,avg}$ (tonnes/yr)	11.43	11.48	14.62	14.96
$GHG_{tot,high}$ (tonnes/yr)	13.11	13.15	14.99	15.34

Table H.58: Test Case House 19, Fredericton – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9828	9831	9565	9555
$Demand_{el,grid}$ (kWh/yr)	2599	2599	356	354
$ICE_{Output,el}$ (kWh/yr)	7229	7231	9208	9201
$ICE_{Output,th}$ (GJ/yr)	74.1	74.5	117.2	117.4
BB_{Output} (GJ/yr)	128.9	130.1	104.5	103.8
Heat Dump (GJ/yr)	49.8	52.5	69.8	70.1
$Demand_{SH}$ (GJ/yr)	142.2	141.0	140.7	139.9
$Demand_{DHW}$ (GJ/yr)	12.3	12.3	12.5	12.5
η_{el} (%)	21.2	21.2	16.2	16.2
η_{CHP} (%)	43.9	44.0	32.3	32.3
$Cost_{el,flat}$ (CAD/yr)	235	235	32	32
$Cost_{el,TOU}$ (CAD/yr)	263	263	37	37
Total Fuel (m^3/yr)	10947	11001	12997	12661
$Cost_{fuel}$ (CAD/yr)	10235	10286	12152	11838
$Cost_{tot,flat}$ (CAD/yr)	10470	10520	12184	11870
$Cost_{tot,TOU}$ (CAD/yr)	10498	10548	12190	11875
$GHG_{el,avg}$ (tonnes/yr)	1.13	1.13	0.15	0.15
$GHG_{el,high}$ (tonnes/yr)	2.10	2.10	0.29	0.29
GHG_{th} (tonnes/yr)	17.54	17.62	20.34	20.28
$GHG_{tot,avg}$ (tonnes/yr)	18.66	18.75	20.49	20.44
$GHG_{tot,high}$ (tonnes/yr)	19.63	19.72	20.63	20.57

Table H.59: Test Case House 19, Saint John – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10155	10162	9800	9782
$Demand_{el,grid}$ (kWh/yr)	2820	2815	381	378
$ICE_{Output,el}$ (kWh/yr)	7336	7346	9419	9404
$ICE_{Output,th}$ (GJ/yr)	75.0	75.5	119.2	119.4
BB_{Output} (GJ/yr)	125.1	125.8	90.8	90.9
Heat Dump (GJ/yr)	45.5	46.4	56.0	56.9
$Demand_{SH}$ (GJ/yr)	143.7	143.1	142.0	141.3
$Demand_{DHW}$ (GJ/yr)	12.2	12.1	12.4	12.3
η_{el} (%)	21.3	21.3	16.5	16.4
η_{CHP} (%)	44.8	44.9	32.7	32.7
$Cost_{el,flat}$ (CAD/yr)	255	255	34	34
$Cost_{el,TOU}$ (CAD/yr)	284	284	40	40
Total Fuel (m^3/yr)	10806	10842	12387	12124
$Cost_{fuel}$ (CAD/yr)	10104	10137	11582	11336
$Cost_{tot,flat}$ (CAD/yr)	10359	10392	11616	11370
$Cost_{tot,TOU}$ (CAD/yr)	10388	10421	11621	11375
$GHG_{el,avg}$ (tonnes/yr)	1.22	1.22	0.16	0.16
$GHG_{el,high}$ (tonnes/yr)	2.28	2.27	0.31	0.30
GHG_{th} (tonnes/yr)	17.31	17.37	19.42	19.42
$GHG_{tot,avg}$ (tonnes/yr)	18.53	18.59	19.59	19.58
$GHG_{tot,high}$ (tonnes/yr)	19.59	19.64	19.73	19.73

Table H.60: Test Case House 20, Fredericton – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10727	10718	10737	10748
$Demand_{el,grid}$ (kWh/yr)	3435	3428	799	804
$ICE_{Output,el}$ (kWh/yr)	7292	7290	9938	9943
$ICE_{Output,th}$ (GJ/yr)	73.9	73.9	120.0	120.0
BB_{Output} (GJ/yr)	51.0	51.3	27.2	31.1
Heat Dump (GJ/yr)	44.1	44.6	66.9	70.9
$Demand_{SH}$ (GJ/yr)	69.6	69.3	69.0	68.8
$Demand_{DHW}$ (GJ/yr)	12.5	12.6	12.6	12.6
η_{el} (%)	21.3	21.3	16.9	16.9
η_{CHP} (%)	46.2	46.2	33.4	33.4
$Cost_{el,flat}$ (CAD/yr)	311	310	72	73
$Cost_{el,TOU}$ (CAD/yr)	348	347	83	84
Total Fuel (m^3/yr)	7278	7291	9385	9491
$Cost_{fuel}$ (CAD/yr)	6805	6817	8775	8874
$Cost_{tot,flat}$ (CAD/yr)	7116	7127	8847	8947
$Cost_{tot,TOU}$ (CAD/yr)	7153	7164	8858	8958
$GHG_{el,avg}$ (tonnes/yr)	1.49	1.48	0.35	0.35
$GHG_{el,high}$ (tonnes/yr)	2.77	2.77	0.64	0.65
GHG_{th} (tonnes/yr)	11.66	11.68	14.91	15.20
$GHG_{tot,avg}$ (tonnes/yr)	13.15	13.16	15.25	15.55
$GHG_{tot,high}$ (tonnes/yr)	14.43	14.45	15.55	15.85

