1-1-2008

A cost optimized energy retrofit upgrade of the Canadian residential sector for the reduction of greenhouse gas emissions

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A COST OPTIMIZED ENERGY RETROFIT UPGRADE OF THE CANADIAN RESIDENTIAL SECTOR FOR THE REDUCTION OF GREENHOUSE GAS EMISSIONS

by

Rachit Bhambri

A thesis project
presented to Ryerson University

in Partial Fulfillment of the Requirements
for the Degree of

Master of Engineering

In the program of: Mechanical Engineering

Toronto, Ontario Canada 2008

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ABSTRACT

A Cost Optimized Energy Retrofit Upgrade of the Canadian housing sector
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The objective of this study is to assess the impact of energy efficiency upgrade scenarios on the greenhouse gas (GHG) emissions from the Canadian housing stock. The study is targeted towards policy makers who can use the results of this techno-economic study to pass appropriate legislation to curtail GHG emissions from the Canadian housing stock

The analysis was conducted using the Canadian Residential End-use Energy Model (CREEM). CREEM is representative of the Canadian housing stock, and is capable of assessing the GHG and energy impact of retrofits.

Cost estimates were updated to assess the economic feasibility of the upgrade by calculating the indicator "GHG emissions reduction per dollar investment" (GHGRPDI) calculated by dividing the reduction in annual GHG emissions by the investment cost.

Retrofits were ranked for each house in CREEM, based on the indicator GHGRPDI. The analysis is for houses that are eligible for a certain upgrade. The top five retrofits were determined for each province, and are presented as part of this study. For example, the top 5 retrofits (in order) that are suited for Ontario based on the GHGRPDI are:

1) Upgrade the lighting system to high efficient compact fluorescent lights.
2) Install programmable thermostats in all eligible houses
3) Ceiling insulation upgrade to RSI 7.04 for all eligible houses
4) Install low flow shower heads and aerators for all eligible houses
5) Basement ceiling insulation of at least RSI 5.5 in all eligible houses.

ACKNOWLEDGMENT

I would like to thank Dr. Wey Leong, for giving me the opportunity to feed my desire to learn. His patience and knowledge is a virtue to the academic community. It has been an honor to be his graduate student.

I would like to extend my gratefulness to Dr. Alan Fung for allowing me to tap into his wealth of knowledge. His grasp of Energy Management principles is a great asset to fight the turbulent times of climate change and energy conservation. I am proud to be one of his ambassadors to confront the status quo of energy use. I thank him for the countless number of hours that were spent to make this study possible.

I would like to thank my parents Ashwani Bhambri and Shailly Bhambri. Their support and guidance cannot be expressed in words. I am lucky to have them as my parents.

I am grateful to Brian Schofield of Carrier Canada. His knowledge of HVAC systems has been a definite asset in the shaping of this project.

I would also like to thank Burak Guler. I appreciate his time and help in troubleshooting the CREEM model. In the end logic and will power prevailed.

I will use the power that I have attained as a result of this thesis to help humanity steer in the right direction for the sake of sustaining our modern civilization.

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LIST OF ABBREVIATIONS

AES	Annual energy savings as a result of the upgrade, MJ/year
AESD	Annual energy savings in dollars, $/year
AGHGR	Annual GHG emissions reduction as a result of the upgrade, kt/year
BCEC	Base case energy consumption, GJ/year
BCEP	Base case emissions production, kt/year/house
CH4EF	CH_4 emission factor
CO2EEFF	CO_2 equivalent GHG emissions due to fossil fuel consumption from the house, tonnes/ year
CO2EF	CO_2 emission factor
COSTA	Cost estimate for location A, $
COSTB	Cost estimate obtained by using the TIC function, for location B, $
CREEM	Canadian Residential Energy End-use Model
DHW	Domestic hot water
Direct	Direct GHG emissions from the house (through fossil fuel use in the house)
ECH4	CH_4 emission, tonne/year
ECO2	CO_2 emission, tonne/year
ECWU	Energy consumption with upgrade, GJ/year/house
ELCON	Electricity consumption of the house, kWh/year
EN2O	N_2O emission, tonne/year
EnvCan	Environment Canada
EPWU	Emissions production with upgrade, kg/year/house
ERAVWU	Emissions reduction with upgrade, kg/year/house
ESAVWU	Energy saving with upgrade, MJ/year/house
ESPDI	Energy saving per dollar investment, MJ/year/$
GHG	Total amount of GHG emissions in CO_2 equivalent (kt)
GHGIF	greenhouse gas intensity factor
GHGRPDI	GHG emissions reduction per dollar investment, kg/year/$

Indirect	Indirect GHG Emissions from the house (through electricity use in the house)
LE	Life expectancy, years
LF	Location factor
LFA	Location factor for location A
LFB	Location factor for location B
MFW	Modified weighting factor
N	Number of houses in CREEM that are from a given province
N2OEF	N_2O emission factor
NECH	National Energy Code for housing
NH	Percentage of houses that received retrofit
NHN	Number of houses that have "Don't Know" and "Not Stated" responses
NRCan	Natural Resources Canada
RSI	Thermal resistance value. A metric measurement of the ability of a material to resist heat transfer, RSI=R(0.1761), m^2 °C/W
SHEU	Survey of Household Energy Use
SPP	Simple payback period, years
TBMWA	Total basement wall area, m^2
TCO2EE	Total CO_2 equivalent GHG emission from the house, tonnes/ year
TCU	Total cost of upgrade, $
TIC	Total investment cost, $
TICAF	Total investment cost for aerator upgrade, $
TICBCIU	Total investment cost for basement ceiling insulation upgrade scenario #1, $
TICBWIU1	Total investment cost for basement wall insulation upgrade scenario #2a, $
TICBWIU2	Total investment cost for basement wall insulation upgrade scenario #2b, $
TICCHS	Total investment cost for central heating system thermostat upgrade, $

TICCIU	Total investment cost for ceiling insulation upgrade, $/m^2$
TICEDWU	Total investment cost for energy-efficient double glazed window upgrade, $
TICETWU	Total investment cost for energy-efficient triple glazed window upgrade, $
TICL	Total investment cost for lighting fixture upgrade, $
TICRT	Total investment cost for room thermostat upgrade, $
TICSDWU	Total investment cost for standard double glazed window upgrade, $
TICSH	Total investment cost for showerhead upgrade, $
TICWIU1	Total investment cost for external wall insulation upgrade scenario #1, $
TICWIU2	Total investment cost for external wall insulation upgrade scenario #2, $
TMFA	Total main floor area, m^2
TMWA	Total main wall area, m^2
TNAE	Total number of aerator(s) and faucet(s) in the house
TNF	Total number of incandescent light bulbs in the house
TNHS	Total number of houses represented by all responses
TNHST	Total number of central heating system thermostat
TNRT	Total number of room thermostats
TNSH	Total number of showerheads
TWA	Total window area, m^2
UEC	End-use unit energy consumption, kWh/year
URSI	Insulation upgrade applied, m^2 °C/W
WF	Weighting factor from SHEU database

Subscripts:

CHS	Canadian housing stock
i	House i in CREEM; type of fuel
p	Province

1.0 INTRODUCTION

The world is not on course to achieve a sustainable energy future! The global energy supply will be dominated by fossil fuels for decades. The global decisions and policies we implement now, will go far in securing our energy needs. Energy services are fundamental in achieving sustainable development. The world's dependence on fossil fuels has lead to the release of 1100 billion tonnes of CO_2 since the mid 19th century. GHG emissions from heat supply, transportation and electricity generation account for 70% of global GHG emissions. Further exploitation of fossil fuels without proactive measures to conserve energy usage is no longer a viable option for sustainable growth. No single policy will be sufficient to foresee any significant decrease in energy usage and GHG reductions, however policies have to be regionally specific. (IPCC, 2007).

In the following decades, business-as-usual energy trends will produce significant growth in the GHG emissions. The main goal is to enhance the quality of life (expectancy, health) and productivity but maintain secure, equitable and sustainable supply of energy. Approximately 45% of global energy is used for low temperature heating (domestic hot water heating, space heating, drying), 10% for high temperature industrial heating, 15% for electric motors, lighting and 30% for transportation. The CO_2 associated by meeting this demand constitutes to 80% of total emissions in the world. Currently, the one billion people living in the Organization for Economic Co-Operation and Development (OECD) countries consume half of the 470 EJ of the world's current annual demand for primary energy usage. In contrast, one billion people of the world's poorest countries use only 4% of the current global demand for primary energy usage, mainly from biomass inefficiently used for cooking and heating.

1.1 Literature Review

1.1.1 Global Energy Outlook

Fossil Fuels

Fossil fuel is abundantly available globally, and can last decades as shown in Figure 1.1. However fossil fuels contain a significant amount of CO_2 (Carbon dioxide) which is detrimental to the Greenhouse Gas effect. Fossil fuel satisfied 80% of the worlds demand in 2004, and is poised to increase in the absence of policies that promote low carbon emissions. The largest constituent was oil (35%), coal (25%) and natural gas (21%). Fossil fuels are responsible for 85% of the anthropogenic CO_2 emissions produced annually. Natural gas has the lowest amount of GHG emissions per unit of energy consumed, and is globally favored in GHG reduction strategies. (IPCC, 2007)

Coal

Coal is the most abundant fossil fuel. Coal constituted of around 25% of total energy consumption with approximately 100,000 EJ in proven reserves. Over half of the worlds coal resources are located in USA (27%), Russia (17%) and China (13%). India, South Africa, Australia, Kazakhstan, and the former Yugoslavia accounted for another 33% in global reserves (which stores over 12,800 $GTCO_2$).

Natural Gas

Natural gas accounted for 21% of global energy consumption, contributing to 5.5 GT CO_2 annually to the atmosphere. In 2005, 11% of natural gas was produced in the Middle East, while Europe and Eurasia produced 38%, and North America 27% . Natural gas is forecasted to be the fastest growing fossil fuel energy source worldwide (IEA, 2006B), maintaining growth of 2% annually and rising to 161 EJ in 2025.

Oil

Conventional oil accounted for 37% of energy consumption, with an estimated energy resource of 10,000 EJ and a consumption of 160 EJ per year. Two thirds of the world's resources are located in the Middle East and North Africa (IPCC, 2007).

Energy class	Specific energy source[a]	Estimated available energy resource[b] (EJ)	Rate of use in 2005 (EJ/yr)[c]	2005 share of total supply (%)	Comments on environmental impacts
Fossil energy	Coal (conventional)	>100,000	120	25	Average 92.0 gCO_2/MJ
	Coal (unconventional)	32,000	0		
	Peat[d]	large	0.2	<0.1	
	Gas (conventional)	13,500	100	21	Average 52.4 gCO_2/MJ
	Gas (unconventional)	18,000	Small		Unknown, likely higher
	Coalbed methane	>8,000?	1.5	0.3	
	Tight sands	8,000	3.3	0.7	
	Hydrates	>60,000	0		
	Oil (conventional)	10,000	160	33	Average 76.3 gCO_2/MJ
	Oil (unconventional)	35,000	3	0.6	Unknown, likely higher
Nuclear	Uranium[e]	7,400	26	5.3	Spent fuel disposition
	Uranium recycle[f]	220,000	Very small		Waste disposal
	Fusion	5 x 109 estimated	0		Tritium handling
Renewables[g]	Hydro (>10 MW)	60 /yr	25	5.1	Land-use impacts
	Hydro (< 10 MW)	2 /yr	0.8	0.2	
	Wind	600 /yr	0.95	0.2	
	Biomass (modern)	250 /yr	9	1.8	Likely land-use for crops
	Biomass (traditional)		37	7.6	Air pollution
	Geothermal	5,000 /yr	2	0.4	Waterway contamination
	Solar PV	1,600 /yr	0.2	<0.1	Toxics in manufacturing
	Concentrating solar	50 /yr[h]	0.03	0.1	Small
	Ocean (all sources)	7/yr (exploitable)	<1	0	Land and coastal issues.

Figure 1.1: Worlds Energy Resources (IPCC, 2007)

1.1.2 Canada's Energy Outlook

Key Drivers for Energy

A number of key macroeconomic drivers have a large influence on the energy consumption and production throughout the economy. The following variables are projections from the modeling and analysis division of Natural Resources of Canada (NRCan, 2006).

Population

The Canadian population projection is reflective of the decreasing birth rates. Immigration is assumed to remain at about 225,000 immigrants per year and a net immigration of 168,000. The population is projected to grow at a rate of 0.8% from 2005 to 2010 reaching 35.8 million in 2010 (NRCan, 2006).

Size of the Economy

The size of the labour force and employment, combined with the productivity per worker determines, the size of the economy. The productivity per worker is projected to increase at an average rate of 1.6%, along with a labour force population increase of 0.8%. The combination of productivity growth and labour force growth leads to an anticipated increase of 2.4% per year in economic activity, measured in terms of Gross Domestic Product (GDP) over the next 15 years (NRCan, 2006).

Composition of the Economy

The economy is divided into two main sectors: one produces goods, the other services. Consumers are expected to spend more on services by the year 2020, which means greater economic activity in Canada's service sector. Growth in the service sector is expected to outpace that of manufacturing. Already representing 69% of the economy, the service sector's share is anticipated to increase to over 70% by 2020 (NRCan, 2006).

Crude Oil Price

The New York Mercantile Exchange (NYMEX) price of the West Texas Intermediate (WTI) crude oil closely follows the world price of crude oil. The WTI oil is the gauge from which regional prices are determined throughout North America and is the price benchmark for Canada.

The current high price of oil can be ascribed to the uncertainty as a result of global terrorism, geopolitical pressures, strong demand (especially China and India). The (IEA) International Energy Association postulates that non OPEC production increases could be limited over the next 20 years, and unconventional oil could only provide 6% of the world crude oil supply. Therefore the price of oil is forecasted to increase. (NRCan, 2006).

Natural Gas Price

In the short term, natural gas prices are determined by the storage levels at the distribution facilities, economic activity and the weather. The US Department of Energy predicts that the 2007 winter season will be colder than previous years which may means double digit percentage increases in natural gas prices. On average, the yearly increase on natural gas prices has been 5%.

In the long term, natural gas prices are determined by economic activity, demand and supply, and the price of oil. Natural gas supply in North America is increasing at a rate of 1% and consumption is increasing at a rate of 3%, therefore overall prices are slated to increase. The level of economic activity in Canada will determine how much natural gas businesses consume. An increase in activity means that demand will outpace supply, leading to a surge in prices, and a downturn may mean a decrease in demand and gas prices (NRCan, 2006).

End-use Price Forecast

Oil is expected to decrease from the high in 2005 through to 2020. Natural gas prices in all sectors are expected to go down from the high in 2005 by 15%. Figure 1.2 summarizes the price forecast for oil, natural gas and other fuels over the forecast period (NRCan, 2006).

End-Use Price CS(2003) per GJ (Unless noted otherwise)	1990	2000	2005	2010	2020
Oil Price (WTI) C$ per barrel	35.79	47.85	70.20	52.65	49.50
Oil Price	5.85	7.82	11.47	8.60	8.09
Natural Gas (Alberta Wellhead)	1.67	4.50	7.98	7.33	6.48
Residential					
Natural Gas	6.40	10.14	13.00	11.89	10.71
Heating Oil	10.86	15.75	18.43	15.25	14.36
Electricity	21.48	24.60	23.56	23.51	23.68
Commercial					
Natural Gas	6.40	8.58	11.87	10.73	9.66
Heavy Fuel Oil	4.30	7.63	10.87	8.43	7.96
Electricity	20.16	17.26	17.10	17.02	17.33
Industrial					
Natural Gas	3.45	5.86	9.64	8.50	7.66
Heavy Fuel Oil	3.59	7.38	10.63	8.06	7.58
Electricity	13.86	15.36	14.33	14.01	13.01
Transportation					
Gasoline	21.1	22.07	25.05	21.06	19.24
Diesel	16.54	18.88	21.51	18.04	16.57
Electricity Generators					
Natural Gas	1.88	5.61	9.51	8.62	8.41
Heavy Fuel Oil	3.46	6.16	9.19	6.94	6.53
Coal	0.97	1.41	1.45	1.65	1.53

Figure 1.2 : End Use Price per GJ forecast (NRCan, 2006)

End use Demand Forecast

Energy demand in the Canadian residential sector is projected to increase by 15%. This is because of the growth in the number of households and the trend towards larger homes offset energy efficiency improvements.

The number of households is expected to increase by about 1.4% annually from 2005 to 2010. The average residential floor space is forecasted to increase by 0.4% per year. The increase in floor space and number of households equates to higher demand for energy. The expected effect of introducing new equipment standards will be to contribute to an overall energy intensity improvement of about 0.5% for the period of 2005 to 2010.

Consequentially, energy intensity per household is expected to continue to decline from 128 GJ in 1990 to 111 GJ in 2005, reaching 106 GJ by 2020 as shown in Figure 1.3 (NRCan, 2006).

Residential Demand, 1990-2020

					AAGR, percent		
	1990	**2005**	**2010**	**2020**	**1990-2004**	**2005-2010**	**2010-2020**
Households (million)	10.1	12.6	13.5	15.2	1.5	1.4	1.1
Energy Consumption (PJ)	1,287	1,402	1,467	1,609	0.7	0.9	0.9
Energy Intensity (GJ/household)	128	111	108	106	-0.8	-0.5	-0.2

Figure1.3: Residential Energy Intensity and Energy demand forecast (NRCan, 2006)

1.1.3 Canada's Residential Energy Consumption

The residential sector in Canada is made up of four types of houses which include: single detached houses, single attached houses, apartments and mobile homes. Energy usage in the residential sector in 1990 was 1289.3 PJ. Between 1990 and 2003 energy usage has increased by 13% (168.2 PJ) to 1457.6 PJ (see Figure 1.4 and Figure 1.5) which factors in the amount of energy used with energy efficient improvements. Had there been no energy efficient improvements, the energy usage would have increased by 32% to 1708.1 PJ. (NRCan, 2004)

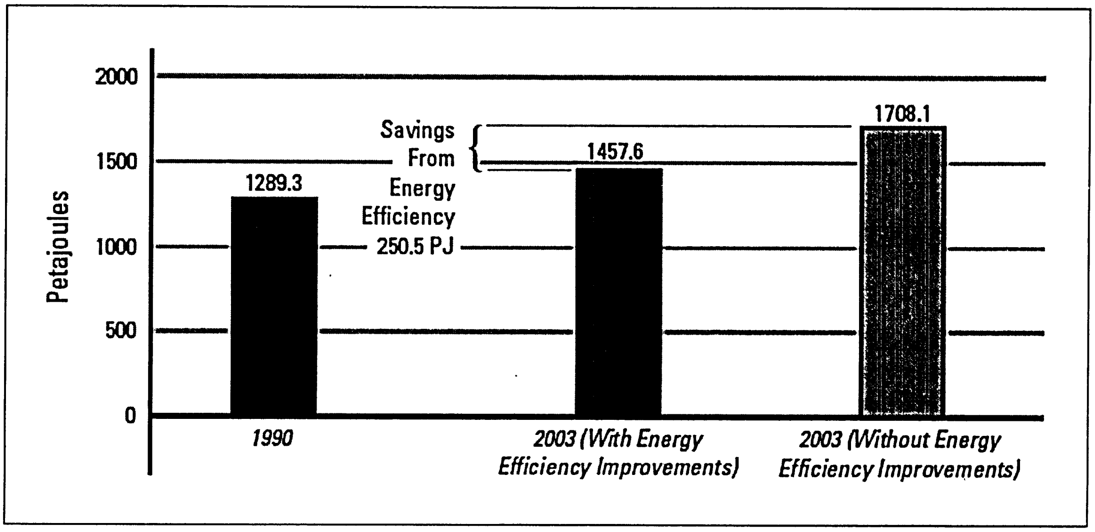

Figure 1.4: Energy Comparison 2003 vs 1990 (NRCan, 2004).