Table H.61: Test Case House 20, Saint John – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10739	10728	10760	10792
$Demand_{el,grid}$ (kWh/yr)	3443	3434	810	813
$ICE_{Output,el}$ (kWh/yr)	7296	7293	9950	9979
$ICE_{Output,th}$ (GJ/yr)	74.4	74.4	120.4	120.5
BB_{Output} (GJ/yr)	44.3	45.4	20.0	21.0
Heat Dump (GJ/yr)	39.0	40.3	61.3	62.9
$Demand_{SH}$ (GJ/yr)	68.6	68.5	67.9	67.3
$Demand_{DHW}$ (GJ/yr)	12.4	12.4	12.5	12.5
η_{el} (%)	21.3	21.3	16.9	16.9
η_{CHP} (%)	46.3	46.3	33.4	33.5
$Cost_{el,flat}$ (CAD/yr)	311	310	73	73
$Cost_{el,TOU}$ (CAD/yr)	349	348	84	84
Total Fuel (m^3/yr)	6962	7015	9025	9026
$Cost_{fuel}$ (CAD/yr)	6509	6559	8439	8440
$Cost_{tot,flat}$ (CAD/yr)	6820	6870	8512	8513
$Cost_{tot,TOU}$ (CAD/yr)	6858	6907	8523	8524
$GHG_{el,avg}$ (tonnes/yr)	1.49	1.49	0.35	0.35
$GHG_{el,high}$ (tonnes/yr)	2.78	2.77	0.65	0.66
GHG_{th} (tonnes/yr)	11.15	11.24	14.37	14.46
$GHG_{tot,avg}$ (tonnes/yr)	12.64	12.72	14.72	14.81
$GHG_{tot,high}$ (tonnes/yr)	13.93	14.01	15.02	15.12

Table H.62: Test Case House 21, Fredericton – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9570	9557	9480	9471
$Demand_{el,grid}$ (kWh/yr)	2654	2645	416	414
$ICE_{Output,el}$ (kWh/yr)	6916	6913	9064	9058
$ICE_{Output,th}$ (GJ/yr)	71.8	72.1	116.0	116.1
BB_{Output} (GJ/yr)	91.7	93.6	67.1	68.4
Heat Dump (GJ/yr)	47.4	50.0	67.6	69.6
$Demand_{SH}$ (GJ/yr)	107.2	106.8	106.5	105.9
$Demand_{DHW}$ (GJ/yr)	10.2	10.2	10.3	10.3
η_{el} (%)	20.6	20.6	15.9	15.9
η_{CHP} (%)	43.4	43.4	32.1	32.1
$Cost_{el,flat}$ (CAD/yr)	240	239	38	37
$Cost_{el,TOU}$ (CAD/yr)	270	269	43	43
Total Fuel (m^3/yr)	9070	9160	11047	10912
$Cost_{fuel}$ (CAD/yr)	8481	8565	10329	10203
$Cost_{tot,flat}$ (CAD/yr)	8720	8804	10367	10241
$Cost_{tot,TOU}$ (CAD/yr)	8751	8834	10372	10246
$GHG_{el,avg}$ (tonnes/yr)	1.15	1.15	0.18	0.18
$GHG_{el,high}$ (tonnes/yr)	2.14	2.13	0.34	0.33
GHG_{th} (tonnes/yr)	14.53	14.67	17.39	17.48
$GHG_{tot,avg}$ (tonnes/yr)	15.68	15.82	17.57	17.66
$GHG_{tot,high}$ (tonnes/yr)	16.67	16.81	17.72	17.81

Table H.63: Test Case House 21, Saint John – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9696	9684	9589	9577
$Demand_{el,grid}$ (kWh/yr)	2719	2709	431	428
$ICE_{Output,el}$ (kWh/yr)	6977	6976	9158	9149
$ICE_{Output,th}$ (GJ/yr)	72.6	73.0	117.2	117.4
BB_{Output} (GJ/yr)	99.1	99.7	69.6	70.0
Heat Dump (GJ/yr)	43.0	44.4	58.6	59.6
$Demand_{SH}$ (GJ/yr)	119.9	119.6	119.3	118.9
$Demand_{DHW}$ (GJ/yr)	10.1	10.0	10.2	10.1
η_{el} (%)	20.7	20.7	16.1	16.0
η_{CHP} (%)	43.7	43.8	32.3	32.3
$Cost_{el,flat}$ (CAD/yr)	246	245	39	39
$Cost_{el,TOU}$ (CAD/yr)	276	275	45	45
Total Fuel (m^3/yr)	9442	9473	11209	11024
$Cost_{fuel}$ (CAD/yr)	8828	8857	10481	10307
$Cost_{tot,flat}$ (CAD/yr)	9074	9102	10520	10346
$Cost_{tot,TOU}$ (CAD/yr)	9105	9133	10526	10352
$GHG_{el,avg}$ (tonnes/yr)	1.18	1.17	0.19	0.19
$GHG_{el,high}$ (tonnes/yr)	2.19	2.19	0.35	0.35
GHG_{th} (tonnes/yr)	15.13	15.18	17.64	17.66
$GHG_{tot,avg}$ (tonnes/yr)	16.30	16.35	17.82	17.85
$GHG_{tot,high}$ (tonnes/yr)	17.32	17.36	17.98	18.01