The corresponding increase in greenhouse gasses from 1990 to 2003 was 10 Mt (from 70 Mt to 80 Mt) (see Figure 1.5).

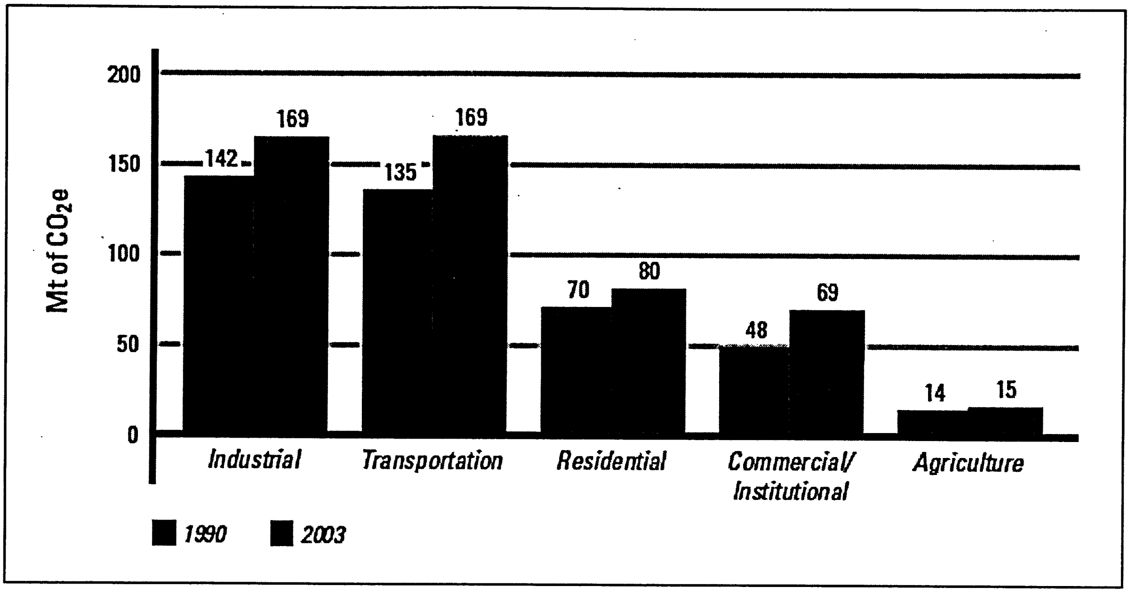

Figure 1.5: CO_2 emissions per sector in Canada (NRCan, 2004).

Survey of household Energy usage

Statistics Canada conducted a survey entitled "Survey of Household Energy Use" (SHEU). The main purpose of this survey was to find out in detail the energy usage pattern of residential households across Canada. The survey is for residential dwellings with less than 5 stories.

The survey was conducted in five regions of Canada (Quebec, Ontario, Prairies, British Columbia and Atlantic Canada). The breakdown of the total population is illustrated in Figure 1.6.

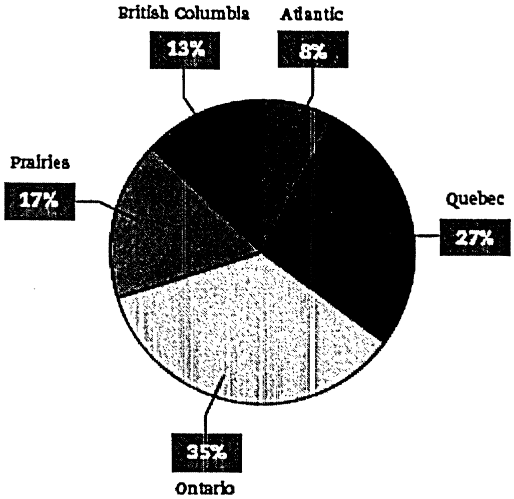

Figure 1.6: Breakdown of population by province (NRCan, 2003)

The Stock of Dwellings in Canada.

According to the SHEU research, in 2003 60% of the houses in Canada were constructed after 1969. Figure 1.7 shows a breakdown of the vintage of the residential stock in Canada.

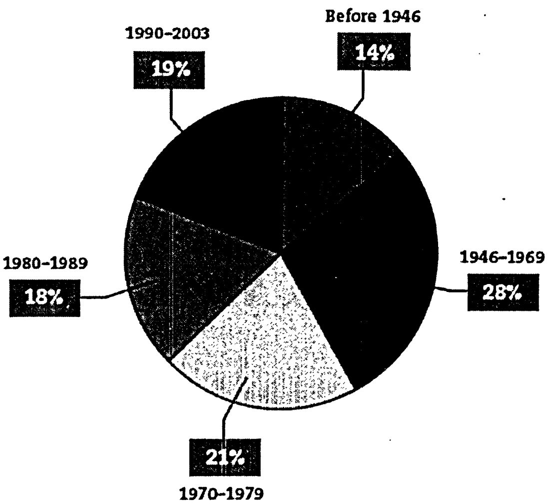

Figure 1.7: Vintage of Canadian Household (NRCan,2003)

The average heated area according to the survey (total floor space of the house minus the basement and the garage) was found to be 1321 ft^2 as illustrated in figure 1.8

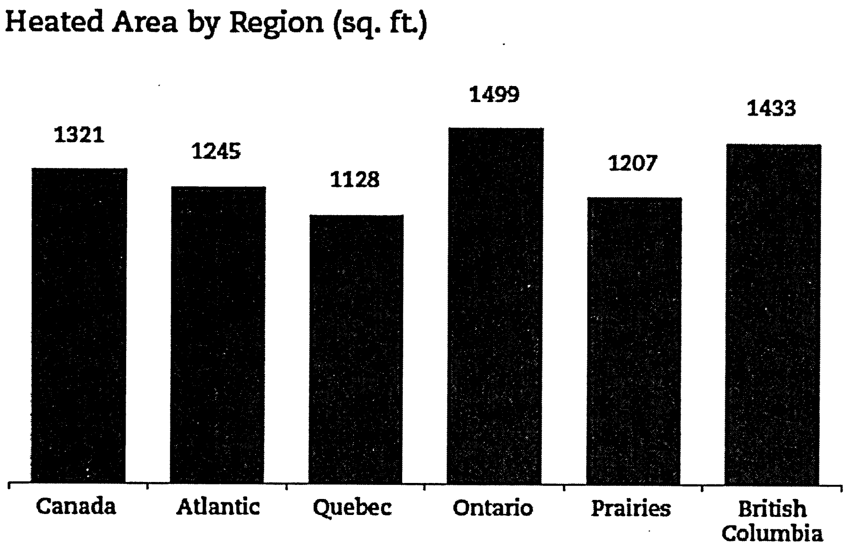

Figure 1.8: Heated area by region (NRCan, 2003)

Dwelling Type

It was found that across Canada, 65 % of the houses were single detached, 2% mobile homes, 18% low rise apartments and 15% double row houses.

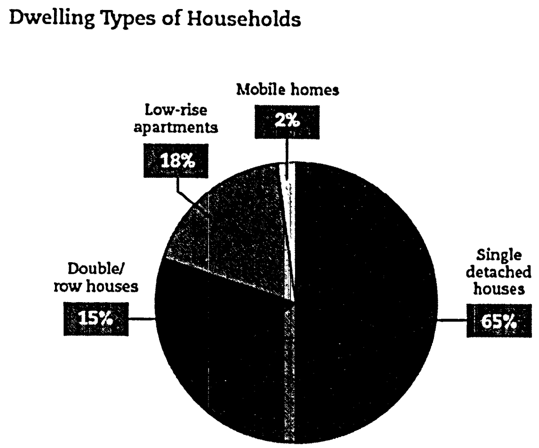

Figure 1.9: Dwelling Types of Households (NRCan, 2003)

Energy Intensity

Energy intensity is defined as the amount of energy consumed per unit of heated area (GJ/m^2). Figure 1.10 illustrates the energy intensity across the Canadian provinces according to SHEU.

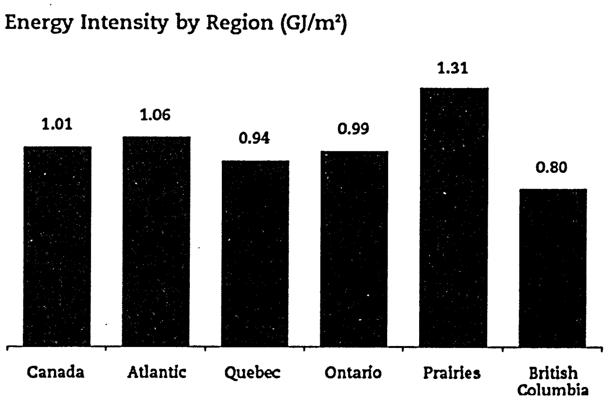

Figure 1.10: Energy intensity by region (NRCan, 2003)

The Thermal Envelope

The thermal envelope is the outer shell of a building that protects its occupants from the ambient elements. The thermal envelope is comprised of the exterior wall, basement walls, floors, roofs, windows and doors.

Residential Heating

Space heating accounted for 60% of the annual energy use in a Canadian dwelling in 2003. 63% of Canadians used a furnace as the main source of heat. 80% of those furnaces were hot air, while the rest of the furnaces were hot water. The rest of the market was divided among electric baseboard heaters, heat pumps and other equipment

Energy Source for Heating

Electricity was the main energy source that was used to power heating equipment in Quebec, having a penetration rate of approximately 75%. Atlantic Canada had a penetration rate of oil at 39%. Ontario had a penetration rate of 68% of natural gas. Prairie provinces had a penetration rate of 78% of natural gas. British Columbia had a penetration rate of 52% of natural gas. (See Figure 1.11)

Main Heating System by Region

Region	Energy Source	Penetration Rate
Atlantic	Oil	39%
	Electricity	38%
Quebec	Electricity	73%
Ontario	Natural gas	68%
Prairies	Natural gas	78%
British Columbia	Natural gas	52%

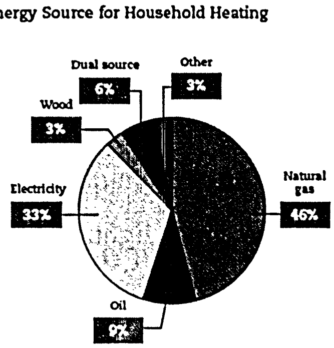

Figure 1.11: Heating by region and by household (NRCan, 2003)

Hot Water

According to the survey hot water heaters had the second highest consumption of energy at approximately 20% of the overall household energy. Figure 1.12 summarizes the energy sources for hot water heating by region:

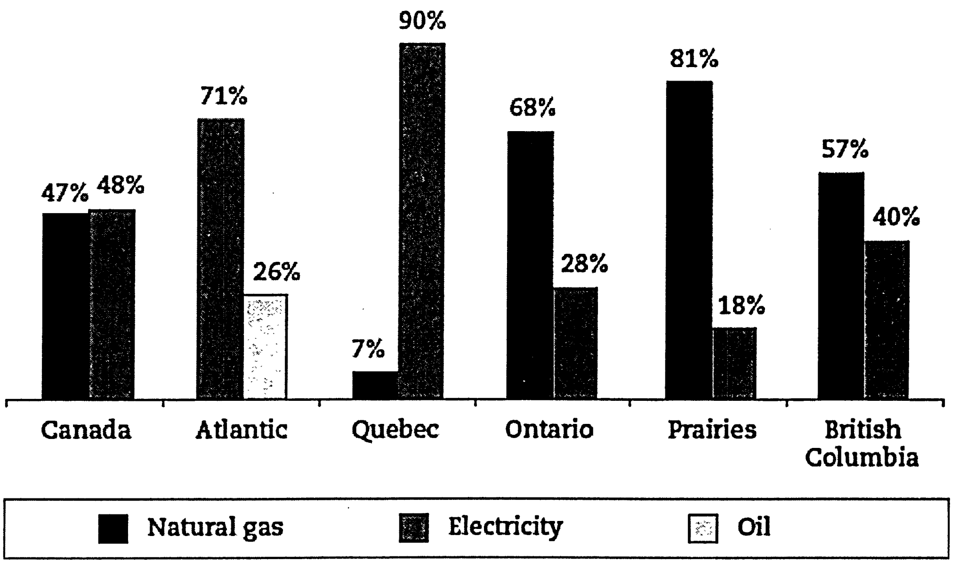

Figure 1.12: Energy use for domestic hot water by province (NRCan, 2003)

Lighting

Although incandescent lighting have a low initial cost, they are not energy efficient. Only 5% - 8% of the energy that of the total energy input is actually transformed into light, while the rest is lost to heat. With the advent of better technologies, light bulbs are now more energy efficient. The following is a comparison on the efficiency of lighting fixtures with respect to incandescent bulbs.

1) Halogen light bulbs can use 15% less energy in comparison to incandescent bulbs.
2) Fluorescent light bulbs can use 60-80 % less energy in comparison to incandescent bulbs.

1.2 OBJECTIVE

The objectives of this study are as follows:

- to update the cost function of each energy efficiency upgrade scenario,
- to update greenhouse gas intensity factors for electricity production for each province and for Canada for the year 2004,
- to rerun all the retrofit scenarios with updated information and generate and indicator to determine the GHG emissions for all provinces,
- to use an indicator to assess the feasibility of energy efficiency upgrade scenario on the annual GHG emission from the Canadian housing stock,
- to rank the retrofits for each house in each province based on the GHG emission reduction potential.
- to conclude which upgrades are suited for each province,

2 METHODOLOGY

As illustrated in Figure 2.1, energy efficiency scenarios were applied in CREEM and the resulting GHG production was compared with the base case GHG production to determine the natural gas savings due to each retrofit.

CREEM consists of 8767 houses. To determine the annual energy consumption and GHG emissions of the houses in CREEM, a HOT2000 batch simulation was conducted on CREEM using the original house files. The annual energy consumption calculated from these original HOT200 batch files is referred to as "base case energy consumption"; whereas the annual GHG emissions production calculated from this simulation reflects the existing GHG emissions production, and is referred to as the "base case GHG emissions production".

In order to determine the annual energy savings and the reduction in GHG emissions associated with each retrofit, it was necessary to first identify the houses that could receive the upgrade. For each upgrade scenario, the houses in CREEM were screened to determine which houses were eligible to receive the upgrade. For example, when the houses in CREEM were screened to determine which houses could be upgraded with ceiling insulation, it was found that 7987 houses out of the 8767 houses in CREEM had ceiling insulation of less than RSI 5.28, therefore these 7987 houses were deemed eligible for the ceiling insulation upgrade. Once the houses to receive a given upgrade were identified, those house files were modified to reflect the upgrade, and another HOT2000 batch simulation was conducted.

The resulting energy consumption reflects the energy savings associated with the given upgrade. Therefore the energy reduction associated with the upgrade was calculated by taking the difference between the consumption with the retrofit and the base case. Similarly, the GHG emissions production with the upgrade reflects the GHG emissions reduction associated with the given upgrade. Thus, the annual GHG emissions reduction associated with the upgrade was determined by subtracting the GHG emissions production with the upgrade from the base case GHG emissions production.

Once the GHGRPDI of all the retrofits were determined, the retrofits were ranked. Each house in the CREEM model was ranked on the most cost optimized retrofit that would reduce GHG emissions (GHGRPDI) to the least attractive retrofit. All the houses were grouped into their respective provinces, and the study successfully concluded which retrofits were the most attractive, on a provincial level.

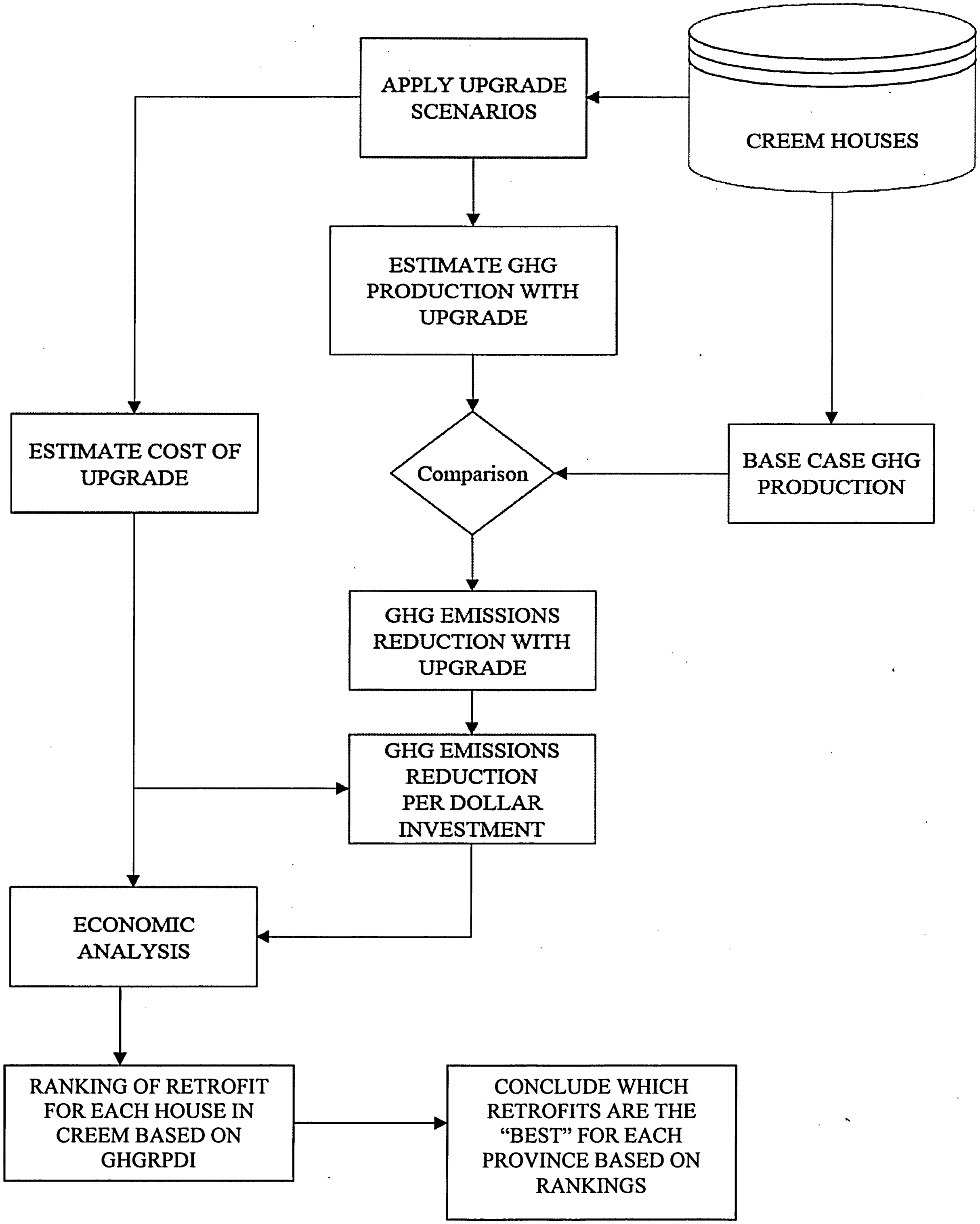

Figure 2.1: The flow chart of the overall methodology used in the study

2.1 Estimation of the Total Investment Cost for each Energy Efficiency Upgrade Scenario

The cost of the materials (e.g. insulation), equipment (e.g. furnace, water heater,), and associated installation costs for the energy efficiency upgrade scenarios were obtained from published cost data (Means, 1998, and Burak, 2000), as well as various contractors, dealers and suppliers in Nova Scotia and across Canada (Burak, 2000). For example, the installed costs of natural gas furnaces were obtained from suppliers in various cities in Canada. Using these price data, a "total investment cost" (TIC) function was developed for each upgrade scenario. These TIC functions include the material and installation costs as well as contractor's overhead and profit, but exclude the provincial taxes and location factors.