Table H.64: Test Case House 22, Halifax – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11496	11552	11586	11601
$Demand_{el,grid}$ (kWh/yr)	4045	4090	1111	1112
$ICE_{Output,el}$ (kWh/yr)	7451	7463	10475	10489
$ICE_{Output,th}$ (GJ/yr)	74.7	74.9	122.3	122.3
BB_{Output} (GJ/yr)	31.1	32.2	9.5	10.4
Heat Dump (GJ/yr)	40.0	41.6	66.5	67.7
$Demand_{SH}$ (GJ/yr)	54.5	54.2	53.9	53.6
$Demand_{DHW}$ (GJ/yr)	12.6	12.6	12.7	12.7
η_{el} (%)	21.6	21.6	17.4	17.5
η_{CHP} (%)	48.1	48.3	34.2	34.3
$Cost_{el,flat}$ (CAD/yr)	410	414	113	113
$Cost_{el,TOU}$ (CAD/yr)	273	276	69	69
Total Fuel (m^3/yr)	6394	6451	8697	8720
$Cost_{fuel}$ (CAD/yr)	6170	6225	8393	8415
$Cost_{tot,flat}$ (CAD/yr)	6580	6639	8505	8528
$Cost_{tot,TOU}$ (CAD/yr)	6443	6501	8461	8484
$GHG_{el,avg}$ (tonnes/yr)	3.07	3.10	0.84	0.84
$GHG_{el,high}$ (tonnes/yr)	3.70	3.75	1.02	1.02
GHG_{th} (tonnes/yr)	10.24	10.33	13.89	13.97
$GHG_{tot,avg}$ (tonnes/yr)	13.31	13.44	14.73	14.81
$GHG_{tot,high}$ (tonnes/yr)	13.95	14.08	14.91	14.99

Table H.65: Test Case House 22, Sydney – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11560	11611	11665	11687
$Demand_{el,grid}$ (kWh/yr)	4074	4115	1129	1130
$ICE_{Output,el}$ (kWh/yr)	7486	7496	10536	10557
$ICE_{Output,th}$ (GJ/yr)	75.4	75.6	123.5	123.6
BB_{Output} (GJ/yr)	39.5	41.1	15.8	16.1
Heat Dump (GJ/yr)	34.8	37.4	60.5	61.2
$Demand_{SH}$ (GJ/yr)	69.0	68.2	67.6	67.3
$Demand_{DHW}$ (GJ/yr)	12.4	12.4	12.5	12.5
η_{el} (%)	21.6	21.6	17.5	17.5
η_{CHP} (%)	48.4	48.5	34.5	34.5
$Cost_{el,flat}$ (CAD/yr)	413	417	114	114
$Cost_{el,TOU}$ (CAD/yr)	275	278	70	70
Total Fuel (m^3/yr)	6803	6884	9036	9013
$Cost_{fuel}$ (CAD/yr)	6565	6644	8720	8697
$Cost_{tot,flat}$ (CAD/yr)	6978	7060	8834	8812
$Cost_{tot,TOU}$ (CAD/yr)	6840	6921	8790	8767
$GHG_{el,avg}$ (tonnes/yr)	3.09	3.12	0.86	0.86
$GHG_{el,high}$ (tonnes/yr)	3.73	3.77	1.03	1.04
GHG_{th} (tonnes/yr)	10.90	11.03	14.40	14.44
$GHG_{tot,avg}$ (tonnes/yr)	13.99	14.15	15.26	15.30
$GHG_{tot,high}$ (tonnes/yr)	14.63	14.80	15.44	15.47

Table H.66: Test Case House 23, Halifax – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9303	9304	9300	9294
$Demand_{el,grid}$ (kWh/yr)	2317	2314	333	334
$ICE_{Output,el}$ (kWh/yr)	6985	6990	8967	8960
$ICE_{Output,th}$ (GJ/yr)	72.0	72.3	115.2	115.2
BB_{Output} (GJ/yr)	88.9	91.8	66.9	69.4
Heat Dump (GJ/yr)	42.8	46.8	65.0	67.6
$Demand_{SH}$ (GJ/yr)	106.9	106.1	105.8	105.6
$Demand_{DHW}$ (GJ/yr)	12.6	12.5	12.6	12.6
η_{el} (%)	20.8	20.8	15.9	15.9
η_{CHP} (%)	42.6	42.7	31.9	31.9
$Cost_{el,flat}$ (CAD/yr)	235	234	34	34
$Cost_{el,TOU}$ (CAD/yr)	156	156	20	20
Total Fuel (m^3/yr)	8962	9102	11018	10939
$Cost_{fuel}$ (CAD/yr)	8648	8783	10632	10556
$Cost_{tot,flat}$ (CAD/yr)	8883	9018	10666	10590
$Cost_{tot,TOU}$ (CAD/yr)	8804	8939	10652	10576
$GHG_{el,avg}$ (tonnes/yr)	1.76	1.76	0.25	0.25
$GHG_{el,high}$ (tonnes/yr)	2.12	2.12	0.30	0.31
GHG_{th} (tonnes/yr)	14.36	14.58	17.34	17.52
$GHG_{tot,avg}$ (tonnes/yr)	16.12	16.34	17.59	17.78
$GHG_{tot,high}$ (tonnes/yr)	16.48	16.70	17.65	17.83