To adjust the cost estimates obtained using the TIC functions so that they reflect the local price differences across Canada, "location factors" (LF) published by R.S. Means Company (Means, 1998) were used as follows in Eq 2.1 (Burak, 2000)

$$COSTA = (COSTB)(LFA)/(LFB) \quad (2.1)$$

where,

COSTA = Cost estimate for location A, $

COSTB = Cost estimate obtained by using the TIC function, based on location B, $

LFA = Location factor for location A

LFB = Location factor for location B.

Thus, for each house in CREEM that received a particular upgrade, the TIC was calculated using the TIC function (Appendix A) and the corresponding LF (Appendix B). The applicable provincial taxes were added to the TIC to determine the total cost of the upgrade (TCU). The applicable taxes in CREEM were outdated, and were upgraded as part of this study (2007 GST & PST) (Appendix B), to reflect the true TIC. The costs of the energy efficiency upgrades are based on data collected in 1997/1998 (Burak, 2000). The Consumer Price Index (CPI) (measure of how much a commodity has increased or decreased in price over time) between 1997 and 2006 was determined. The CPI factor has been applied to CREEM, providing updated costs of each energy efficiency retrofit.

2.2 Fuel Prices

For each province, natural gas, residential heating oil, electricity and propane prices were obtained for 2004 in order to calculate the energy cost savings due to retrofits. The fuel costs used in this study are given in Table 2.1.

Table 2.1: Fuel prices in each province (Statistics Canada, 2004)

	NFLD	PEI	NS	NB	QB	ON	MAN	SAS	AB	BC
Electricity (cents/kWh)	9.27	12.65	10.37	10.16	6.89	9.88	6.98	9.08	9.06	7.30
Natural Gas (cents / m^3)	-	-	-	-	54.50	45.04	51.02	46.58	37.21	48.95
Residential Oil (cents/ liter)	78.31	74.00	83.46	83.52	71.57	77.43	85.56	78.57	-	83.41
Propane (cents/liter)	80.01	103.50	95.99	95.90	81.76	51.41	61.77	75.20	69.48	65.27

2.3 Calculating Indirect GHG emissions due to the electricity generation for the residential sector (secondary energy)

The main objective of this study is to estimate the impact of energy efficiency upgrades on the amount of GHG emissions produced due to the energy consumed in the Canadian housing stock. A significant amount of energy consumed in the residential sector is in the form of electrical energy. It is important to capture the GHG emissions associated with the production of electricity for the residential sector, as part of this study. The amount of GHG emissions from electricity generation can be calculated using the "GHG Intensity Factor" (GHGIF) for electricity generation. GHGIF is the amount of GHG emissions produced as a result of generating one kWh of electricity.

Fuels used in every province in Canada differ significantly. Therefore the GHGIF is based on the actual fuel mix of the province and the amount of GHG emissions produced by each fuel used.

In Canada, electricity production is primarily from three sources: fossil fuels, nuclear and hydro. Amongst fossil fuels, three are most commonly used: coal, oil and natural gas.

There are three major fossil fuels that are produced as a result of electricity generation: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The amount of emissions of CO_2, CH_4 and N_2O varies from one fuel to another, and they are calculated using Emission Factors.

For the purposes of this study a simplified approach will be used to asses the green house gas associated with CO_2, CH_4 and N_2O. This will be done by converting CH_4 and N_2O in equivalent amounts of CO_2 using the Global Warming Potential multiplier (GWP) (EnvCan, 1999). To convert one tonne of CH_4 emission to equivalent CO_2 emission, a GWP multiplier of 21 is used, whereas for N_2O, the GWP multiplier is 310 (EnvCan, 1999). Thus,

1 tonne of CH_4 emission = 21 tonnes of CO_2 emission

1 tonne of N_2O emission = 310 tonnes of CO_2 emission

Provinces	NFLD	PEI	NS	NB	QUE	ON	MAN	SAS	AB	BC
GHG Intensity (g/kWh)	21	1120	759	433	8	222	31	840	861	24

Table 2.2: Updated greenhouse Gas Intensity Factors for Canada (Environment Canada)

2.4 Calculation of Direct GHG Emissions due to Residential Energy Consumption (Primary Energy)

The amount of GHG emissions due to the energy consumption of each house in CREEM was calculated based on the amount of each fuel used in the house since the GHG emissions for each fuel are different. The fuels used in the Canadian housing stock and their GHG Emission Factors are given in Table 2.3.

Table 2.3: GHG Emission Factors for non- Electric Use

Canada Energy Sources	GHG Emission Factor		
	CO_2	CH_4	N_2O
Light Fuel Oil (Residential)	2,830 t/ML	0.214 t/ML	0.006 t/ML
Natural Gas	1,880 t/Mm^3	0.043 t/Mm^3	0.02 t/Mm^3
Propane	1,530 t/ML	0.03 t/ML	N/A

Source: Environmental Protection Series
Canada's greenhouse Gas Emissions Estimates

Using the data given in Table 2.3, the GHG emissions due to the non-electric energy (primary energy) consumed in any given house was calculated as follows in Eq 2.2, 2.3, 2.4 (Burak, 2000) .

$$ECO_2 = \sum_{i=1}^{3} (AFC_i)(CO2EF) \quad (2.2)$$

$$ECH4 = \sum_{i=1}^{3} (AFC_i)(CH4EF) \quad (2.3)$$

$$EN2O = \sum_{i=1}^{3} (AFC_i)(N2OEF) \qquad (2.4)$$

where,

$ECO_2 = CO_2$ emission, tonne/year

$ECH_4 = CH_4$ emission, tonne/year

$EN_2O = N_2O$ emission, tonne/year

AFC_i = Annual consumption of fuel type i for the house

$CO_2EF = CO_2$ emission factor, as per Table 2.3

$CH4EF = CH_4$ emission factor, as per Table 2.3

$N2OEF = N_2O$ emission factor, as per Table 2.3

i = type of fuel

i = 1 Oil

i = 2 Natural Gas

i = 3 Propane

Thus, the CO_2 equivalent GHG emissions due to the fossil fuel consumption of each house was calculated in Eq. 2.5 (Burak, 2000):

$$CO2EEFF = (ECO2) + (ECH4)(21) + (EN2O)(310) \qquad (2.5)$$

The total CO_2 equivalent GHG emission from each house due to all of its energy consumption, including fossil fuels and electricity (primary & secondary), was calculated in Eq. 2.6:

$$TCO2EE = CO2EEFF + (ELCON)(GHGIF) \qquad (2.6)$$

where,

CO2EEFF = CO_2 equivalent GHG emissions due to fossil fuel consumption from the house, tonnes/ year

TCO2EE = Total CO_2 equivalent GHG emission from the house, tonnes/ year

ELCON = electricity consumption of the house, kWh/year

GHGIF = as per Table 2.2

2.5 Extrapolating the Results of CREEM to the Canadian housing stock

CREEM is based on the 8767 houses in the SHEU 1993 database. In order to extrapolate the results from CREEM to the entire housing stock, the use of weighting factors were required. Statistics Canada (1993) provides a weighting factor for each one of the houses in the database. The weighting factor for each house in SHEU indicates the number of houses that particular house in SHEU represents in the Canadian housing stock. Therefore, the amount of GHG emissions can be determined from all the houses in Canada as opposed to only 8767 houses in CREEM. Similarly, the cost of applying an upgrade was extrapolated from CREEM to the Canadian housing stock using the weighting factors.

2.5.1 GHG Emissions Reduction per Dollar Investment

The indicator "GHG emission reduction per dollar investment" (GHGRPDI) was used, to determine the economic feasibility for each upgrade. This indicator is calculated by dividing the reduction in annual GHG emissions by the total cost of the upgrade (TCU), as stated in Eq. 2.7.:

$$\text{GHGRPDI} = \text{AGHGR} / \text{TCU} \qquad (2.7)$$

where,

AGHGR = Annual GHG emissions reduction as a result of the upgrade, kt/year,

$$\text{AGHGR} = \sum_{i=1}^{N} \text{AGHGRH}_i$$

where,

AGHGRH_i = Annual GHG emissions reduction per house i that received the upgrade, kg/year/house

N = number of houses that received the upgrade

TCU = Total cost of the upgrade, \$.

$$TCU = \sum_{i=1}^{N} CSTU_i$$

where,

$CSTU_i$ = Cost of undertaking the upgrade for house i, \$/house

N = number of houses that received the upgrade.

3 ENERGY EFFICIENCY UPGRADE SCENARIOS

Retrofit upgrades studied in this report are used to determine the amount of GHG reduction. Retrofit scenarios such as adding insulation to the building envelope, replacing existing windows with energy efficient ones, and increasing the efficiency of furnaces, boilers, heat pumps, etc were evaluated. In this study, upgrade scenarios were categorized into two main groups: (A) major retrofits, and (B) minor retrofits.

Major retrofit options: these retrofit options are classified to be major retrofits because of their high installation, material, and equipment costs. These include:

building envelope upgrades,

mechanical system upgrades and

appliance upgrades.

Minor retrofit options: these retrofit options are classified to be minor retrofits because of their relatively lower installation and equipment costs. These include:

lighting fixture upgrades,

thermostat upgrades and

showerhead and aerator upgrades.

The main objective of this study is to determine the reduction of GHG emissions as a result of the retrofits across Canada, thus energy efficiency upgrades are applied to all houses in the residential sector that are eligible for the retrofit. Thus, for example, for the ceiling insulation upgrade scenario, all houses that have ceiling thermal resistances lower than RSI 5.28 (R30) were assumed to receive an insulation upgrade to increase the insulation level to RSI 5.28.

The two retrofit options are discussed and presented in detail in the following two chapters respectively.

4 MAJOR ENERGY EFFICIENCY UPGRADE SCENARIOS

4.1 Building Envelope upgrade Scenarios

4.1.1 Ceiling Insulation upgrade Scenarios

Three ceiling insulation upgrade scenarios were evaluated:

1. Add insulation to the ceiling to obtain an overall thermal resistance of RSI 5.28 (R30).
2. Add insulation to the ceiling to obtain an overall thermal resistance of RSI 7.04 (R40).
3. Add insulation to the ceiling to obtain an overall thermal resistance of RSI 8.8 (R50).

It was assumed that blown–in cellulose insulation would be used in these upgrade scenarios due to its practicality and price. The three insulation levels used are in the range of the National Energy Code for Housing (Farahbaksh et al., 1997).

The numbers of houses in each province that are eligible to receive the three levels of ceiling insulation upgrades are given in Table 4.1. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993).

Table 4.1: Retrofit statistics for ceiling insulation upgrades

	Total number	RSI 5.28 Upgrade		RSI 7.04 Upgrade		RSI 8.8 Upgrade	
Province	of houses in Canada	Number	%	Number	%	Number	%
NFLD	169,601	142,611	84	148,344	87	148,344	87
PEI	37,699	33,432	89	34,899	93	34,899	93
NS	256,675	230,739	90	236,323	92	236,323	92
NB	207,428	189,498	91	196,933	95	196,933	95
QUE	1,485,663	1,337,265	90	1,358,456	91	1,358,456	91
ON	2,729,354	2,443,890	90	2,538,380	93	2,538,380	93
MAN	304,401	283,856	93	283,856	93	283,856	93
SAS	300,211	277,956	93	277,956	93	277,956	93
AB	704,141	653,870	93	653,870	93	653,870	93
BC	906,610	835,738	92	835,738	92	835,738	92
Canada	7,101,783	6,428,855	91	6,564,755	92	6,564,755	92

The TIC function for the ceiling insulation upgrade scenarios is given by Eq 4.1 (Burak,2000) :

$$TICCIU = 1.6 + (URSI)(0.9) \tag{4.1}$$

where,

TICCIU = Total investment cost for ceiling insulation Upgrade, $\$/m^2$

URSI = Insulation upgrade applied, RSI

The development of the TIC function is given in Appendix A.

4.1.1.1 GHG Emission Reduction Results for Ceiling Insulation upgrade Scenarios

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. Table 4.2 provides the "base case" GHG emissions in the Canadian housing stock, with no retrofits. This table will serve as the benchmark in comparing GHG emissions with retrofits and will be used to determine the applicable GHG savings.

Table 4.2: Base case GHG emissions for the entire housing stock in Canada in 2004

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	0	0	0.00
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.95	12.00	0	0	0.00
NS	256675	1.29	3.23	5.04	12.57	1.29	3.23	5.04	12.57	0	0	0.00
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.87	0	0	0.00
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.31	1.48	0.21	0	0	0.00
ON	2729354	10.82	9.26	3.96	3.39	10.82	9.26	3.96	3.39	0	0	0.00
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.93	0.57	0	0	0.00
SAS	300211	2.01	3.39	6.69	11.28	2.01	3.39	6.69	11.28	0	0	0.00
AB	704141	4.95	6.54	7.03	9.29	4.95	6.54	7.03	9.29	0	0	0.00
BC	906610	2.81	0.31	3.10	0.34	2.81	0.31	3.10	0.34	0	0	0.00
CANADA	7101782	26.89	26.00	3.79	3.66	26.89	26.00	3.79	3.66	0	0	0.00

"Base Case" – GHG emissions **without** any retrofits. Direct emissions is a result of combustion at the house. Indirect Emissions is the emissions due to providing electricity to the house (depends on fuel source)

"Retrofit Case" – GHG emissions **with** retrofits

Difference between "Base Case" per house and "Retrofit per house". This shows how much increase or decrease in kg of GHG as a result of the retrofit. Note that this value is for the entire housing sector, including houses that are eligible for the retrofit, and for the houses that don't have retrofits.

The results are provided in Tables 4.3-4.5 for ceiling insulation upgrade to RSI 5.28, 7.04 and 8.8 respectively. The GHGRPDI for ceiling upgrades are given in Table 4.6. It can be seen that for the ceiling upgrade to RSI 7.04 it has the best value across Canada in terms of GHG emission reduction. For ceiling upgrade more than RSI 7.04, there is no more change in GHG emission reduction, therefore, leading to the decrease in GHGRPDI.

Table 4.3: Average annual reduction in GHG emissions with ceiling insulation upgrade to RSI 5.28 (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.51	0.08	3.00	0.49	88	2	3.31
PEI	37699	0.30	0.45	7.96	12.02	0.29	0.45	7.74	11.97	217	44	3.09
NS	256675	1.29	3.23	5.04	12.57	1.25	3.21	4.88	12.50	162	79	3.84
NB	207428	0.50	2.25	2.42	10.87	0.48	2.23	2.34	10.74	84	130	4.66
QUE	1485663	2.19	0.31	1.48	0.21	2.15	0.31	1.45	0.21	25	2	2.63
ON	2729354	10.82	9.26	3.96	3.39	10.62	9.22	3.89	3.38	71	14	2.19
MAN	304401	1.50	0.17	4.93	0.57	1.47	0.17	4.84	0.57	94	5	2.71
SAS	300211	2.01	3.39	6.69	11.28	1.97	3.38	6.56	11.24	135	39	2.36
AB	704141	4.95	6.54	7.03	9.29	4.85	6.53	6.89	9.28	133	13	2.03
BC	906610	2.81	0.31	3.10	0.34	2.74	0.31	3.02	0.34	76	2	2.93
CANADA	7101782	26.89	26.00	3.79	3.66	26.35	25.89	3.71	3.65	77	16	2.46

Table 4.4: Average annual reduction in GHG emissions with ceiling insulation upgrade to RSI 7.04 (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.49	0.08	2.91	0.48	139	6	5.71
PEI	37699	0.30	0.45	7.96	12.02	0.28	0.45	7.55	11.95	330	60	4.66
NS	256675	1.29	3.23	5.04	12.57	1.22	3.18	4.75	12.40	239	139	5.84
NB	207428	0.50	2.25	2.42	10.87	0.47	2.20	2.27	10.59	123	222	7.12
QUE	1485663	2.19	0.31	1.48	0.21	2.08	0.31	1.40	0.21	55	4	5.65
ON	2729354	10.82	9.26	3.96	3.39	10.31	9.15	3.78	3.35	141	30	4.45
MAN	304401	1.50	0.17	4.93	0.57	1.43	0.17	4.69	0.56	184	9	5.29
SAS	300211	2.01	3.39	6.69	11.28	1.90	3.36	6.34	11.18	266	76	4.65
AB	704141	4.95	6.54	7.03	9.29	4.70	6.52	6.68	9.26	265	25	4.03
BC	906610	2.81	0.31	3.10	0.34	2.66	0.31	2.93	0.34	130	3	5.04
CANADA	7101782	26.89	26.00	3.79	3.66	25.56	25.72	3.60	3.62	145	31	4.67

Table 4.5: Average annual reduction in GHG emissions with ceiling insulation upgrade to RSI 8.8 (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.49	0.08	2.91	0.48	171	8	7.72
PEI	37699	0.30	0.45	7.96	12.02	0.28	0.45	7.55	11.95	402	70	5.44
NS	256675	1.29	3.23	5.04	12.57	1.22	3.18	4.75	12.40	286	176	7.08
NB	207428	0.50	2.25	2.42	10.87	0.47	2.20	2.27	10.59	148	278	8.66
QUE	1485663	2.19	0.31	1.48	0.21	2.08	0.31	1.40	0.21	73	5	7.52
ON	2729354	10.82	9.26	3.96	3.39	10.31	9.15	3.78	3.35	185	40	5.85
MAN	304401	1.50	0.17	4.93	0.57	1.43	0.17	4.69	0.56	239	12	6.88
SAS	300211	2.01	3.39	6.69	11.28	1.90	3.36	6.34	11.18	347	98	6.06
AB	704141	4.95	6.54	7.03	9.29	4.70	6.52	6.68	9.26	346	32	5.27
BC	906610	2.81	0.31	3.10	0.34	2.66	0.31	2.93	0.34	164	4	6.39
CANADA	7101782	26.89	26.00	3.79	3.66	25.56	25.72	3.60	3.62	187	40	6.04

Table 4.6: GHGRPDI for ceiling upgrades

	GHG Emissions Reduction Per Dollar Investment		
	W/ RSI 5.28 upgrade	W/ RSI 7.04 upgrade	W/ 8.8 upgrade
Province	kg/year/$	kg/year/$	kg/year/$
NFLD	0.28	0.43	0.25
PEI	0.59	0.90	0.53
NS	0.61	0.94	0.57
NB	0.57	0.89	0.53
QUE	0.08	0.17	0.10
ON	0.24	0.49	0.28
MAN	0.30	0.59	0.35
SAS	0.57	1.12	0.66
AB	0.46	0.90	0.53
BC	0.22	0.37	0.22
CANADA	0.26	0.49	0.28

4.1.2 External Wall Insulation upgrade Scenarios

In this study, two external wall insulation upgrade scenarios were evaluated:

- Upgrade the external wall insulation of houses that have 2"x4" wall construction to obtain an overall wall RSI of 2.28 (R13) if the existing insulation level is less than 75% of the possible level of insulation with the 2"x4" wall.[1]
- Upgrade the external wall insulation of houses that have 2"x6" wall construction to obtain an overall wall RSI of 3.34 (R19) if the existing insulation level is less than 75% of the possible level of insulation with the 2"x6" wall.[2]

It was assumed that blown–in cellulose insulation would be used in these upgrade scenarios due to its practicality and price.