Table H.67: Test Case House 23, Sydney – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9474	9475	9455	9443
$Demand_{el,grid}$ (kWh/yr)	2396	2396	349	347
$ICE_{Output,el}$ (kWh/yr)	7078	7078	9107	9096
$ICE_{Output,th}$ (GJ/yr)	72.9	73.1	116.6	116.6
BB_{Output} (GJ/yr)	113.8	115.9	82.4	84.4
Heat Dump (GJ/yr)	41.1	43.8	54.3	56.7
$Demand_{SH}$ (GJ/yr)	134.5	134.2	133.6	133.2
$Demand_{DHW}$ (GJ/yr)	12.4	12.3	12.4	12.4
η_{el} (%)	20.9	20.9	16.1	16.1
η_{CHP} (%)	43.1	43.1	32.2	32.2
$Cost_{el,flat}$ (CAD/yr)	243	243	35	35
$Cost_{el,TOU}$ (CAD/yr)	161	162	21	21
Total Fuel (m^3/yr)	10173	10273	11845	11703
$Cost_{fuel}$ (CAD/yr)	9817	9913	11431	11293
$Cost_{tot,flat}$ (CAD/yr)	10060	10156	11466	11328
$Cost_{tot,TOU}$ (CAD/yr)	9979	10075	11452	11314
$GHG_{el,avg}$ (tonnes/yr)	1.82	1.82	0.26	0.26
$GHG_{el,high}$ (tonnes/yr)	2.19	2.20	0.32	0.32
GHG_{th} (tonnes/yr)	16.30	16.46	18.60	18.75
$GHG_{tot,avg}$ (tonnes/yr)	18.12	18.28	18.86	19.01
$GHG_{tot,high}$ (tonnes/yr)	18.49	18.65	18.92	19.06

Table H.68: Test Case House 24, Halifax – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9986	9984	9984	9985
$Demand_{el,grid}$ (kWh/yr)	2842	2841	531	536
$ICE_{Output,el}$ (kWh/yr)	7144	7143	9454	9449
$ICE_{Output,th}$ (GJ/yr)	73.0	73.2	117.6	117.6
BB_{Output} (GJ/yr)	69.0	70.9	47.9	51.2
Heat Dump (GJ/yr)	41.0	43.2	65.1	68.8
$Demand_{SH}$ (GJ/yr)	89.8	89.5	89.0	88.6
$Demand_{DHW}$ (GJ/yr)	12.6	12.6	12.7	12.6
η_{el} (%)	21.0	21.0	16.4	16.4
η_{CHP} (%)	44.4	44.4	32.6	32.6
$Cost_{el,flat}$ (CAD/yr)	288	288	54	54
$Cost_{el,TOU}$ (CAD/yr)	191	191	32	32
Total Fuel (m^3/yr)	8079	8164	10242	10259
$Cost_{fuel}$ (CAD/yr)	7796	7878	9884	9900
$Cost_{tot,flat}$ (CAD/yr)	8084	8166	9938	9954
$Cost_{tot,TOU}$ (CAD/yr)	7987	8070	9916	9932
$GHG_{el,avg}$ (tonnes/yr)	2.16	2.16	0.40	0.41
$GHG_{el,high}$ (tonnes/yr)	2.60	2.60	0.49	0.49
GHG_{th} (tonnes/yr)	12.94	13.08	16.19	16.43
$GHG_{tot,avg}$ (tonnes/yr)	15.10	15.23	16.59	16.84
$GHG_{tot,high}$ (tonnes/yr)	15.55	15.68	16.67	16.92

Table H.69: Test Case House 24, Sydney – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10234	10237	10227	10227
$Demand_{el,grid}$ (kWh/yr)	2905	2903	543	548
$ICE_{Output,el}$ (kWh/yr)	7329	7334	9684	9678
$ICE_{Output,th}$ (GJ/yr)	74.4	74.7	119.1	119.1
BB_{Output} (GJ/yr)	84.2	85.6	56.9	59.3
Heat Dump (GJ/yr)	34.7	37.5	53.4	56.7
$Demand_{SH}$ (GJ/yr)	112.9	111.7	111.4	110.6
$Demand_{DHW}$ (GJ/yr)	12.4	12.4	12.5	12.5
η_{el} (%)	21.4	21.4	16.7	16.7
η_{CHP} (%)	45.1	45.1	33.0	33.0
$Cost_{el,flat}$ (CAD/yr)	294	294	55	56
$Cost_{el,TOU}$ (CAD/yr)	195	195	33	33
Total Fuel (m^3/yr)	8863	8931	10793	10743
$Cost_{fuel}$ (CAD/yr)	8553	8619	10415	10367
$Cost_{tot,flat}$ (CAD/yr)	8847	8913	10470	10423
$Cost_{tot,TOU}$ (CAD/yr)	8748	8814	10448	10400
$GHG_{el,avg}$ (tonnes/yr)	2.20	2.20	0.41	0.42
$GHG_{el,high}$ (tonnes/yr)	2.66	2.66	0.50	0.50
GHG_{th} (tonnes/yr)	14.20	14.31	17.03	17.21
$GHG_{tot,avg}$ (tonnes/yr)	16.40	16.51	17.44	17.63
$GHG_{tot,high}$ (tonnes/yr)	16.86	16.97	17.52	17.71

Table H.70: Test Case House 25, Prince Edward Island – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	8790	8845	8866	8881
$Demand_{el,grid}$ (kWh/yr)	2028	2063	271	272
$ICE_{Output,el}$ (kWh/yr)	6762	6782	8595	8610
$ICE_{Output,th}$ (GJ/yr)	70.5	70.7	112.1	112.1
BB_{Output} (GJ/yr)	30.2	31.7	11.3	12.2
Heat Dump (GJ/yr)	39.6	41.7	62.9	64.1
$Demand_{SH}$ (GJ/yr)	49.7	49.3	49.0	48.7
$Demand_{DHW}$ (GJ/yr)	12.7	12.7	12.8	12.8
η_{el} (%)	20.4	20.4	15.5	15.6
η_{CHP} (%)	41.4	41.5	31.3	31.3
$Cost_{el,flat}$ (CAD/yr)	217	220	29	29
$Cost_{el,TOU}$ (CAD/yr)	243	247	34	34
Total Fuel (m^3/yr)	6099	6177	8079	8097
$Cost_{fuel}$ (CAD/yr)	3598	3644	4766	4778
$Cost_{tot,flat}$ (CAD/yr)	3815	3865	4795	4807
$Cost_{tot,TOU}$ (CAD/yr)	3841	3892	4800	4811
$GHG_{el,avg}$ (tonnes/yr)	2.27	2.31	0.30	0.30
$GHG_{el,high}$ (tonnes/yr)	2.46	2.50	0.33	0.33
GHG_{th} (tonnes/yr)	9.77	9.89	12.89	12.97
$GHG_{tot,avg}$ (tonnes/yr)	12.04	12.21	13.19	13.28
$GHG_{tot,high}$ (tonnes/yr)	12.23	12.39	13.22	13.30