The number of houses in each province that are eligible to receive the two levels of external wall insulation upgrades are given in Table 4.7. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.7: Retrofit statistics for external wall insulation upgrades

	Total number	RSI 2.28 Upgrade		RSI 3.34 Upgrade	
Province	of houses in Canada	Number	%	Number	%
NFLD	169,601	21,856	13	65,054	38
PEI	37,699	10,322	27	11,308	30
NS	256,675	65,028	25	78,229	30
NB	207,428	42,491	20	57,486	28
QUE	1,485,663	0	0	262,324	18
ON	2,729,354	0	0	268,865	10
MAN	304,401	37,356	12	0	0
SAS	300,211	28,981	10	0	0
AB	704,141	46,123	7	0	0
BC	906,610	0	0	353,568	39
Canada	7,101,783	252,157	4	1,096,834	15

The TIC function for the external wall insulation upgrade scenario #1 is given by Eq 4.2 (Burak, 2000):

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1 Typically, houses built prior to 1977 had 2"x4" wall construction (NRCan, 1996b).
2 Typically, houses built after 1977 had 2"x6" wall construction (NRCan, 1996b).

$$TICWIU1 = (TMWA)(17.2) \tag{4.2}$$

where,

TICWIU1 = Total investment cost for external wall insulation upgrade scenario #1, \$

TMWA = Total main wall area, m^2

The total investment cost (TIC) function for the external wall insulation upgrade scenario #2 is given by Equation 4.3:

$$TICWIU2 = (TMWA)(19.4) \tag{4.3}$$

where,

TICWIU2 = Total investment cost for external wall insulation upgrade scenario #2, \$

TMWA = Total main wall area, m^2

The development of the TIC functions is given in Appendix A.

4.1.2.1 GHG Emission Reduction Results for External Wall Insulation upgrade scenarios

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix C. In Tables 4.8-4.9, the reduction in GHG emissions associated with the two external wall upgrade scenarios are given for each province and for all of Canada. The GHGRPDI values for the external wall upgrade scenarios are given in Table 4.10.

Table 4.8: Average annual reduction in GHG emissions with external wall insulation upgrade to RSI 2.28 (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case Per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.05	0.49	40	2	1.66
PEI	37699	0.30	0.45	7.96	12.02	0.29	0.45	7.80	11.99	155	25	2.16
NS	256675	1.29	3.23	5.04	12.57	1.26	3.22	4.90	12.53	137	33	2.99
NB	207428	0.50	2.25	2.42	10.87	0.49	2.24	2.35	10.81	69	57	3.39
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.31	1.48	0.21	0	0	0.00
ON	2729354	10.82	9.26	3.96	3.39	10.82	9.26	3.96	3.39	0	0	0.00
MAN	304401	1.50	0.17	4.93	0.57	1.49	0.17	4.89	0.57	39	1	0.99
SAS	300211	2.01	3.39	6.69	11.28	2.00	3.38	6.65	11.27	41	8	0.68
AB	704141	4.95	6.54	7.03	9.29	4.93	6.54	7.00	9.29	26	3	0.40
BC	906610	2.81	0.31	3.10	0.34	2.81	0.31	3.10	0.34	0	0	0.00
CANADA	7101782	26.89	26.00	3.79	3.66	26.79	25.97	3.77	3.66	15	4	0.49

Table 4.9: Average annual reduction in GHG emissions with external wall insulation upgrade to RSI 3.34 (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.51	0.08	3.03	0.49	51	3	2.33
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.84	11.99	117	28	1.70
NS	256675	1.29	3.23	5.04	12.57	1.28	3.20	5.00	12.46	39	110	1.65
NB	207428	0.50	2.25	2.42	10.87	0.50	2.23	2.41	10.76	11	102	1.38
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.31	1.47	0.21	2	1	0.75
ON	2729354	10.82	9.26	3.96	3.39	10.78	9.23	3.95	3.38	14	9	0.60
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.93	0.57	0	0	0.00
SAS	300211	2.01	3.39	6.69	11.28	2.01	3.39	6.69	11.28	0	0	0.00
AB	704141	4.95	6.54	7.03	9.29	4.95	6.54	7.03	9.29	0	0	0.00
BC	906610	2.81	0.31	3.10	0.34	2.76	0.31	3.05	0.34	50	2	2.23
CANADA	7101782	26.89	26.00	3.79	3.66	26.78	25.92	3.77	3.65	16	11	0.71

Table 4.10: GHGRPDI for External wall upgrades

	GHG Emissions Reduction Per Dollar Investment	
	W /RSI 2.28 upgrade	W / RSI 3.34 upgrade
Province	kg/year/$	kg/year/$
NFLD	0.18	0.05
PEI	0.29	0.16
NS	0.30	0.19
NB	0.28	0.15
QUE	0.00	0.01
ON	0.00	0.07
MAN	0.16	0.00
SAS	0.27	0.00
AB	0.22	0.00
BC	0.00	0.05
CANADA	0.25	0.06

4.1.3 Basement Insulation upgrade Scenarios

Two basement insulation upgrade scenarios were evaluated:

1. If the basement of a house was not insulated, not heated and not finished, the ceiling of the basement was upgraded by adding insulation of RSI 5.28 (R30) between joists.

2. If the basement of a house was heated and/or finished, below grade walls would be upgraded. In this scenario, two options were evaluated:

(a) upgrade existing below grade walls by adding insulation of RSI 2.1 (R12),

(b) upgrade existing below grade walls by adding insulation of RSI 3.5 (R20).

In both below grade wall upgrade scenarios, new wood framing, fiberglass batt insulation and vapor barrier were added. (No paint, trim, and finishing were included in the pricing since these depend highly on the individual occupant's choice.)

The numbers of houses in each province that are eligible to receive the three levels of basement insulation upgrades are given in Table 4.11. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix C.

Table 4.11: Retrofit statistics for basement insulation upgrades

	Total number	RSI 5.28 Upgrade		RSI 2.1 Upgrade		RSI 3.5 Upgrade	
Province	of houses in Canada	Number	%	Number	%	Number	%
NFLD	169,601	16,772	10	50,947	30	50,947	30
PEI	37,699	11,978	32	8,682	23	8,682	23
NS	256,675	49,422	19	84,503	33	84,503	33
NB	207,428	28,761	14	78,600	38	78,600	38
QUE	1,485,663	57,596	4	830,596	56	830,596	56
ON	2,729,354	280,609	10	1,084,108	40	1,084,108	40
MAN	304,401	21,539	7	148,776	49	148,776	49
SAS	300,211	25,345	8	134,985	45	134,985	45
AB	704,141	47,165	7	325,545	46	325,545	46
BC	906,610	38,763	4	301,680	33	301,680	33
Canada	7,101,783	577,950	8	3,048,422	43	3,048,422	43

The TIC function for the basement ceiling insulation upgrade scenario #1 is given by Eq 4.4 (Burak, 2000):

$$TICBCIU = (TMFA)(10.4) \tag{4.4}$$

where,

TICBCIU = Total investment cost for basement ceiling insulation upgrade scenario #1, \$

TMFA = Total main floor area, m^2

The total investment cost (TIC) function for the basement wall insulation upgrade scenario #2a is given by Eq 4.5:

$$TICBWIU1 = (TBMWA)(21.7) \quad (4.5)$$

where,

TICBWIU1 = Total investment cost for basement wall insulation upgrade scenario #2a, \$

TBMWA = Total basement wall area, m^2

The total investment cost (TIC) function for the basement wall insulation upgrade scenario #2b is given by Eq 4.6:

$$TICBWIU2 = (TBMWA)(23.6) \quad (4.6)$$

where,

TICBWIU2 = Total investment cost for basement wall insulation upgrade scenario #2b, \$

TBMWA = Total basement wall area, m^2

The development of the TIC functions is given in Appendix A.

4.1.3.1 GHG Emission Reduction Results for Basement Insulation Upgrade Scenarios

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix C. In Tables 4.12-4.14, the reduction in GHG emissions associated with the three basement wall insulation upgrade scenarios are given for each province and for all of Canada. The GHGRPDI values for the basement wall upgrade scenarios are given in Table 4.16.

Table 4.12: Average annual reduction in GHG emissions with basement ceiling insulation upgrade to RSI 5.28 (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.50	0.08	2.93	0.48	153	7	6.96
PEI	37699	0.30	0.45	7.96	12.02	0.28	0.45	7.34	11.94	614	80	8.19
NS	256675	1.29	3.23	5.04	12.57	1.21	3.20	4.72	12.46	321	115	7.27
NB	207428	0.50	2.25	2.42	10.87	0.47	2.21	2.26	10.67	160	191	8.35
QUE	1485663	2.19	0.31	1.48	0.21	2.06	0.31	1.39	0.21	89	2	7.08
ON	2729354	10.82	9.26	3.96	3.39	10.21	9.17	3.74	3.36	221	31	6.50
MAN	304401	1.50	0.17	4.93	0.57	1.42	0.17	4.66	0.56	275	10	7.24
SAS	300211	2.01	3.39	6.69	11.28	1.90	3.37	6.33	11.21	366	72	6.11
AB	704141	4.95	6.54	7.03	9.29	4.66	6.52	6.62	9.26	408	33	6.16
BC	906610	2.81	0.31	3.10	0.34	2.69	0.31	2.96	0.34	135	2	4.97
CANADA	7101782	26.89	26.00	3.79	3.66	25.39	25.79	3.58	3.63	212	30	6.40

Table 4.13: Average annual reduction in GHG emissions with basement wall insulation upgrade to RSI 2.1 (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.49	0.08	2.89	0.48	197	8	8.58
PEI	37699	0.30	0.45	7.96	12.02	0.29	0.45	7.61	11.96	341	60	4.58
NS	256675	1.29	3.23	5.04	12.57	1.22	3.18	4.76	12.37	280	203	7.16
NB	207428	0.50	2.25	2.42	10.87	0.47	2.18	2.25	10.53	172	338	10.23
QUE	1485663	2.19	0.31	1.48	0.21	1.94	0.30	1.30	0.20	171	11	16.80
ON	2729354	10.82	9.26	3.96	3.39	9.95	9.09	3.64	3.33	319	60	9.82
MAN	304401	1.50	0.17	4.93	0.57	1.35	0.17	4.43	0.55	500	19	13.48
SAS	300211	2.01	3.39	6.69	11.28	1.82	3.34	6.05	11.12	637	166	10.99
AB	704141	4.95	6.54	7.03	9.29	4.50	6.50	6.39	9.23	635	63	9.72
BC	906610	2.81	0.31	3.10	0.34	2.63	0.31	2.90	0.34	201	4	7.53
CANADA	7101782	26.89	26.00	3.79	3.66	24.64	25.59	3.47	3.60	317	58	9.94

Table 4.14: Average annual reduction in GHG emissions with basement wall insulation upgrade to RSI 3.5 (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.50	0.08	2.96	0.48	120	9	5.78
PEI	37699	0.30	0.45	7.96	12.02	0.29	0.45	7.76	12.00	196	18	2.61
NS	256675	1.29	3.23	5.04	12.57	1.25	3.18	4.86	12.38	177	176	4.91
NB	207428	0.50	2.25	2.42	10.87	0.48	2.20	2.32	10.59	102	277	6.76
QUE	1485663	2.19	0.31	1.48	0.21	2.00	0.30	1.35	0.20	128	9	12.92
ON	2729354	10.82	9.26	3.96	3.39	10.25	9.14	3.76	3.35	207	43	6.48
MAN	304401	1.50	0.17	4.93	0.57	1.39	0.17	4.56	0.56	366	15	10.09
SAS	300211	2.01	3.39	6.69	11.28	1.87	3.35	6.23	11.17	466	114	7.98
AB	704141	4.95	6.54	7.03	9.29	4.62	6.51	6.56	9.24	469	48	7.19
BC	906610	2.81	0.31	3.10	0.34	2.69	0.31	2.97	0.34	131	2	4.86
CANADA	7101782	26.89	26.00	3.79	3.66	25.34	25.69	3.57	3.62	218	44	6.95

Table 4.15: GHGRPDI for the basement upgrades

	GHG Emissions Reduction Per Dollar Investment		
	w/RSI 5.3 upgrade	W / RSI 2.1 upgrade	W / RSI 3.5 upgrade
Province	kg/year/$	kg/year/$	kg/year/$
NFLD	0.27	0.24	0.16
PEI	0.78	0.45	0.30
NS	0.63	0.50	0.38
NB	0.51	0.47	0.37
QUE	0.13	0.13	0.09
ON	0.39	0.30	0.21
MAN	0.43	0.40	0.30
SAS	0.78	0.70	0.52
AB	0.62	0.57	0.19
BC	0.22	0.25	0.16
CANADA	0.35	0.30	0.21

4.1.4 Window Upgrade Scenarios

The following are the window upgrade scenarios. The old window was retrofitted with the following logic:

(1) If a house had single glazed windows, the windows would be replaced by:

   (i) standard double-glazed windows,

   (ii) energy-efficient double-glazed windows, Argon filled and with low E coating,

   (iii) energy efficient triple glazed windows, Argon filled and with low E coating.

(2) If a house had single glazing and storm windows, the windows would be replaced by:

   (i) standard double-glazed windows,

   (ii) energy-efficient double glazed windows, Argon filled and with low E coating,

   (iii) energy efficient triple glazed windows, Argon filled and with low E coating.

(3) If a house had standard double glazing windows, the windows would be replaced by:

   (i) energy-efficient double-glazed windows, Argon filled and with low E coating,

   (ii) energy-efficient triple glazed windows, Argon filled and with low E coating.

4.1.4.1 Houses with Single Glazed Windows

The numbers of houses with single glazed windows in each province that are eligible to receive the three levels of window upgrades are given in Table 4.16. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.16: Retrofit statistics for window upgrades – houses with single glazed windows

	Total number	Double Glazing		Low-E Double Glazing		Low-E Triple Glazing	
Province	of houses in Canada	Number	%	Number	%	Number	%
NFLD	169,601	7,796	5	7,796	5	7,796	5
PEI	37,699	2,938	8	2,938	8	2,938	8
NS	256,675	21,280	8	21,280	8	21,280	8
NB	207,428	12,268	6	12,268	6	12,268	6
QUE	1,485,663	79,831	5	79,831	5	79,831	5
ON	2,729,354	244,611	9	244,611	9	244,611	9
MAN	304,401	11,035	4	11,035	4	11,035	4
SAS	300,211	15,702	5	15,702	5	15,702	5
AB	704,141	43,938	6	43,938	6	43,938	6
BC	906,610	326,142	36	326,142	36	326,142	36
Canada	7,101,783	765,541	11	765,541	11	765,541	11

The TIC function for the standard double glazed window upgrade scenario is given by Eq 4.7 (Burak, 2000):

$$TICSDWU = (TWA)(342) \tag{4.7}$$

where,

TICSDWU = Total investment cost for standard double glazed window upgrade, $

TWA = Total window area, m^2

The TIC function for the energy efficient double glazed window upgrade scenario is given by Eq 4.8:

$$TICEDWU = (TWA)(392) \quad (4.8)$$

where,

TICEDWU = Total investment cost for energy efficient double glazed window upgrade, $

TWA = Total window area, m^2

The TIC function for the energy efficient triple glazed window upgrade scenario is given by Eq 4.9:

$$TICETWU = (TWA)(443) \quad (4.9)$$

where,

TICETWU = Total investment cost for energy efficient triple glazed window upgrade, $

TWA = Total window area, m^2

The development of the TIC functions is given in Appendix A.

4.1.4.1.1 GHG Emission Reduction Results for Houses with Single Glazed Windows

In Tables 4.17-4.19, the reduction in GHG emissions associated with upgrading the single glazed windows are given for each province and for all of Canada. The GHGRPDI values are given in Table 4.20.

Table 4.17: Average annual reduction in GHG emissions with upgrading single glazed windows with standard double glazed windows (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	0	0	0.02
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.95	12.01	2	7	0.08
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.03	12.56	7	4	0.17
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.86	5	1	0.20
QUE	1485663	2.19	0.31	1.48	0.21	2.17	0.31	1.46	0.21	12	0	0.95
ON	2729354	10.82	9.26	3.96	3.39	10.79	9.25	3.95	3.39	10	2	0.30
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.91	0.57	18	0	0.40
SAS	300211	2.01	3.39	6.69	11.28	2.01	3.39	6.68	11.28	12	4	0.21
AB	704141	4.95	6.54	7.03	9.29	4.92	6.54	6.98	9.28	42	4	0.65
BC	906610	2.81	0.31	3.10	0.34	2.80	0.31	3.09	0.34	11	0	0.39
CANADA	7101782	26.89	26.00	3.79	3.66	26.80	25.98	3.77	3.66	14	2	0.40

Table 4.18: Average annual reduction in GHG emissions with upgrading single glazed windows with double glazed low-E windows (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.07	0.49	13	0	0.34
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.92	12.01	33	8	0.49
NS	256675	1.29	3.23	5.04	12.57	1.28	3.22	5.00	12.55	37	9	0.81
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.40	10.85	23	16	1.10
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.32	1.47	0.21	1	-1	-0.29
ON	2729354	10.82	9.26	3.96	3.39	10.69	9.25	3.92	3.39	46	2	1.23
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.91	0.57	20	0	0.39
SAS	300211	2.01	3.39	6.69	11.28	2.00	3.39	6.66	11.28	30	6	0.50
AB	704141	4.95	6.54	7.03	9.29	4.92	6.54	6.99	9.29	32	2	0.48
BC	906610	2.81	0.31	3.10	0.34	2.61	0.31	2.88	0.34	217	4	8.07
CANADA	7101782	26.89	26.00	3.79	3.66	26.51	25.98	3.73	3.66	53	3	1.48

Table 4.19: Average annual reduction in GHG emissions with upgrading single glazed windows with triple glazed low-E windows
(averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.07	0.49	14	0	0.56
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.92	12.01	37	9	0.54
NS	256675	1.29	3.23	5.04	12.57	1.28	3.22	5.00	12.54	41	16	0.95
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.39	10.85	26	19	1.24
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.31	1.47	0.21	1	1	0.78
ON	2729354	10.82	9.26	3.96	3.39	10.68	9.24	3.91	3.38	51	7	1.50
MAN	304401	1.50	0.17	4.93	0.57	1.49	0.17	4.91	0.57	22	0	0.51
SAS	300211	2.01	3.39	6.69	11.28	2.00	3.38	6.66	11.27	33	7	0.55
AB	704141	4.95	6.54	7.03	9.29	4.92	6.54	6.99	9.29	35	3	0.53
BC	906610	2.81	0.31	3.10	0.34	2.60	0.31	2.86	0.34	237	4	8.80
CANADA	7101782	26.89	26.00	3.79	3.66	26.48	25.96	3.73	3.65	59	5	1.70

Table 4.20: GHGRPDI for upgrading single glazed windows

	GHG Emissions Reduction Per Dollar Investment		
	Single to standard double	Single to high efficiency Double glaze	Single to high efficiency triple glaze
Province	kg/year/$	kg/year/$	kg/year/$
NFLD	0.00	0.00	0.10
PEI	0.00	0.00	0.18
NS	0.07	0.00	0.16
NB	0.07	0.00	0.18
QUE	0.00	0.00	0.02
ON	0.05	0.01	0.12
MAN	0.07	0.02	0.17
SAS	0.10	0.01	0.27
AB	0.08	0.02	0.20
BC	0.00	0.00	0.10
CANADA	0.05	0.02	0.11

4.1.4.2 Houses with Single Glazing and Storm Windows

The number of houses with single glazing and storm windows that are eligible to receive the three levels of window upgrades are given in Table 4.21. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.21: Retrofit statistics for window upgrades – houses with single glazing and storm windows

	Total number	Double Glazing		Low-E Double Glazing		Low-E Triple Glazing	
Province	of houses in Canada	Number	%	Number	%	Number	%
NFLD	169,601	617	0	617	0	617	0
PEI	37,699	310	1	310	1	310	1
NS	256,675	6,577	3	6,577	3	6,577	3
NB	207,428	3,016	1	3,016	1	3,016	1
QUE	1,485,663	129,805	9	129,805	9	129,805	9
ON	2,729,354	124,259	5	124,259	5	124,259	5
MAN	304,401	19,619	6	19,619	6	19,619	6
SAS	300,211	11,061	4	11,061	4	11,061	4
AB	704,141	96,115	14	96,115	14	96,115	14
BC	906,610	54,307	6	54,307	6	54,307	6
Canada	7,101,783	445,686	6	445,686	6	445,686	6

The TIC functions given in Eq 4.7-4.9 were used for the three levels of upgrades for single glazing and storm windows.