Table H.71: Test Case House 26, Prince Edward Island – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	9231	9289	9314	9331
$Demand_{el,grid}$ (kWh/yr)	2318	2356	359	360
$ICE_{Output,el}$ (kWh/yr)	6913	6933	8955	8971
$ICE_{Output,th}$ (GJ/yr)	71.6	71.8	114.5	114.6
BB_{Output} (GJ/yr)	35.8	36.3	14.5	15.4
Heat Dump (GJ/yr)	37.2	38.4	59.7	61.0
$Demand_{SH}$ (GJ/yr)	59.0	58.5	57.9	57.6
$Demand_{DHW}$ (GJ/yr)	12.6	12.6	12.7	12.7
η_{el} (%)	20.7	20.7	15.9	15.9
η_{CHP} (%)	42.5	42.6	31.8	31.8
$Cost_{el,flat}$ (CAD/yr)	248	252	38	38
$Cost_{el,TOU}$ (CAD/yr)	278	282	45	45
Total Fuel (m^3/yr)	6421	6451	8378	8387
$Cost_{fuel}$ (CAD/yr)	3788	3806	4943	4948
$Cost_{tot,flat}$ (CAD/yr)	4036	4058	4982	4987
$Cost_{tot,TOU}$ (CAD/yr)	4066	4088	4988	4993
$GHG_{el,avg}$ (tonnes/yr)	2.60	2.64	0.40	0.40
$GHG_{el,high}$ (tonnes/yr)	2.81	2.85	0.44	0.44
GHG_{th} (tonnes/yr)	10.29	10.33	13.35	13.43
$GHG_{tot,avg}$ (tonnes/yr)	12.88	12.97	13.76	13.84
$GHG_{tot,high}$ (tonnes/yr)	13.09	13.19	13.79	13.87

Table H.72: Test Case House 27, Prince Edward Island – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	8830	8821	8790	8774
$Demand_{el,grid}$ (kWh/yr)	1958	1951	214	212
$ICE_{Output,el}$ (kWh/yr)	6873	6870	8577	8562
$ICE_{Output,th}$ (GJ/yr)	71.3	71.5	113.2	113.3
BB_{Output} (GJ/yr)	106.9	107.8	81.3	83.0
Heat Dump (GJ/yr)	44.6	46.2	61.6	64.0
$Demand_{SH}$ (GJ/yr)	122.3	121.9	121.6	121.0
$Demand_{DHW}$ (GJ/yr)	12.6	12.5	12.6	12.6
η_{el} (%)	20.6	20.6	15.6	15.5
η_{CHP} (%)	41.4	41.5	31.4	31.4
$Cost_{el,flat}$ (CAD/yr)	209	208	23	23
$Cost_{el,TOU}$ (CAD/yr)	234	234	27	26
Total Fuel (m^3/yr)	9773	9816	11591	11433
$Cost_{fuel}$ (CAD/yr)	5766	5791	6839	6745
$Cost_{tot,flat}$ (CAD/yr)	5975	6000	6861	6768
$Cost_{tot,TOU}$ (CAD/yr)	6001	6025	6865	6772
$GHG_{el,avg}$ (tonnes/yr)	2.19	2.19	0.24	0.24
$GHG_{el,high}$ (tonnes/yr)	2.37	2.36	0.26	0.26
GHG_{th} (tonnes/yr)	15.66	15.72	18.19	18.31
$GHG_{tot,avg}$ (tonnes/yr)	17.85	17.91	18.43	18.55
$GHG_{tot,high}$ (tonnes/yr)	18.03	18.09	18.45	18.57

Table H.73: Test Case House 28, Goose Bay – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11224	11214	11259	11295
$Demand_{el,grid}$ (kWh/yr)	3797	3791	977	982
$ICE_{Output,el}$ (kWh/yr)	7427	7423	10282	10313
$ICE_{Output,th}$ (GJ/yr)	75.4	75.4	122.9	123.1
BB_{Output} (GJ/yr)	66.3	69.8	34.6	37.8
Heat Dump (GJ/yr)	36.9	40.6	53.6	57.3
$Demand_{SH}$ (GJ/yr)	93.9	93.6	92.9	92.6
$Demand_{DHW}$ (GJ/yr)	12.3	12.3	12.4	12.4
η_{el} (%)	21.5	21.5	17.3	17.3
η_{CHP} (%)	47.6	47.6	34.1	34.1
$Cost_{el,flat}$ (CAD/yr)	339	338	87	88
$Cost_{el,TOU}$ (CAD/yr)	378	377	100	100
Total Fuel (m^3/yr)	8052	8218	9888	9952
$Cost_{fuel}$ (CAD/yr)	6289	6418	7722	7772
$Cost_{tot,flat}$ (CAD/yr)	6627	6756	7809	7860
$Cost_{tot,TOU}$ (CAD/yr)	6666	6795	7822	7872
$GHG_{el,avg}$ (tonnes/yr)	0.08	0.08	0.02	0.02
$GHG_{el,high}$ (tonnes/yr)	2.96	2.95	0.76	0.77
GHG_{th} (tonnes/yr)	12.90	13.16	15.68	15.94
$GHG_{tot,avg}$ (tonnes/yr)	12.98	13.24	15.70	15.96
$GHG_{tot,high}$ (tonnes/yr)	15.86	16.12	16.44	16.71