4.1.4.2.1 GHG Emission Reduction Results for Houses with single glazing and storm windows

To extrapolate the estimates of reduction GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Tables 4.22-4.24, the reduction in GHG emissions associated with upgrading the single glazing and storm windows are given for each province and for all of Canada. The GHGRPDI values are given in Table 4.25.

Table 4.22: Average annual reduction in GHG emissions with upgrading single glazing and storm windows with standard double glazed windows (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	0	0	0.02
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.95	12.01	2	7	0.08
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.03	12.56	7	4	0.17
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.86	5	1	0.20
QUE	1485663	2.19	0.31	1.48	0.21	2.17	0.31	1.46	0.21	12	0	0.95
ON	2729354	10.82	9.26	3.96	3.39	10.79	9.25	3.95	3.39	10	2	0.30
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.91	0.57	18	0	0.40
SAS	300211	2.01	3.39	6.69	11.28	2.01	3.39	6.68	11.28	12	4	0.21
AB	704141	4.95	6.54	7.03	9.29	4.92	6.54	6.98	9.28	42	4	0.65
BC	906610	2.81	0.31	3.10	0.34	2.80	0.31	3.09	0.34	11	0	0.39
CANADA	7101782	26.89	26.00	3.79	3.66	26.80	25.98	3.77	3.66	14	2	0.40

Table 4.23: Average annual reduction in GHG emissions with upgrading single glazing and storm windows with double glazed low-E windows (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	1	0	0.03
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.95	12.00	4	12	0.15
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.03	12.55	13	7	0.31
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.41	10.86	8	2	0.35
QUE	1485663	2.19	0.31	1.48	0.21	2.16	0.31	1.45	0.21	21	1	1.70
ON	2729354	10.82	9.26	3.96	3.39	10.77	9.25	3.95	3.39	17	3	0.54
MAN	304401	1.50	0.17	4.93	0.57	1.49	0.17	4.90	0.57	33	0	0.73
SAS	300211	2.01	3.39	6.69	11.28	2.00	3.38	6.67	11.27	21	8	0.38
AB	704141	4.95	6.54	7.03	9.29	4.90	6.54	6.95	9.28	74	8	1.14
BC	906610	2.81	0.31	3.10	0.34	2.79	0.31	3.08	0.34	20	0	0.69
CANADA	7101782	26.89	26.00	3.79	3.66	26.72	25.97	3.76	3.66	24	3	0.72

Table 4.24: Average annual reduction in GHG emissions with upgrading single glazing and storm windows with triple glazed low-E windows (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	1	0	0.04
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.95	12.00	5	15	0.19
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.03	12.55	16	9	0.38
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.41	10.86	10	3	0.43
QUE	1485663	2.19	0.31	1.48	0.21	2.15	0.31	1.45	0.21	26	1	2.07
ON	2729354	10.82	9.26	3.96	3.39	10.76	9.25	3.94	3.39	21	4	0.66
MAN	304401	1.50	0.17	4.93	0.57	1.49	0.17	4.89	0.57	40	0	0.90
SAS	300211	2.01	3.39	6.69	11.28	2.00	3.38	6.67	11.27	26	9	0.47
AB	704141	4.95	6.54	7.03	9.29	4.88	6.53	6.94	9.28	91	10	1.40
BC	906610	2.81	0.31	3.10	0.34	2.79	0.31	3.07	0.34	24	0	0.84
CANADA	7101782	26.89	26.00	3.79	3.66	26.68	25.97	3.76	3.66	29	4	0.88

Table 4.25: GHGRPDI for upgrading single glazing and storm windows

	GHG Emissions Reduction Per Dollar Investment		
	Single (with storm) to standard double	Single (with storm) to high efficiency Double glaze	Single (with storm) to high efficiency triple glaze
Province	kg/year/$	kg/year/$	kg/year/$
NFLD	0	0	0
PEI	0	0	0
NS	0.07	0.12	0.13
NB	0.07	0.10	0.11
QUE	0	0	0
ON	0.05	0.08	0.08
MAN	0.07	0.11	0.11
SAS	0.10	0.16	0.17
AB	0.08	0.12	0.13
BC	0	0	0
CANADA	0.05	0.08	0.09

4.1.4.3 Houses with Standard Double Glazed Windows

The numbers of houses with double glazed windows that are eligible to receive the two levels of window upgrades are given in Table 4.26. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.26: Retrofit statistics for window upgrades – houses with standard double glazed windows

	Total number	Low-E Double Glazing		Low-E Triple Glazing	
Province	of houses in Canada	Number	%	Number	%
NFLD	169,601	9,403	6	9,403	6
PEI	37,699	1,461	4	1,461	4
NS	256,675	11,622	5	11,622	5
NB	207,428	10,835	5	10,835	5
QUE	1,485,663	154,738	10	154,738	10
ON	2,729,354	179,828	7	179,828	7
MAN	304,401	116,159	38	116,159	38
SAS	300,211	61,217	20	61,217	20
AB	704,141	41,138	6	41,138	6
BC	906,610	4,759	1	4,759	1
Canada	7,101,783	591,160	8	591,160	8

The TIC functions given in Equations 4.8-4.9 were used for the two levels of upgrades for standard double glazed windows.

4.1.4.3.1 GHG Emission Reduction Results for Houses with Standard Double Glazed Windows

For each window upgrade scenario for single glazing and storm windows, the average annual reduction in GHG emissions per house was calculated from the results of the batch simulations.

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Tables 4.27-4.28, the reduction in GHG emissions associated with upgrading the standard double glazed windows are given for each province and for all of Canada. The GHGRPDI values are given in Table 4.29

Table 4.27: Average annual reduction in GHG emissions with upgrading standard double glazed windows with low-E double glazed windows (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	4	0	0.18
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.95	12.02	7	1	0.09
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.04	12.56	5	3	0.13
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.86	2	6	0.15
QUE	1485663	2.19	0.31	1.48	0.21	2.18	0.31	1.47	0.21	10	0	0.74
ON	2729354	10.82	9.26	3.96	3.39	10.80	9.25	3.96	3.39	7	1	0.21
MAN	304401	1.50	0.17	4.93	0.57	1.49	0.17	4.89	0.57	42	2	1.16
SAS	300211	2.01	3.39	6.69	11.28	2.00	3.38	6.66	11.27	27	10	0.49
AB	704141	4.95	6.54	7.03	9.29	4.94	6.54	7.02	9.29	9	1	0.14
BC	906610	2.81	0.31	3.10	0.34	2.81	0.31	3.10	0.34	0	0	0.02
CANADA	7101782	26.89	26.00	3.79	3.66	26.83	25.99	3.78	3.66	9	1	0.28

Table 4.28: Average annual reduction in GHG emissions with upgrading standard double glazed windows with low-E triple glazed windows (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	7	0	0.28
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.94	12.01	11	1	0.14
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.03	12.55	8	5	0.20
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.86	3	9	0.23
QUE	1485663	2.19	0.31	1.48	0.21	2.17	0.31	1.46	0.21	14	0	1.10
ON	2729354	10.82	9.26	3.96	3.39	10.79	9.25	3.95	3.39	10	2	0.31
MAN	304401	1.50	0.17	4.93	0.57	1.48	0.17	4.87	0.57	63	3	1.74
SAS	300211	2.01	3.39	6.69	11.28	2.00	3.38	6.65	11.27	41	15	0.74
AB	704141	4.95	6.54	7.03	9.29	4.94	6.54	7.01	9.29	14	1	0.21
BC	906610	2.81	0.31	3.10	0.34	2.81	0.31	3.10	0.34	1	0	0.03
CANADA	7101782	26.89	26.00	3.79	3.66	26.80	25.98	3.77	3.66	14	2	0.41

Table 4.29: GHGRPDI for window upgrades

	GHG Emissions Reduction Per Dollar Investment	
	Double to high efficiency double glaze	Double to high efficiency triple glaze
Province	kg/year/$	kg/year/$
NFLD	0.03	0.05
PEI	0.04	0.06
NS	0.05	0.07
NB	0.05	0.06
QUE	0.03	0.04
ON	0.04	0.05
MAN	0.04	0.05
SAS	0.07	0.10
AB	0.05	0.07
BC	0.00	0.00
CANADA	0.04	0.05

4.2 Mechanical System Upgrade Scenarios

4.2.1 Space Heating System Upgrade Scenarios

The type of heating system upgrade scenario that was considered for retrofits was based on the type of fuel used in that particular house. The following were the retrofits considered:

(1) If the fuel type of a house is natural gas or oil, and the space heating equipment of the house is standard efficiency type (50-65%), replace the space heating equipment by:

   (i) medium efficiency equipment (75-80%),

   (ii) high efficiency equipment (90% or higher)

(2) If the fuel type of a house is electricity, the following upgrades were conducted:

   (i) if the house has standard air-to-air heat pump, replace this heat pump with a high efficiency one,

   (ii) if the house has electric baseboard heaters and a standard efficiency central air conditioner, replace this system with a high efficiency air-to-air heat pump system.

   (iii) if the house has central electric forced-air system, replace this system with a high efficiency air-to-air heat pump system.

Upgrading of electric baseboard heating systems was not considered due to the extensive modifications (i.e. addition of duct work) needed to install heat pump systems.

The number of houses that are eligible to receive the heating system upgrades are given in Table 4.30 these numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.30: Retrofit statistics for space heating system upgrades

	Total number	Upgrade to medium eff.		Upgrade to high eff.	
Province	of houses in Canada	Number	%	Number	%
NFLD	169,601	28,631	17	28,631	17
PEI	37,699	16,872	45	16,872	45
NS	256,675	85,544	33	86,243	34
NB	207,428	36,986	18	38,657	19
QUE	1,485,663	148,986	10	185,274	12
ON	2,729,354	1,044,149	38	1,170,472	43
MAN	304,401	120,348	40	128,267	42
SAS	300,211	155,749	52	160,670	54
AB	704,141	375,033	53	376,023	53
BC	906,610	398,900	44	406,300	45
Canada	7,101,783	2,411,198	34	2,597,409	37

For the space heating system upgrade scenarios, retail and installation costs are given in Appendix A. The costs consist of the equipment and installation costs as well as the contractor's overhead and profit, but excludes the provincial taxes.

4.2.1.1 GHG Emission Reduction Results for Space Heating System Upgrade Scenarios

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Tables 4.31-4.32, the reduction in GHG emissions associated with the space heating system upgrade scenarios are given for each province and for all of Canada. The GHGRPDI values are given in Table 4.33.

Table 4.31: Average annual reduction in GHG emissions by replacing existing space heating systems with medium efficiency systems (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.49	0.08	2.90	0.49	187	-1	5.68
PEI	37699	0.30	0.45	7.96	12.02	0.29	0.45	7.59	12.02	363	0	4.55
NS	256675	1.29	3.23	5.04	12.57	1.21	3.22	4.71	12.55	332	11	6.59
NB	207428	0.50	2.25	2.42	10.87	0.45	2.25	2.19	10.85	228	21	9.37
QUE	1485663	2.19	0.31	1.48	0.21	2.08	0.32	1.40	0.21	77	-1	4.57
ON	2729354	10.82	9.26	3.96	3.39	9.35	9.17	3.42	3.36	538	31	13.36
MAN	304401	1.50	0.17	4.93	0.57	1.26	0.17	4.15	0.57	786	2	15.73
SAS	300211	2.01	3.39	6.69	11.28	1.70	3.38	5.68	11.26	1013	23	15.18
AB	704141	4.95	6.54	7.03	9.29	4.17	6.53	5.92	9.28	1103	9	15.54
BC	906610	2.81	0.31	3.10	0.34	2.37	0.31	2.62	0.34	480	0	16.31
CANADA	7101782	26.89	26.00	3.79	3.66	23.38	25.89	3.29	3.65	495	15	12.97

Table 4.32: Average annual reduction in GHG emissions by replacing existing space heating systems with high efficiency systems (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52n	0.08	3.08	0.49	0.47	0.08	2.79	0.49	290	-1	9.23
PEI	37699	0.30	0.45	7.96	12.02	0.28	0.45	7.35	12.02	607	0	7.63
NS	256675	1.29	3.23	5.04	12.57	1.17	3.22	4.54	12.54	502	17	10.08
NB	207428	0.50	2.25	2.42	10.87	0.43	2.25	2.10	10.84	325	27	13.68
QUE	1485663	2.19	0.31	1.48	0.21	2.01	0.31	1.35	0.21	122	-1	7.88
ON	2729354	10.82	9.26	3.96	3.39	8.97	9.14	3.29	3.35	676	43	18.33
MAN	304401	1.50	0.17	4.93	0.57	1.20	0.17	3.93	0.57	998	4	20.86
SAS	300211	2.01	3.39	6.69	11.28	1.62	3.38	5.41	11.25	1279	32	19.40
AB	704141	4.95	6.54	7.03	9.29	3.99	6.53	5.66	9.28	1365	12	19.55
BC	906610	2.81	0.31	3.10	0.34	2.27	0.31	2.51	0.34	592	0	19.22
CANADA	7101782	26.89	26.00	3.79	3.66	22.41	25.85	3.16	3.64	631	21	17.22

Table 4.33: GHGRPDI for space heating system upgrades

	GHG Emissions Reduction Per Dollar Investment	
	Medium efficiency	High efficiency
Province	kg/year/$	kg/year/$
NFLD	0.38	0.47
PEI	0.22	0.29
NS	0.30	0.38
NB	0.43	0.51
QUE	0.18	0.23
ON	0.35	0.36
MAN	0.58	0.58
SAS	0.73	0.72
AB	0.73	0.70
BC	0.49	0.48
CANADA	0.39	0.40

4.2.2 Domestic Hot Water Heater Upgrade Scenario

One DHW heater upgrade scenario was evaluated, based on the type of fuel used in that particular house:

If a house has standard efficiency electric (89%), or natural gas (55%) or oil (55%) heated DHW heater, replace this system by:

(a) high efficiency equipment (93% electric, 85% oil, 65% natural gas)

The numbers of houses that are eligible to receive the DHW heater upgrade scenario are given in Table 4.34. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.34: Retrofit statistics for DHW heater upgrade

Province	Total number of houses in Canada	Upgrade to high eff. Number	%
NFLD	169,601	138,590	82
PEI	37,699	15,132	40
NS	256,675	184,989	72
NB	207,428	178,115	86
QUE	1,485,663	1,307,719	88
ON	2,729,354	2,423,768	89
MAN	304,401	276,341	91
SAS	300,211	269,935	90
AB	704,141	624,046	89
BC	906,610	787,349	87
Canada	7,101,783	6,205,984	87

For the DHW heater upgrade scenario, retail costs are given in Appendix A. The costs consist of the equipment costs.

4.2.2.1 GHG Emission Reduction Results for Domestic Hot Water upgrade Scenario

For DHW heater upgrade scenario, the average annual reduction in GHG emissions per house was calculated for the houses that received the upgrade using the results of the batch simulations.

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 4.35, the reduction in GHG emissions associated with upgrading the DHW heater is given for each province and for all of Canada. The GHGRPDI values are given in Table 4.36.

Table 4.35: Average annual reduction in GHG emissions by upgrading existing DHW heaters with high efficiency heaters
(averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.53	0.08	3.11	0.48	-26	4	0.40
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.84	11.89	120	130	2.39
NS	256675	1.29	3.23	5.04	12.57	1.28	3.18	4.98	12.38	62	197	2.79
NB	207428	0.50	2.25	2.42	10.87	0.50	2.23	2.43	10.73	-7	139	0.99
QUE	1485663	2.19	0.31	1.48	0.21	2.17	0.31	1.46	0.21	12	2	1.92
ON	2729354	10.82	9.26	3.96	3.39	10.67	9.14	3.91	3.35	54	42	2.61
MAN	304401	1.50	0.17	4.93	0.57	1.49	0.17	4.89	0.57	37	5	1.70
SAS	300211	2.01	3.39	6.69	11.28	1.99	3.36	6.62	11.19	68	92	1.83
AB	704141	4.95	6.54	7.03	9.29	4.89	6.53	6.95	9.27	81	15	1.31
BC	906610	2.81	0.31	3.10	0.34	2.76	0.31	3.04	0.34	55	4	3.00
CANADA	7101782	26.89	26.00	3.79	3.66	26.57	25.75	3.74	3.63	45	35	2.13

As seen in Newfoundland, the direct reduction in greenhouse gas emissions is -26kg. This is because of the fact that the existing heaters were inefficient, and contributing to satisfying the heating load. Therefore, when more efficient heaters were installed, the space heating required more fuel to satisfy the deficit of the heat gain by the inefficient boilers.

Table 4.36: GHGRPDI for upgrading DHW heaters

	GHG Emissions Reduction Per Dollar Investment
	upgrade to high efficiency
Province	kg/year/$
NFLD	0.47
PEI	0.29
NS	0.38
NB	0.51
QUE	0.23
ON	0.36
MAN	0.58
SAS	0.72
AB	0.70
BC	0.48
CANADA	0.40

4.3 Household Appliance upgrade Scenarios

The household appliances that were chosen to be included as part of this study are: freezers, refrigerators, clothes washer, clothes dryer, dishwasher and electric range. It was assumed that because of the lengthy life expectancy of appliances, only if the age of an appliance is bigger than its LE, it is the appliance is eligible for replacement.

LE of refrigerator:	19 years
LE of freezer:	19 years
LE of clothes washer:	14 years
LE of clothes dryer:	17 years
LE of dishwasher:	13 years
LE of electric range:	18 years
LE of microwave oven:	10 years

4.3.1 Refrigerators

The following refrigerator upgrade scenario was evaluated:

- If a house has only one refrigerator and its age is 19 years or older, the refrigerator is replaced with same type, size and high energy efficient refrigerator,
- If a house has two or more refrigerators, the oldest refrigerator is replaced with the same type, size and high energy efficient refrigerator if it is older than 19 years old.

End-use unit energy consumption (UEC) values for standard and energy efficient refrigerators are given in Table 1 of Appendix E.

The numbers of houses that are eligible to receive refrigerator upgrades are given in Table 4.37. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.37: Retrofit statistics for refrigerator upgrades

Province	Total number of houses in Canada	Refrigerator Number	%
NFLD	169,601	25,196	15
PEI	37,699	3,532	9
NS	256,675	25,031	10
NB	207,428	17,793	9
QUE	1,485,663	197,472	13
ON	2,729,354	396,880	15
MAN	304,401	65,791	22
SAS	300,211	71,463	24
AB	704,141	92,047	13
BC	906,610	104,056	11
Canada	7,101,783	999,261	14

4.3.1.1 GHG Emission Reduction Results for Refrigerators

The average annual reduction in GHG emissions per house was calculated for the houses that received high efficiency refrigerators from the results of the batch simulations.

Refrigerator efficiency upgrades have resulted in increasing the end-use energy consumption and consequently the GHG emissions in some provinces. This is because of the reduced electrical energy consumption and heat gain from the refrigerator. High efficiency refrigerators result in smaller heat gain to the house. This reduction in heat gain is made up by the space heating system. Depending on the fuel used and the efficiency of the heating system, the end-use energy consumption of the house and the GHG emissions may increase.

To extrapolate the estimates of reduction GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 4.38, the reduction in GHG emissions associated with the refrigerator upgrade is given for each province and for all of Canada.

Table 4.38: Average annual reduction in GHG emissions with refrigerator upgrade (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.53	0.08	3.10	0.49	-14	2	-0.11
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.97	11.89	-19	124	0.79
NS	256675	1.29	3.23	5.04	12.57	1.30	3.20	5.06	12.47	-23	91	0.27
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.43	10.83	-10	32	-0.14
QUE	1485663	2.19	0.31	1.48	0.21	2.21	0.31	1.49	0.21	-14	1	-0.38
ON	2729354	10.82	9.26	3.96	3.39	10.91	9.09	4.00	3.33	-36	61	0.87
MAN	304401	1.50	0.17	4.93	0.57	1.52	0.17	4.98	0.56	-48	11	0.89
SAS	300211	2.01	3.39	6.69	11.28	2.03	3.28	6.77	10.92	-73	366	2.15
AB	704141	4.95	6.54	7.03	9.29	4.98	6.39	7.07	9.08	-48	211	1.59
BC	906610	2.81	0.31	3.10	0.34	2.83	0.30	3.13	0.34	-27	4	0.37
CANADA	7101782	26.89	26.00	3.79	3.66	27.12	25.53	3.82	3.59	-32	66	0.96

4.3.2 Freezers

The following freezer upgrade scenario was evaluated:

- If a house has only one freezer and its age was 19 years or older, the freezer was replaced with the same type, size and high energy efficient freezer,
- If a house has two or more freezers, the oldest freezer was replaced with the same type, size and high energy efficient freezer if it is older than 19 years old.

End-use energy consumption (UEC) values for standard and energy efficient freezers are given Table 2 of Appendix E.

The numbers of houses that are eligible to receive freezer upgrades are given in Table 4.39. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.39: Retrofit statistics for freezer upgrades

Province	Total number of houses in Canada	Freezer Number	%
NFLD	169,601	18,097	11
PEI	37,699	5,328	14
NS	256,675	28,934	11
NB	207,428	24,094	12
QUE	1,485,663	159,188	11
ON	2,729,354	383,439	14
MAN	304,401	60,450	20
SAS	300,211	82,264	27
AB	704,141	106,674	15
BC	906,610	114,324	13
Canada	7,101,783	982,792	14

4.3.2.1 GHG Emission Reduction Results for Freezers

The average annual reduction in GHG emissions per house was calculated for the houses that received high efficiency freezers from the results of the batch simulations.

Freezer efficiency upgrades have resulted in increasing the end-use energy consumption and consequently the GHG emissions in some provinces. This is because of the reduced electrical energy consumption and heat gain from the freezer. High efficiency freezers result in smaller heat gain to the house. This reduction in heat gain is made up by the space heating system. Depending on the fuel used and the efficiency of the heating system, the end-use energy consumption of the house and the GHG emissions may increase.

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 4.40, the reduction in GHG emissions associated with the freezer upgrade is given for each province and for all of Canada.

Table 4.40: Average annual reduction in GHG emissions with freezer upgrade (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.09	0.49	-8	1	-0.05
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.97	11.94	-12	76	0.49
NS	256675	1.29	3.23	5.04	12.57	1.30	3.21	5.05	12.52	-11	44	0.13
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.43	10.84	-9	27	-0.10
QUE	1485663	2.19	0.31	1.48	0.21	2.20	0.31	1.48	0.21	-7	1	-0.24
ON	2729354	10.82	9.26	3.96	3.39	10.84	9.20	3.97	3.37	-11	20	0.31
MAN	304401	1.50	0.17	4.93	0.57	1.51	0.17	4.95	0.57	-15	4	0.39
SAS	300211	2.01	3.39	6.69	11.28	2.02	3.32	6.73	11.07	-42	213	1.26
AB	704141	4.95	6.54	7.03	9.29	4.96	6.47	7.05	9.19	-24	103	0.77
BC	906610	2.81	0.31	3.10	0.34	2.82	0.31	3.11	0.34	-13	2	0.25
CANADA	7101782	26.89	26.00	3.79	3.66	26.98	25.78	3.80	3.63	-13	30	0.48

4.3.3 Clothes Washers

The following clothes washer upgrade scenario was evaluated:

- If the age of the clothes washer and is 14 years or older, the clothes washer is replaced with the same type, size and high energy efficient clothes washer.

End-use energy consumption (UEC) values for standard and energy efficient clothes washers are given Table 3 of Appendix E.

The numbers of houses that are eligible to receive clothes washer upgrades are given in Table 4.41. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.41: Retrofit statistics for clothes washer upgrade

Province	Total number of houses in Canada	Clothes Washer	
		Number	%
NFLD	169,601	16,235	10
PEI	37,699	5,487	15
NS	256,675	31,973	12
NB	207,428	24,353	12
QUE	1,485,663	210,702	14
ON	2,729,354	372,391	14
MAN	304,401	42,615	14
SAS	300,211	38,870	13
AB	704,141	88,848	13
BC	906,610	118,030	13
Canada	7,101,783	949,504	13

4.3.3.1 GHG Emission Reduction Results for Clothes Washers

The average annual reduction in GHG emissions per house was calculated for the houses that received high efficiency clothes washers from the results of the batch simulations.

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 4.42, the reduction in GHG emissions associated with the clothes washer upgrade is given for each province and for all of Canada.

Table 4.42: Average annual reduction in GHG emissions with clothes washer upgrade (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	2	0	0.14
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.94	12.01	13	2	0.18
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.03	12.54	6	15	0.24
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.85	1	12	0.16
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.31	1.47	0.21	3	0	0.40
ON	2729354	10.82	9.26	3.96	3.39	10.80	9.25	3.96	3.39	6	2	0.19
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.93	0.57	5	0	0.17
SAS	300211	2.01	3.39	6.69	11.28	2.00	3.39	6.67	11.28	24	4	0.40
AB	704141	4.95	6.54	7.03	9.29	4.94	6.54	7.02	9.29	8	1	0.12
BC	906610	2.81	0.31	3.10	0.34	2.80	0.31	3.09	0.34	6	0	0.27
CANADA	7101782	26.89	26.00	3.79	3.66	26.85	25.98	3.78	3.66	6	2	0.21

4.3.4 Clothes dryer

The following clothes dryer upgrade scenario was evaluated:

- If a house has clothes dryer and its age is 17 years or older, the clothes dryer was replaced with the same type, size and high energy efficient clothes dryer.

End-use energy consumption (UEC) values for standard and energy efficient clothes dryers are given in Table 4 of Appendix E.

4.3.4.1 GHG Emission Reduction Results for Clothes Dryers

To extrapolate the estimates of GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 4.43, the reduction in GHG emissions associated with the clothes dryer upgrade is given for each province and for all of Canada.

Table 4.43: Average annual reduction in GHG emissions with clothes dryer upgrade (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	0	0	0.07
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.96	12.01	0	8	0.07
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.04	12.55	0	5	0.04
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.86	0	9	0.08
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.31	1.48	0.21	0	0	0.09
ON	2729354	10.82	9.26	3.96	3.39	10.82	9.25	3.96	3.39	0	3	0.09
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.93	0.57	0	1	0.10
SAS	300211	2.01	3.39	6.69	11.28	2.01	3.38	6.69	11.26	0	26	0.23
AB	704141	4.95	6.54	7.03	9.29	4.95	6.53	7.03	9.28	0	9	0.09
BC	906610	2.81	0.31	3.10	0.34	2.81	0.31	3.10	0.34	0	0	0.12
CANADA	7101782	26.89	26.00	3.79	3.66	26.89	25.97	3.79	3.66	0	4	0.10

4.3.5 Dishwashers

The following dishwasher upgrade scenario was evaluated:

- If the age of the dishwasher and is nine 14 or older, the dishwasher was replaced with same the type and size energy efficient dishwasher.

End-use energy consumption (UEC) values for standard and energy efficient dishwashers are given in Table 5 of Appendix E.

The numbers of houses that are eligible to receive dishwasher upgrades are given in Table 4.44. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D

Table 4.44: Retrofit statistics for dishwasher upgrade

	Total number	Dishwasher	
Province	of houses in Canada	Number	%
NFLD	169,601	980	1
PEI	37,699	847	2
NS	256,675	5,164	2
NB	207,428	2,990	1
QUE	1,485,663	50,179	3
ON	2,729,354	68,922	3
MAN	304,401	9,243	3
SAS	300,211	6,345	2
AB	704,141	15,306	2
BC	906,610	26,524	3
Canada	7,101,783	186,500	3

4.3.5.1 GHG Emission Reduction Results for Dishwashers

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 4.45, the reduction in GHG emissions associated with the dishwasher upgrade scenario are given for each province and for all of Canada.

Table 4.45 Average annual reduction in GHG emissions with dishwasher upgrade (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	0	0	0.02
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.95	12.02	4	0	0.05
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.04	12.56	1	3	0.04
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.86	0	3	0.03
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.31	1.48	0.21	0	0	0.04
ON	2729354	10.82	9.26	3.96	3.39	10.81	9.26	3.96	3.39	2	1	0.06
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.93	0.57	3	0	0.08
SAS	300211	2.01	3.39	6.69	11.28	2.01	3.39	6.69	11.28	2	1	0.04
AB	704141	4.95	6.54	7.03	9.29	4.95	6.54	7.02	9.29	2	2	0.05
BC	906610	2.81	0.31	3.10	0.34	2.81	0.31	3.10	0.34	1	0	0.05
CANADA	7101782	26.89	26.00	3.79	3.66	26.88	25.99	3.79	3.66	1	1	0.05

4.3.6 Cooking appliances

The following cooking appliances upgrade scenario was evaluated:

- If a house has an electric range and its age is 18 years or older, the equipment was replaced with the same type, size and high energy efficient electric range.
- If a house has gas oven and its age is 18 years or older, the gas oven was replaced with the same type, size and high energy efficient gas oven.
- If a house has a microwave and its age is ten years or older, the dishwasher was replaced with the same type and size energy efficient microwave.

End-use energy consumption (UEC) values for standard and energy efficient cooking appliances are given in Table 6 of Appendix E.

The numbers of houses that are eligible to receive cooking appliance upgrades are given in Table 4.46. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 4.46: Retrofit statistics for cooking appliance upgrade

Province	Total number of houses in Canada	Cooking Appliances Number	Cooking Appliances %
NFLD	169,601	20,967	12
PEI	37,699	4,053	11
NS	256,675	27,214	11
NB	207,428	24,438	12
QUE	1,485,663	196,623	13
ON	2,729,354	251,342	9
MAN	304,401	40,015	13
SAS	300,211	39,902	13
AB	704,141	79,599	11
BC	906,610	78,184	9
Canada	7,101,783	762,337	11

4.3.6.1 GHG Emission Reduction Results for Cooking Appliances

Increasing the efficiency of the cooking appliances, could lead to an increase in end-use energy consumption an subsequently the GHG emissions in some provinces. The reason for this is due to the reduced electrical energy consumption and heat gain from cooking appliances. This reduction in heat gain is made up by the space heating system. Depending on the fuel used and the efficiency of the heating system, the end-use energy consumption of the house and the GHG emissions may increase.

To extrapolate the estimates of GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 4.47, the reduction in GHG emissions associated with the cooking appliances upgrade scenario are given for each province and for all of Canada.

Table 4.47: Average annual reduction in GHG emissions with cooking appliances upgrade (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.52	0.08	3.08	0.49	0	0	0.00
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.45	7.96	12.01	0	1	0.00
NS	256675	1.29	3.23	5.04	12.57	1.29	3.22	5.04	12.56	0	0	0.00
NB	207428	0.50	2.25	2.42	10.87	0.50	2.25	2.42	10.87	0	0	0.00
QUE	1485663	2.19	0.31	1.48	0.21	2.19	0.31	1.48	0.21	0	0	0.00
ON	2729354	10.82	9.26	3.96	3.39	10.82	9.26	3.96	3.39	0	0	0.00
MAN	304401	1.50	0.17	4.93	0.57	1.50	0.17	4.93	0.57	0	0	0.00
SAS	300211	2.01	3.39	6.69	11.28	2.01	3.39	6.69	11.28	0	1	0.01
AB	704141	4.95	6.54	7.03	9.29	4.95	6.54	7.03	9.29	-1	4	0.03
BC	906610	2.81	0.31	3.10	0.34	2.81	0.31	3.10	0.34	0	0	0.00
CANADA	7101782	26.89	26.00	3.79	3.66	26.89	25.99	3.79	3.66	0	1	0.01

5 MINOR ENERGY EFFICIENCY UPGRADE SCENARIOS

5.1 Upgrade Scenario for Lighting

A significant number of houses in Canada use incandescent lighting which are less efficient than fluorescent lighting (Fung and Ugursal, 1998). As part of this study, all houses that used incandescent lighting were replaced to use fluorescent lighting. In CREEM, average wattage of an incandescent bulb is 67.1W (Fung and Ugursal, 1995). A 20-W energy efficient fluorescent provides the same level of lighting as a 60-W incandescent bulb. Therefore in the retrofit scenario, all incandescent light bulbs were replaced with 20-W energy efficient fluorescent light bulbs.

The numbers of houses that are eligible to receive the lighting upgrade are given in Table 5.1. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 5.1: Retrofit statistics for upgrading of lighting

Province	Total number of houses in Canada	Lighting	
		Number	%
NFLD	169,601	169,487	100
PEI	37,699	37,541	100
NS	256,675	255,632	100
NB	207,428	206,066	99
QUE	1,485,663	1,473,436	99
ON	2,729,354	2,696,292	99
MAN	304,401	303,149	100
SAS	300,211	299,727	100
AB	704,141	699,225	99
BC	906,610	898,985	99
Canada	7,101,783	7,039,540	99

The TIC function for upgrading of lighting is given in Eq (5.1) (Burak, 2000):

$$TICL = (TNF)(2.5) \tag{5.1}$$

where,

TICL = Total investment cost for lighting fixtures upgrade, $

TNF = Total number of incandescent light bulbs in the house

The development of the TIC function is given in Appendix A.

5.1.1 GHG Emission Reduction Results for Lighting Upgrade

To extrapolate the estimates of GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 5.2, the reduction in GHG emissions associated with upgrading lighting is given for each province and for all of Canada. The GHGRPDI for upgrading lighting is given in Table 5.3.

Table 5.2: Average annual reduction in GHG emissions with lighting upgrade (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.53	0.08	3.15	0.48	-62	8	-0.37
PEI	37699	0.30	0.45	7.96	12.02	0.30	0.43	8.08	11.33	-125	689	4.16
NS	256675	1.29	3.23	5.04	12.57	1.32	3.12	5.13	12.14	-91	421	1.54
NB	207428	0.50	2.25	2.42	10.87	0.51	2.22	2.46	10.68	-42	182	-0.04
QUE	1485663	2.19	0.31	1.48	0.21	2.24	0.31	1.51	0.21	-33	4	-0.49
ON	2729354	10.82	9.26	3.96	3.39	11.06	8.79	4.05	3.22	-91	173	2.79
MAN	304401	1.50	0.17	4.93	0.57	1.53	0.17	5.03	0.55	-95	21	1.69
SAS	300211	2.01	3.39	6.69	11.28	2.05	3.19	6.82	10.62	-131	660	3.89
AB	704141	4.95	6.54	7.03	9.29	5.06	6.03	7.19	8.57	-161	723	5.50
BC	906610	2.81	0.31	3.10	0.34	2.90	0.29	3.20	0.32	-99	20	2.63
CANADA	7101782	26.89	26.00	3.79	3.66	27.51	24.61	3.87	3.47	-87	195	3.02

Table 5.3: GHGRPDI for upgrading lighting

	GHG Emissions Reduction Per Dollar Investment
	upgrade to high efficiency lighting
Province	kg/year/$
NFLD	-0.54
PEI	7.36
NS	4.23
NB	1.81
QUE	-0.19
ON	0.98
MAN	-0.78
SAS	7.25
AB	8.02
BC	-1.00
CANADA	1.44

5.2 Upgrade Scenario for Showerhead and Aerators

This energy retrofit scenario entailed replacing all standard shower heads with low flow shower heads and aerators in order to reduce the energy consumed by the DHW heater. The daily DHW consumption of a house can be estimated based on the number of occupants as follows:

$$\frac{\text{Lit}}{\text{Day}} = 85 + (35)(\#\text{of occupants})$$

Low flow showerheads and aerators reduce the water flow by almost 50%. Thus, DHW load becomes:

$$\frac{\text{Lit}}{\text{Day}} = 85 + (20)(\#\text{of occupants})$$

The numbers of houses that are eligible to receive the showerhead upgrade are given in Table 5.4. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 5.4: Retrofit statistics for upgrading of showerheads and aerators

	Total number	Showerhead and Aerator	
Province	of houses in Canada	Number	%
NFLD	169,601	110,947	65
PEI	37,699	23,785	63
NS	256,675	131,445	51
NB	207,428	118,661	57
QUE	1,485,663	593,580	40
ON	2,729,354	1,208,610	44
MAN	304,401	176,301	58
SAS	300,211	193,758	65
AB	704,141	396,975	56
BC	906,610	445,778	49
Canada	7,101,783	3,399,840	48

The TIC function for upgrading of showerhead is given in Eq (5.2) (Burak, 2000):

$$\text{TICSH} = (\text{TNSH})(10.3) \qquad (5.2)$$

where,

TICSH = Total investment cost for showerhead upgrade, $

TNSH = Total number of showerheads

The development of the TIC function is given in Appendix A.

The TIC function for upgrading of aerator is given in Equation (5.3) (Burak, 2000):

$$TICAF = (TNAE)(4.1) \qquad (13)$$

where,

TICAF = Total investment cost for aerator and faucet upgrade, $

TNAE = Total number of aerator(s) and faucet(s) in the house

The development of the TIC function is given in Appendix A.

5.2.1 GHG Emission Reduction Results for Showerhead and Aerator upgrade Scenarios

To extrapolate the estimates of reduction in GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table 5.5, the reduction in GHG emissions associated with the showerhead upgrade is given for each province and for all of Canada. The GHGRPDI for upgrading lighting is given in Table 5.6.