Table H.74: Test Case House 28, St. John's – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	11165	11260	11285	11301
$Demand_{el,grid}$ (kWh/yr)	3772	3845	980	982
$ICE_{Output,el}$ (kWh/yr)	7393	7416	10305	10320
$ICE_{Output,th}$ (GJ/yr)	75.3	75.6	122.7	122.6
BB_{Output} (GJ/yr)	33.1	33.0	7.2	6.3
Heat Dump (GJ/yr)	31.4	32.4	54.2	54.0
$Demand_{SH}$ (GJ/yr)	66.0	65.2	64.5	63.7
$Demand_{DHW}$ (GJ/yr)	12.3	12.3	12.5	12.5
η_{el} (%)	21.5	21.5	17.3	17.3
η_{CHP} (%)	47.5	47.8	34.1	34.1
$Cost_{el,flat}$ (CAD/yr)	336	343	87	88
$Cost_{el,TOU}$ (CAD/yr)	375	383	100	100
Total Fuel (m^3/yr)	6466	6468	8516	8463
$Cost_{fuel}$ (CAD/yr)	5050	5051	6651	6610
$Cost_{tot,flat}$ (CAD/yr)	5386	5394	6738	6697
$Cost_{tot,TOU}$ (CAD/yr)	5425	5434	6751	6710
$GHG_{el,avg}$ (tonnes/yr)	0.08	0.08	0.02	0.02
$GHG_{el,high}$ (tonnes/yr)	2.94	3.00	0.76	0.76
GHG_{th} (tonnes/yr)	10.36	10.36	13.61	13.56
$GHG_{tot,avg}$ (tonnes/yr)	10.44	10.44	13.63	13.58
$GHG_{tot,high}$ (tonnes/yr)	13.30	13.36	14.37	14.32

Table H.75: Test Case House 29, Goose Bay – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10264	10252	10275	10293
$Demand_{el,grid}$ (kWh/yr)	3040	3031	616	628
$ICE_{Output,el}$ (kWh/yr)	7225	7221	9659	9665
$ICE_{Output,th}$ (GJ/yr)	74.4	74.4	120.2	120.1
BB_{Output} (GJ/yr)	78.3	79.3	42.9	47.8
Heat Dump (GJ/yr)	33.8	35.1	45.3	50.5
$Demand_{SH}$ (GJ/yr)	108.0	107.6	106.8	106.5
$Demand_{DHW}$ (GJ/yr)	12.2	12.3	12.3	12.3
η_{el} (%)	21.2	21.2	16.6	16.6
η_{CHP} (%)	45.2	45.2	33.1	33.1
$Cost_{el,flat}$ (CAD/yr)	271	270	55	56
$Cost_{el,TOU}$ (CAD/yr)	303	302	63	64
Total Fuel (m^3/yr)	8547	8594	10070	10182
$Cost_{fuel}$ (CAD/yr)	6675	6712	7865	7952
$Cost_{tot,flat}$ (CAD/yr)	6946	6982	7919	8008
$Cost_{tot,TOU}$ (CAD/yr)	6978	7014	7928	8017
$GHG_{el,avg}$ (tonnes/yr)	0.06	0.06	0.01	0.01
$GHG_{el,high}$ (tonnes/yr)	2.37	2.36	0.48	0.49
GHG_{th} (tonnes/yr)	13.69	13.77	15.93	16.31
$GHG_{tot,avg}$ (tonnes/yr)	13.76	13.83	15.95	16.32
$GHG_{tot,high}$ (tonnes/yr)	16.06	16.13	16.41	16.80

Table H.76: Test Case House 29, St. John's – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10176	10216	10268	10296
$Demand_{el,grid}$ (kWh/yr)	2991	3024	622	622
$ICE_{Output,el}$ (kWh/yr)	7185	7192	9646	9674
$ICE_{Output,th}$ (GJ/yr)	74.5	74.6	120.3	120.3
BB_{Output} (GJ/yr)	39.6	42.3	12.0	11.9
Heat Dump (GJ/yr)	26.7	29.8	45.4	45.9
$Demand_{SH}$ (GJ/yr)	76.5	76.2	75.9	75.3
$Demand_{DHW}$ (GJ/yr)	12.2	12.2	12.3	12.3
η_{el} (%)	21.1	21.1	16.6	16.7
η_{CHP} (%)	45.1	45.2	33.1	33.1
$Cost_{el,flat}$ (CAD/yr)	267	270	55	55
$Cost_{el,TOU}$ (CAD/yr)	298	302	64	64
Total Fuel (m^3/yr)	6698	6831	8513	8486
$Cost_{fuel}$ (CAD/yr)	5231	5335	6649	6627
$Cost_{tot,flat}$ (CAD/yr)	5498	5605	6704	6683
$Cost_{tot,TOU}$ (CAD/yr)	5529	5636	6713	6691
$GHG_{el,avg}$ (tonnes/yr)	0.06	0.06	0.01	0.01
$GHG_{el,high}$ (tonnes/yr)	2.33	2.36	0.48	0.48
GHG_{th} (tonnes/yr)	10.73	10.94	13.58	13.59
$GHG_{tot,avg}$ (tonnes/yr)	10.79	11.01	13.60	13.61
$GHG_{tot,high}$ (tonnes/yr)	13.06	13.30	14.07	14.08

Table H.77: Test Case House 30, Goose Bay – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10907	10899	10967	11002
$Demand_{el,grid}$ (kWh/yr)	3660	3656	899	900
$ICE_{Output,el}$ (kWh/yr)	7247	7243	10068	10102
$ICE_{Output,th}$ (GJ/yr)	74.7	74.6	121.6	121.9
BB_{Output} (GJ/yr)	53.5	58.0	27.7	27.5
Heat Dump (GJ/yr)	31.3	36.1	53.5	54.2
$Demand_{SH}$ (GJ/yr)	83.6	83.2	82.5	81.7
$Demand_{DHW}$ (GJ/yr)	14.6	14.6	14.7	14.7
η_{el} (%)	21.2	21.2	17.0	17.0
η_{CHP} (%)	46.9	46.9	33.7	33.7
$Cost_{el,flat}$ (CAD/yr)	326	326	80	80
$Cost_{el,TOU}$ (CAD/yr)	364	363	91	91
Total Fuel (m^3/yr)	7382	7592	9457	9378
$Cost_{fuel}$ (CAD/yr)	5765	5929	7386	7324
$Cost_{tot,flat}$ (CAD/yr)	6092	6255	7466	7404
$Cost_{tot,TOU}$ (CAD/yr)	6129	6293	7477	7415
$GHG_{el,avg}$ (tonnes/yr)	0.08	0.08	0.02	0.02
$GHG_{el,high}$ (tonnes/yr)	2.85	2.85	0.70	0.70
GHG_{th} (tonnes/yr)	11.83	12.16	15.02	15.02
$GHG_{tot,avg}$ (tonnes/yr)	11.90	12.24	15.04	15.04
$GHG_{tot,high}$ (tonnes/yr)	14.68	15.01	15.72	15.72

Table H.78: Test Case House 30, St. John's – ICE Based Cogeneration Annual Simulation Results

	1 kW, 300L	1kW, 450L	2kW, 300L	2kW, 450L
$Demand_{el}$ (kWh/yr)	10894	10985	10999	11006
$Demand_{el,grid}$ (kWh/yr)	3665	3728	894	895
$ICE_{Output,el}$ (kWh/yr)	7229	7257	10106	10111
$ICE_{Output,th}$ (GJ/yr)	74.6	74.9	121.4	121.3
BB_{Output} (GJ/yr)	28.0	28.3	4.4	3.8
Heat Dump (GJ/yr)	28.4	29.5	52.4	52.1
$Demand_{SH}$ (GJ/yr)	61.0	60.4	59.8	59.4
$Demand_{DHW}$ (GJ/yr)	14.6	14.6	14.9	14.9
η_{el} (%)	21.2	21.2	17.0	17.0
η_{CHP} (%)	47.0	47.2	33.7	33.7
$Cost_{el,flat}$ (CAD/yr)	327	333	80	80
$Cost_{el,TOU}$ (CAD/yr)	364	370	90	90
Total Fuel (m^3/yr)	6167	6191	8296	8261
$Cost_{fuel}$ (CAD/yr)	4817	4835	6479	6452
$Cost_{tot,flat}$ (CAD/yr)	5144	5168	6559	6532
$Cost_{tot,TOU}$ (CAD/yr)	5181	5206	6570	6542
$GHG_{el,avg}$ (tonnes/yr)	0.08	0.08	0.02	0.02
$GHG_{el,high}$ (tonnes/yr)	2.86	2.90	0.70	0.70
GHG_{th} (tonnes/yr)	9.88	9.92	13.27	13.23
$GHG_{tot,avg}$ (tonnes/yr)	9.96	10.00	13.29	13.25
$GHG_{tot,high}$ (tonnes/yr)	12.73	12.82	13.97	13.93

Table H.79: Annual Simulation Results – Prince George, 3.0 kW, 1000 kg Thermal Storage

	Test Case House 1	Test Case House 2	Test Case House 3
$Demand_{el}$ (kWh/yr)	19270	19109	16985
$Demand_{el,grid}$ (kWh/yr)	2461	2933	1501
$ICE_{Output,el}$ (kWh/yr)	16809	16177	15485
$ICE_{Output,th}$ (GJ/yr)	176.2	166	169
BB_{Output} (GJ/yr)	8.9	0.0	0.0
Heat Dump (GJ/yr)	68.0	110.1	82.9
$Demand_{SH}$ (GJ/yr)	107.8	46.0	76.6
$Demand_{DHW}$ (GJ/yr)	10.5	11.4	10.8
η_{el} (%)	18.9	18.4	18.1
η_{CHP} (%)	35.4	35.1	33.7
$Cost_{el,flat}$ (CAD/yr)	156	186	95
$Cost_{el,TOU}$ (CAD/yr)	179	208	8560
Total Fuel (m^3/yr)	9202	8740	110
$Cost_{fuel}$ (CAD/yr)	3751	3563	3490
$Cost_{tot,flat}$ (CAD/yr)	3907	3749	3585
$Cost_{tot,TOU}$ (CAD/yr)	3931	3771	3600
$GHG_{el,avg}$ (tonnes/yr)	0.06	0.07	0.04
$GHG_{el,high}$ (tonnes/yr)	0.92	1.10	0.56
GHG_{th} (tonnes/yr)	17.08	16.22	15.89
$GHG_{tot,avg}$ (tonnes/yr)	17.14	16.30	15.93
$GHG_{tot,high}$ (tonnes/yr)	18.01	17.32	16.45

H.2 Discussion

There is variability in the space heating demand results due to:

- The difference in casual gains due to the equipment usage
- The difference in control strategy used between the base and ICE based cogeneration cases. As mentioned in Section 7.9.1, the space heating demand in the base case was met by idealized HVAC using idealized control, which does not actually simulate system response and thus the temperature in the zone is held, without variability, at the set point temperature. In contrast, the control

implemented in the ICE based cogeneration case is through the control imposed on the space-heating fan. On/off control was used with a 1°C temperature band around the set point temperature defined. Since the system response is actually simulated, the temperature falls between the 1°C temperature band, as opposed to the exact temperature set point. Due to this difference, there is variability (less than 2.5%) in the space heating results.

There is variability in the domestic hot water demand due to:

- The differences in average tank temperature, thus the energy balance on the tank.
- The demand in litres between the base case, and the ICE based cogeneration cases remains the same, however, the demand in watts changes.

The ICE based cogeneration annual simulation results show the benefit of using a larger thermal storage tank capacity during the non-space heating months is outweighed by the cost of using a larger tank capacity in the space heating months. During times of high space heating demands, the thermal output from the ICE based cogeneration system is not enough to keep the tank temperature at the required 55°C, thus the backup burner is activated. Since the thermal mass of the 450 kg tank requires more energy to remain at the set point temperature compared to the 300 kg tank, the thermal output of the backup burner is greater when using a 450 kg tank during the space heating months. This results in higher fuel costs and GHG emissions. In addition, the ICE capacities simulated are relatively small (1.0 kW and 2.0 kW) as they were chosen to follow the electrical demand of the house, thus the thermal output is not large enough to warrant a larger thermal capacity. The severity and duration of the space-heating season affect the required output by the backup burner. Comparing the results for test case house 11 simulated in Le Pas and test case house 24 simulated in Sydney highlight this dependency. Figure H.1 plots the heating degree-day (HDD) for Le Pas and Sydney.

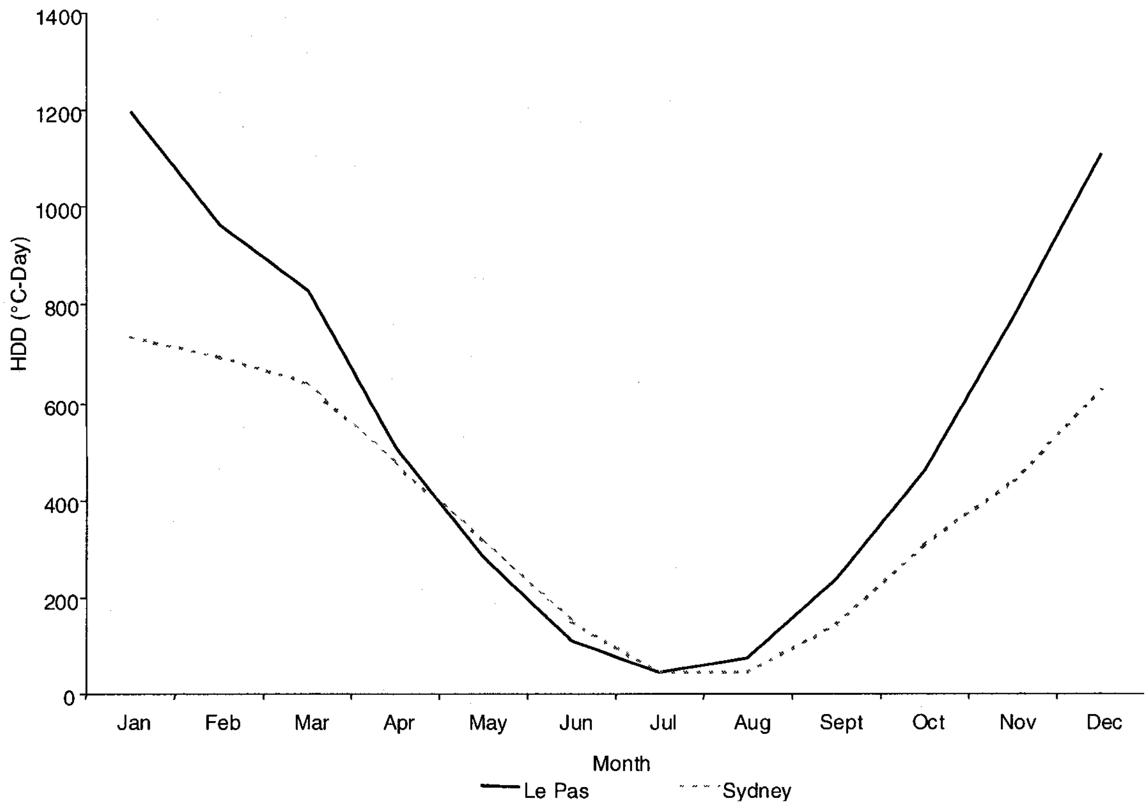

Figure H.1: Le Pas and Sydney HDD (Environment Canada, 2004)

As can be seen in Figure H.1, the heating season in Le Pas is more severe and longer in duration. Although the space heating demand of these two test case houses is comparable, the requirement of the backup burner in the test case house in Le Pas is higher than the backup burner output of the test case house in Sydney. Not only does the magnitude of the space heating requirement affect the backup burner requirement, so too does severity and duration of the space heating season.

In cases when the thermal output of the ICE based cogeneration system was sufficient to meet the thermal demand of the house, as in test case house 2 simulated in Vancouver, the benefit of the larger thermal storage tank is apparent as the requirement from the backup burner is decreased.