Table 5.5: Average annual reduction in GHG emissions with showerhead and aerator upgrade (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.51	0.08	2.99	0.46	93	30	9.23
PEI	37699	0.30	0.45	7.96	12.02	0.28	0.44	7.53	11.65	423	368	8.38
NS	256675	1.29	3.23	5.04	12.57	1.25	3.10	4.86	12.07	178	489	7.43
NB	207428	0.50	2.25	2.42	10.87	0.49	2.14	2.37	10.31	48	553	7.06
QUE	1485663	2.19	0.31	1.48	0.21	2.15	0.30	1.45	0.20	30	6	5.03
ON	2729354	10.82	9.26	3.96	3.39	10.45	9.05	3.83	3.32	132	76	5.57
MAN	304401	1.50	0.17	4.93	0.57	1.45	0.17	4.77	0.55	163	19	6.69
SAS	300211	2.01	3.39	6.69	11.28	1.93	3.31	6.41	11.01	279	272	6.58
AB	704141	4.95	6.54	7.03	9.29	4.74	6.51	6.73	9.25	300	42	4.72
BC	906610	2.81	0.31	3.10	0.34	2.69	0.30	2.97	0.33	131	11	7.54
CANADA	7101782	26.89	26.00	3.79	3.66	25.94	25.39	3.65	3.58	134	85	5.87

Table 5.6: GHGRPDI for upgrading showerheads and aerators

	GHG Emissions Reduction Per Dollar Investment
	Shower head and aerator upgrade
Province	kg/year/$
NFLD	0.21
PEI	3.97
NS	2.21
NB	1.60
QUE	0.10
ON	0.56
MAN	0.40
SAS	1.31
AB	0.90
BC	0.48
CANADA	0.60

5.3 Upgrade Scenario for Thermostats

In this upgrade scenario, houses that did not have programmable thermostats, were replaced with programmable thermostats. In houses where electric baseboard or electric radiant heating systems are used, all room thermostats were replaced with programmable ones. In houses where a central heating system is used, the central thermostat was replaced with a programmable thermostat. The following temperature schedule was used in all houses that received the thermostat upgrade:

Midnight – 7:00 AM: 17°C

7:00 AM – Midnight: 20°C

The corresponding average temperature for this schedule is 19 °C.

The numbers of houses that are eligible to receive the thermostat upgrades are given in Table 5.7. These numbers were determined from the corresponding number of houses in the CREEM database using the weighting factors given by SHEU (Statistics Canada, 1993) as described in Appendix D.

Table 5.7: Retrofit statistics for thermostat upgrade

Province	Total number of houses in Canada	Thermostat Number	Thermostat %
NFLD	169,601	39,326	23
PEI	37,699	7,601	20
NS	256,675	52,214	20
NB	207,428	56,021	27
QUE	1,485,663	460,600	31
ON	2,729,354	921,158	34
MAN	304,401	129,747	43
SAS	300,211	135,043	45
AB	704,141	277,286	39
BC	906,610	193,693	21
Canada	7,101,783	2,272,689	32

The total investment cost (TIC) function for the room thermostat scenario is given in Eq (5.4) (Burak, 2000):

$$TICRT = (TNRT)(75) \qquad (5.4)$$

where,

TICRT = Total investment cost for room thermostat upgrade, $

TNRT = Total number of room thermostats

The total investment cost (TIC) function for the central heating system thermostat scenario is given in Eq (5.5) (Burak, 2000):

$$TICCHS = (TNHST)(96) \tag{5.5}$$

where,

TICCHS = Total investment cost for central heating system thermostat upgrade, $

TNHST = Total number of central heating system thermostat

The development of the TIC function is given in Appendix A.

5.3.1 GHG Emission Reduction Results for Thermostat upgrade

For the thermostat upgrade scenario, the average annual reduction in GHG emissions per retrofitted house calculated from the results of the batch simulations are given in Table 5.8 for each province and for all of Canada.

Table 5.8: Thermostat upgrade: average annual reduction in GHG emissions saving per retrofitted house

	Reduction in GHG Emissions		
	Thermostat		
	kg/year/house		
Province	Direct	Indirect	Total
NFLD	494	68	562
PEI	998	42	1,040
NS	806	356	1,162
NB	397	528	925
QUE	144	3	147
ON	475	36	511
MAN	443	7	450
SAS	546	79	625
AB	626	48	674
BC	473	12	485
Canada	436	50	486

To extrapolate the estimates of GHG emissions obtained for the houses in CREEM to the Canadian housing stock, the weighting factor for each house in CREEM given by SHEU (Statistics Canada, 1993) was used as described in Appendix D. In Table

5.9, the reduction in GHG emissions associated with the thermostat upgrade is given for each province and for all of Canada. The GHGRPDI for thermostat upgrading is given in Table 5.10.

Table 5.9: Annual average reduction in GHG emissions with thermostat upgrade for (averages calculated for the entire housing stock)

Base Case Scenario		Base Case (Mt/y)		Base Case per house (t/y)		Retrofit Case (Mt/y)		Retrofit per house (t/y)		Reduction (kg/y)		
Province	Number of Houses	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Percentage (%)
NFLD	169601	0.52	0.08	3.08	0.49	0.50	0.08	2.97	0.48	114	10	5.76
PEI	37699	0.30	0.45	7.96	12.02	0.29	0.45	7.75	11.99	201	23	2.72
NS	256675	1.29	3.23	5.04	12.57	1.25	3.20	4.88	12.48	164	75	3.85
NB	207428	0.50	2.25	2.42	10.87	0.48	2.21	2.31	10.68	107	189	6.17
QUE	1485663	2.19	0.31	1.48	0.21	2.13	0.31	1.43	0.21	45	3	4.51
ON	2729354	10.82	9.26	3.96	3.39	10.38	9.20	3.80	3.37	160	19	4.61
MAN	304401	1.50	0.17	4.93	0.57	1.44	0.17	4.74	0.56	189	8	5.27
SAS	300211	2.01	3.39	6.69	11.28	1.94	3.38	6.45	11.25	246	37	4.00
AB	704141	4.95	6.54	7.03	9.29	4.77	6.53	6.78	9.27	247	18	3.70
BC	906610	2.81	0.31	3.10	0.34	2.72	0.31	3.00	0.34	101	2	3.73
CANADA	7101782	26.89	26.00	3.79	3.66	25.90	25.85	3.65	3.64	140	21	4.25

Table 5.10: GHGRPDI for thermostat upgrades

	GHG Emissions Reduction Per Dollar Investment
	Thermostat upgrade
Province	kg/year/$
NFLD	0.89
PEI	4.09
NS	2.49
NB	1.88
QUE	0.24
ON	0.76
MAN	0.67
SAS	1.11
AB	1.13
BC	0.74
CANADA	0.77

6 TECHNO-ECONOMIC RECOMMENDATION TO POLICY MAKERS:

The results presented in Chapters 3,4 and 5 are representative of all the provinces in Canada. The GHGPDI for all houses in all provinces were ranked in descending order for determining the optimal solution for GHG reduction. The GHGPDI were sorted by provinces. The following figures show what mix of retrofits must be implemented by policy makers in order to reduce the GHG foot print from the Canadian housing sector.

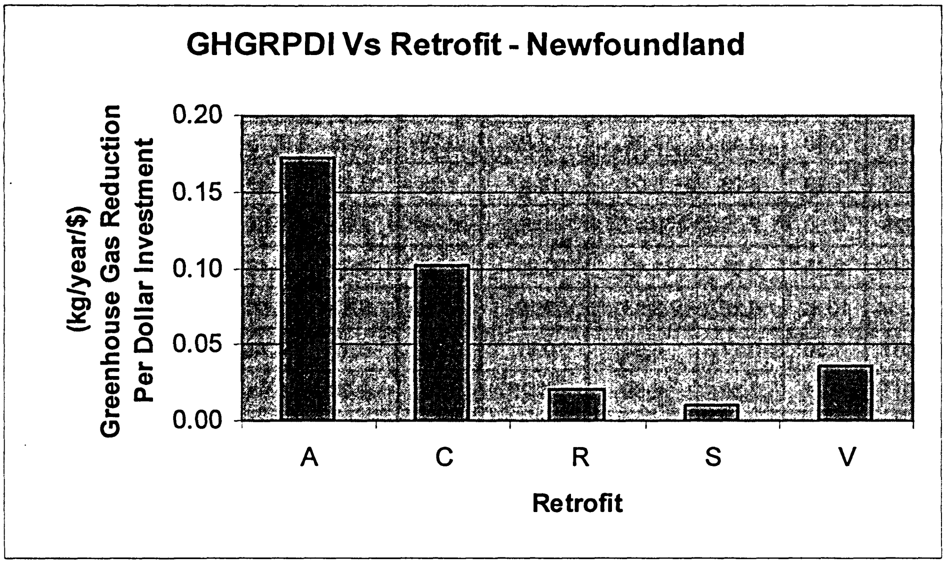

Figure 6.1: Retrofit Ranking for Newfoundland

Top five recommendations for Newfoundland in descending order, ranked based on number of households applicable for the retrofit and the Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits are as follows,

1. Thermostat upgrade (A)
2. Ceiling upgrade to RSI 7.04 (C)
3. Basement upgrade to RSI 5.3 (V)
4. High Efficiency Lighting upgrade (R)
5. Shower and Aerator upgrade (S)

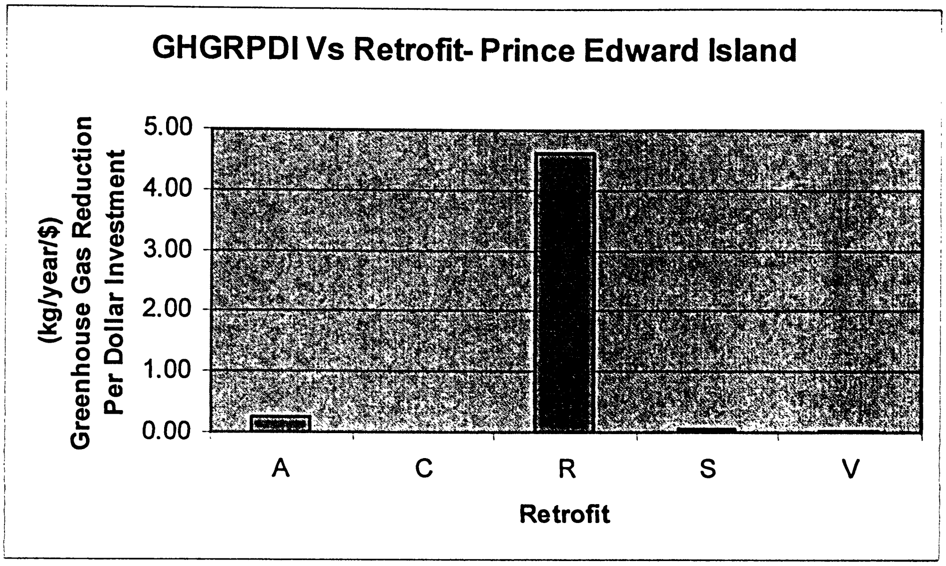

Figure 6.2: Retrofit Ranking for PEI

Top five recommendations for Prince Edward Islands in descending order, ranked based on number of households applicable for the retrofit and the Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits, are as follows:

1. High Efficiency Lighting upgrade (R)
2. Thermostat upgrade (A)
3. Shower and Aerator upgrade (S)
4. Basement Insulation upgrade to RSI 5.5 (V)
5. Ceiling upgrade to RSI 7.04 (C)

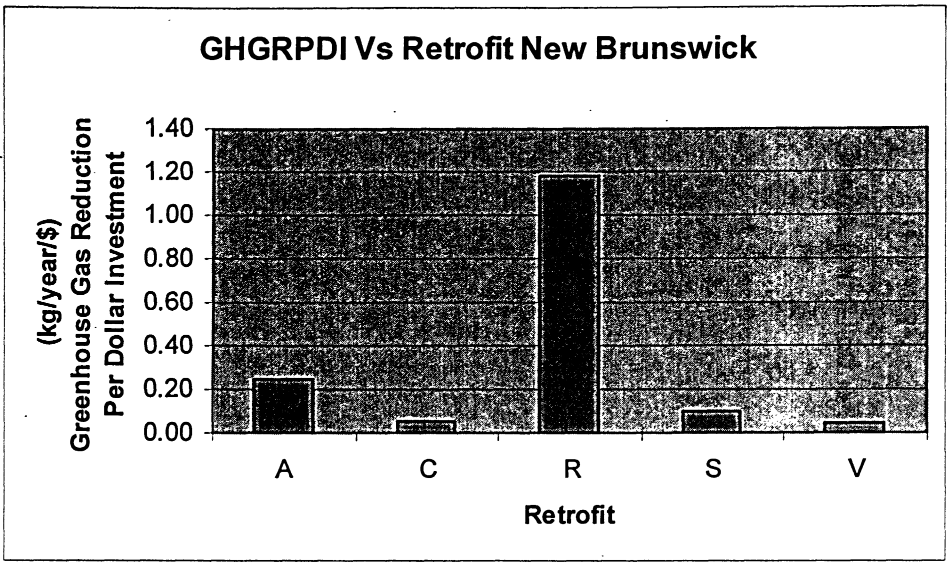

Figure 6.3: Retrofit Ranking for New Brunswick

Top five recommendations for New Brunswick in descending order, ranked based on number of households applicable for the retrofit and the Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits, are as follows:

1. High Efficiency Lighting upgrade (R)
2. Thermostat upgrade (A)
3. Shower and Aerator upgrade (S)
4. Ceiling upgrade to RSI 7.04 (C)
5. Basement Insulation upgrade to RSI 5.5 (V)

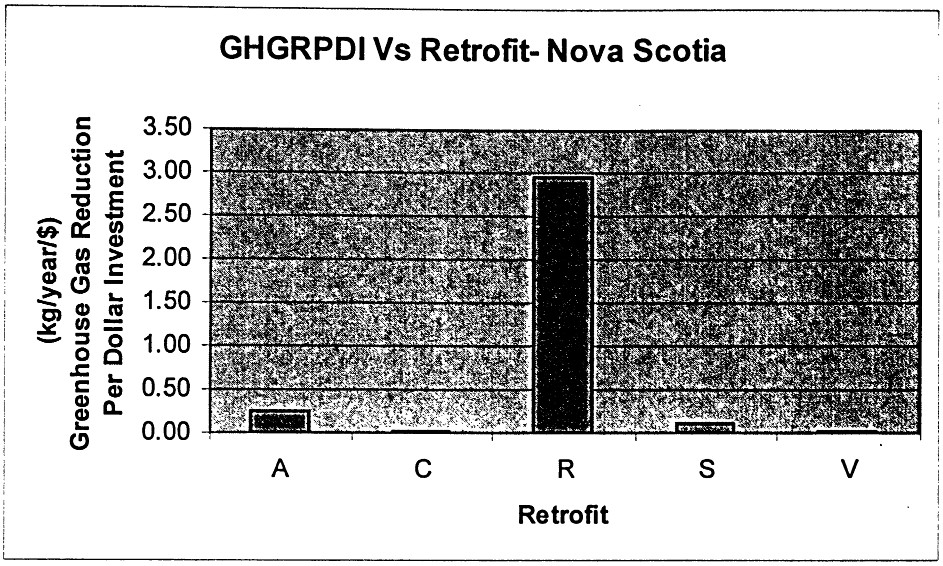

Figure 6.4: Retrofit Ranking for Nova Scotia

Top five recommendations for Nova Scotia in descending order, ranked based on number of households applicable for the retrofit and the greenhouse Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits are as follows:

1. High Efficiency Lighting upgrade (R)
2. Thermostat upgrade (A)
3. Shower and Aerator upgrade (S)
4. Ceiling upgrade to RSI 7.04 (C)
5. Basement Insulation upgrade to RSI 5.5 (V)

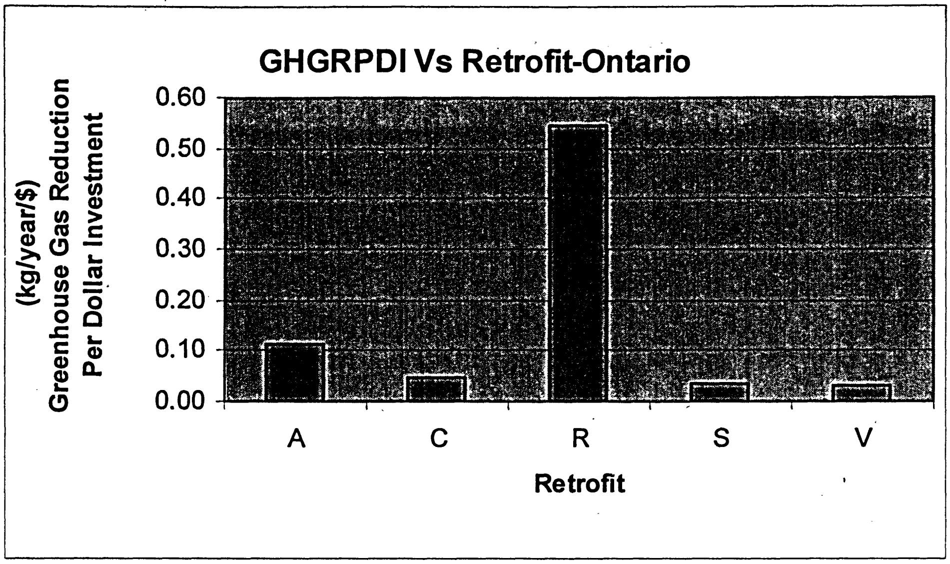

Figure 6.5: Retrofit Ranking for Ontario

Top five recommendations for Ontario in descending order, ranked based on number of households applicable for the retrofit and the Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits, are as follows:

1. High Efficiency Lighting upgrade (R)
2. Thermostat upgrade (A)
3. Ceiling upgrade to RSI 7.04 (C)
4. Shower and Aerator upgrade (S)
5. Basement Insulation upgrade to RSI 5.5 (V)

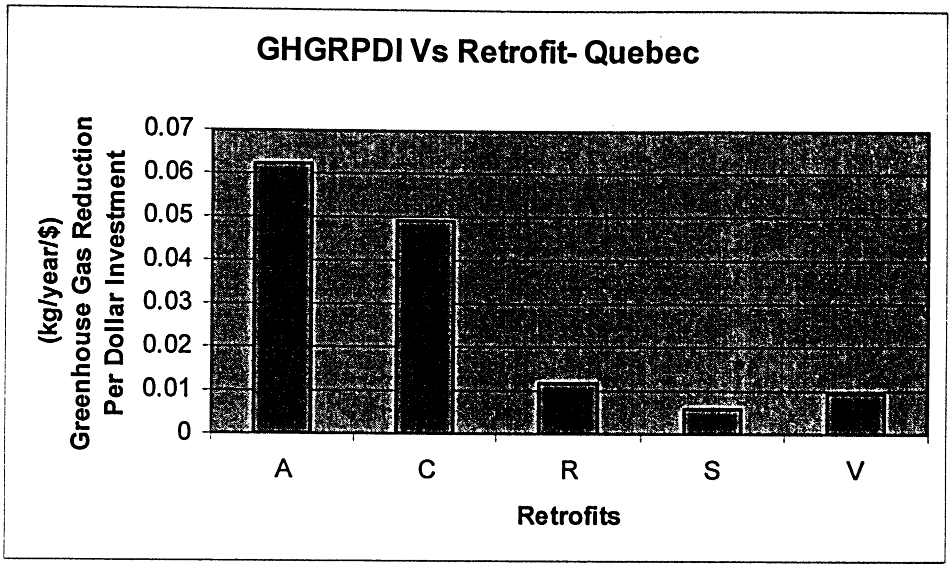

Figure 6.6: Retrofit Ranking for Quebec

Top five recommendations for Quebec in descending order, ranked based on number of households applicable for the retrofit and the Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits, are as follows:

1. Thermostat upgrade (A)
2. Ceiling upgrade to RSI 7.04 (C)
3. High Efficiency Lighting upgrade (R)
4. Basement Insulation upgrade to RSI 5.5 (V)
5. Shower and Aerator upgrade (S)

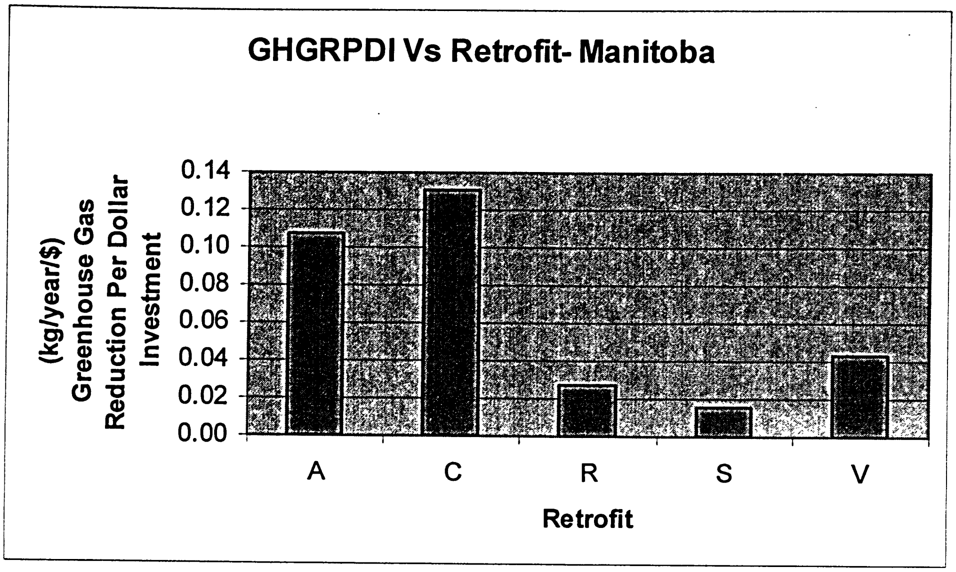

Figure 6.7: Retrofit Ranking for Manitoba

Top five recommendations for Manitoba in descending order, ranked based on number of households applicable for the retrofit and the Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits, are as follows:

1. Ceiling upgrade to RSI 7.04 (C)
2. Thermostat upgrade (A)
3. Basement Insulation upgrade to RSI 5.5 (V)
4. High Efficiency Lighting upgrade (R)
5. Shower and Aerator upgrade (S)

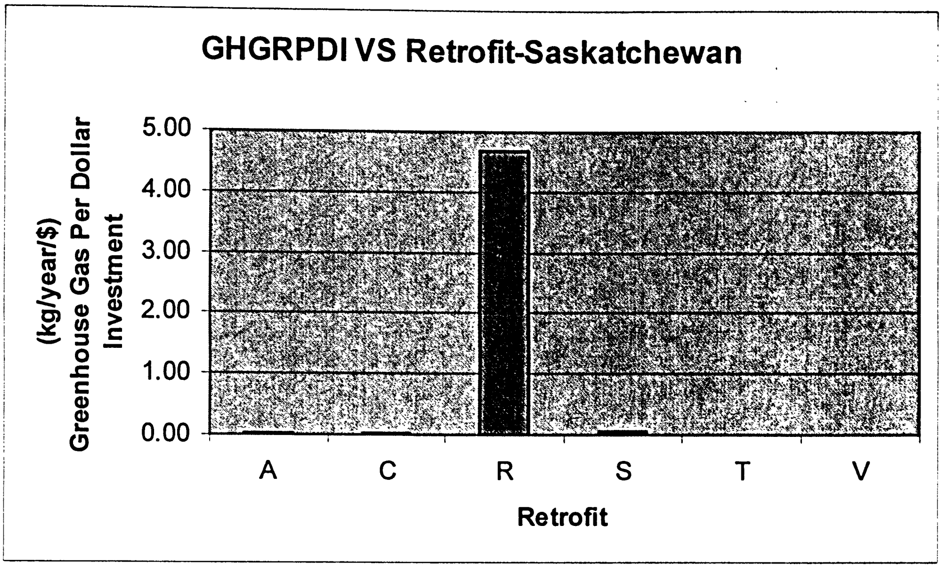

Figure 6.8: Retrofit Ranking for Saskatchewan

Top five recommendations for Saskatchewan in descending order, ranked based on number of households applicable for the retrofit and the Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits, are as follows:

1. High Efficiency Lighting upgrade (R)
2. Shower and Aerator upgrade (S)
3. Thermostat upgrade (A)
4. Ceiling upgrade to RSI 7.04 (C)
5. Basement Insulation upgrade to RSI 5.5 (V)

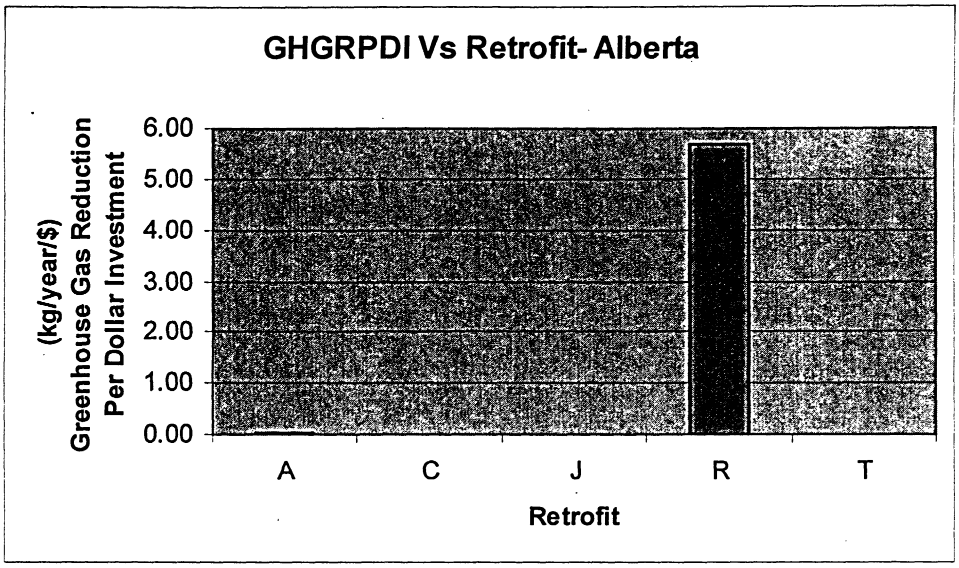

Figure 6.9: Retrofit Ranking for Alberta

Top five recommendations for Alberta in descending order, ranked based on number of households applicable for the retrofit and the Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits, are as follows:

1. High Efficiency Lighting upgrade (R)
2. Thermostat upgrade (A)
3. Ceiling upgrade to RSI 7.04 (C)
4. Window upgrade for single glazed storm windows to high efficiency triple glazed (J)
5. Basement Insulation upgrade to RSI 2.1 (T)

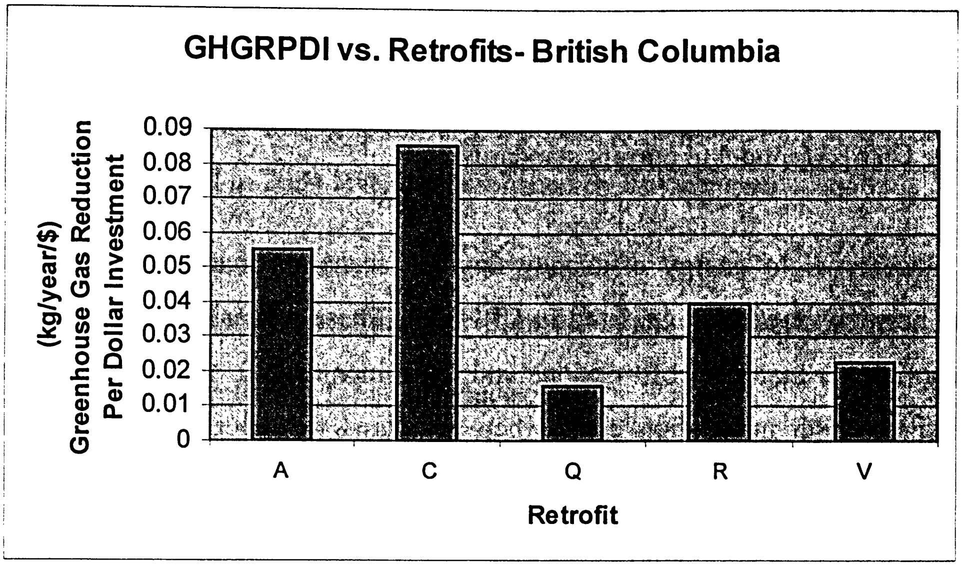

Figure 6.10: Retrofit Ranking for British Columbia

Top five recommendations for British Columbia in descending order, ranked based on number of households applicable for the retrofit and Greenhouse Gas Reduction Per Dollar Investment corresponding to the retrofits, are as follows:

1. Ceiling upgrade to RSI 7.04 (C)
2. Thermostat upgrade (A)
3. High Efficiency Lighting upgrade (R)
4. Basement Insulation upgrade to RSI 5.5 (V)
5. Furnace / Boiler upgrade to Medium Efficiency (Q)

7 CONCLUSIONS

All the objectives as presented in section 1.2 have been achieved as shown below.

Update the CREEM model to current standards:

Twenty eight energy efficiency upgrade scenarios that are practical for the Canadian housing stock were updated in CREEM . These scenarios were classified into two categories: (i) major retrofit options and (ii) minor retrofit options. Major retrofits have relatively high installation costs when compared to minor retrofits, and include retrofits such as the improvement of the house envelope by adding insulation, and the replacement of the existing heating system and appliances by higher efficiency units, while minor retrofits evaluated are lighting fixture, thermostat, showerhead and aerator upgrades. All the retrofits in the CREEM model were updated, to reflect current pricing and efficiency standards. This has enabled the CREEM model to provide practical and useful conclusions relating to the current state of energy usage.

Update the cost function of each energy efficiency upgrade scenario:

The total investment cost (TIC) function was updated for each upgrade scenario as described in Appendix A. These TIC functions include the material and installation costs as well as contractor's overhead and profit, but exclude the provincial taxes. The prices in CREEM were outdated, and were updated using the Consumer Price Index to reflect current pricing levels.

Update greenhouse gas intensity factors for electricity production for each province and Canada for the year 2004:

Since a substantial amount of residential energy consumption is in the form of electricity, it is necessary to determine the change in the amount of GHG emissions resulting from a change in electricity consumption. The amount of GHG emissions from electricity generation was calculated using the "GHG Intensity Factor" (GHGIF) for electricity generation. GHGIF, which is the amount of GHG emissions produced as a result of generating one kWh of electricity was determined for each province. Therefore, the amount of GHG emissions (indirect) produced at the house was calculated by multiplying the electricity consumption at the house by GHGIF indicator. The GHGIF was updated in CREEM to 2004 levels, as published by Environment Canada.

Rerun all the retrofit scenarios with updated information and generate updated GHGRPDI and GHG emissions for all provinces:

All retrofits in the CREEM were rerun with the updated costs. Once the energy consumption for each retrofit was obtained, an updated template was used to determine the revised GHGRPDI, for all 8,767 houses. Weighting factors were used to extrapolate the results across 7,101,782 houses in the Canadian housing sector.

Use the GHGRPDI indicator to assess the feasibility of energy efficiency upgrade scenarios:

The indicator, greenhouse gas reduction per dollar investment (GHGRPDI), was used to identify feasible energy efficiency upgrade scenarios in terms of GHG emissions reduction. (GHGRPDI is calculated by dividing the reduction in annual GHG emissions by the investment cost).

Assessment of reduction of GHG emissions as a result of energy efficiency upgrade scenarios:

The objectives of this study were to assess the impact of various energy efficiency upgrade scenarios on the annual energy consumption of the Canadian housing stock and the associated GHG emissions.

The energy efficiency upgrade scenarios that were considered in the analysis include major retrofits such as the improvement of the house envelope by adding insulation, and the replacement of the existing heating system and appliances by higher efficiency units, as well as minor retrofits such as lighting fixture, thermostat, showerhead and aerator upgrades that increase energy efficiency and, consequently reduce the production of GHG emissions and the energy consumption.

The analysis was conducted using the Canadian Residential End-use Energy Model (CREEM), and the results obtained from CREEM were extrapolated to the entire Canadian housing stock.

The investment cost for each upgrade scenario was used from (Gulers,2000) study, who obtained price information from suppliers, contractors and dealers, as well as from published data. The cost estimates were used to assess the economic feasibility of the upgrade by calculating the indicator "GHG emissions reduction per dollar investment" calculated by dividing the reduction in annual GHG emissions by the investment cost.

Each retrofit upgrade was studied to determine the impact on the GHG emissions relative to the "base case" GHG emissions from SHEU. The emissions from each retrofit were tabulated and the overall GHGPDI was determined. The results were extrapolated across all houses (7,101,782) in ten provinces in Canada using weighting factors.

The GHGRPDI was used to rank the top five retrofits for each province. These results should be used by policy makers for passing legislation to reduce the GHG emissions in Canada. The results are summarized in Table 7.1.

Table 7.1: Summary of retrofit recommendation to policy makers

Province	Retrofit # 1	Retrofit # 2	Retrofit # 3	Retrofit # 4	Retrofit # 5
NFLD	Thermostat upgrade	Ceiling upgrade to RSI 7.04	Basement Insulation upgrade to RSI 5.3	High efficiency lighting	Shower and aerator upgrade
PEI	High efficiency lighting	Thermostat upgrade	Shower and aerator upgrade	Basement Insulation upgrade to RSI 5.5	Ceiling upgrade to RSI 7.04
NS	High efficiency lighting	Thermostat upgrade	Shower and aerator upgrade	Ceiling upgrade to RSI 7.04	Basement Insulation upgrade to RSI 5.5
NB	High efficiency lighting	Thermostat upgrade	Shower and aerator upgrade	Ceiling upgrade to RSI 7.04	Basement Insulation upgrade to RSI 5.5
QUE	Thermostat upgrade	Ceiling upgrade to RSI 7.04	High efficiency lighting	Basement Insulation upgrade to RSI 5.5	Shower and aerator upgrade
ON	High efficiency lighting	Thermostat upgrade	Ceiling upgrade to RSI 7.04	Shower and aerator upgrade	Basement Insulation upgrade to RSI 5.5
MAN	Ceiling upgrade to RSI 7.04	Thermostat upgrade	Basement Insulation upgrade to RSI 5.5	High efficiency lighting	Shower and aerator upgrade
SAS	High efficiency lighting	Shower and aerator upgrade	Thermostat upgrade	Ceiling upgrade to RSI 7.04	Basement Insulation upgrade to RSI 5.5
AB	High efficiency lighting	Shower and aerator upgrade	Ceiling upgrade to RSI 7.04	Window upgrade: single glazed storm window to high efficient triple glazed.	Basement Insulation upgrade to RSI 2.1
BC	Ceiling upgrade to RSI 7.04	Thermostat upgrade	High efficiency lighting	Basement Insulation upgrade to RSI 5.5	Furnace / Boiler upgrade to medium efficiency

8.0 RECOMMENDATIONS

The following are some recommendations that should be implemented to further quantify the energy savings and GHG reduction as a result of energy retrofit upgrades.

1) Determine what upgrades are required to reduce the GHG emissions by 30% (in order to meet the Kyoto protocol) in the Canadian housing sector. The GHG emissions and energy reduction as a result of the retrofits are not cumulative. Therefore in order to quantify a savings of 30% reduction in GHG emissions, the CREEM simulation must be run with multiple retrofits (in a ranked order as determined in this study), and iterated until a 30% reduction in GHG emissions is achieved.

2) If energy savings are required to be below a certain benchmark level, the same procedure can be followed as per point number 1 above.

3) This study has used the GHGRPDI as the sole index to recommend retrofits to policy makers. The ESPDI (Energy Savings Per Dollar Investment) can also be ranked on a province by province basis, and can be used as an additional index to report which retrofits are most beneficial to saving energy. A simple payback analysis can also be ranked on a province by province basis, and can be used as an additional index to report which retrofits are most beneficial from an investment stand point.

4) The CREEM model is primarily based on the 1993 SHEU study. This is the most comprehensive survey that has been carried out by Statistics Canada. All the updates to make the model as current as possible, have been carried out as part of this report. However, when new 2003 SHEU data becomes available, it is worthwhile to update the CREEM model to reflect the current energy usage pattern.

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APPENDICES

APPENDIX A

A. 1. TIC FUNCTION FOR CEILING UPGRADE SCENARIOS

To identify the most commonly used material and methods for ceiling insulation upgrades in Canada and to develop the total investment cost TIC functions for ceiling insulation upgrade scenarios, several building material suppliers and house contractors from various regions of Canada were contacted. As a result, it was determined that blown-in cellulose and fiberglass batt insulation were the most commonly used materials in the Canadian market.

Installed costs for blown-in cellulose and fiberglass batt insulation obtained from various house contractors, building material suppliers and published cost data were compared to identify which of the two insulation materials is more economical. A comparison of the installed costs per RSI is shown in Table A.1. It can be seen from Table A.1 that the installed cost of fiberglass batt insulation is 25 percent higher than that of blown-in cellulose insulation for the same RSI value. Therefore, for ceiling insulation upgrades, blown-in cellulose insulation is used in this study.

Table A.1. Installed cost comparison of blown-in cellulose and fiberglass batt insulation (Burak, 2000)

	Installed Cost ($/m2/RSI)	
	Blown-in Cellulose	Fiberglass Batt
RSI 7.04	1.14	1.43
RSI 8.8	1.09	1.37

To develop the TIC function for the ceiling insulation upgrade scenarios, the installed incremental cost of blown-in cellulose insulation to provide increasing levels of insulation was calculated from the data. The costs of blown-in cellulose insulation for various insulation levels are given in Table A.2.

Table A.2. Cost of blown-in cellulose insulation for various insulation levels (Burak, 2000)

	RSI 1.76	RSI 3.52	RSI 5.28	RSI 7.04	RSI 8.8
$/m2	3.22	4.84	6.45	8.06	9.67

It can be seen from Table A.2 that the incremental cost for blown-in cellulose insulation is $1.6/m^2$ for each 1.76 RSI, or $0.9/m^2$ for each RSI, and the fixed cost is

$1.6/m^2$. Thus, the TIC function for ceiling insulation upgrades using blown-in cellulose insulation is given as follows:

$$TICCIU = 1.6 + (URSI)(0.9)$$

where,

TICCIU = Total investment cost for ceiling insulation upgrade, $\$/m^2$

URSI = Insulation upgrade applied, RSI

A. 2. TIC FUNCTION FOR EXTERNAL WALL UPGRADE SCENARIOS

To develop the wall insulation upgrade scenarios, several building material suppliers and house contractors from various regions of Canada were contacted to find out the most commonly used materials and methods in wall insulation upgrades. As a result, blown-in cellulose was identified to be the most commonly used material in the Canadian market.

The installed costs of blown-in cellulose insulation for 2"x4" and 2"x6" stud walls developed from estimates obtained from contractors, suppliers and published data (Means, 1998) are given in Table A.3.

Table A.3. Installed costs for the Main Wall Upgrade Scenarios (Burak, 2000)

Main Wall	Material	Cost ($/m2)
2"x 4" Stud	Cellulose Blown-in Insulation	17.2
2"x 6" Stud	Cellulose Blown-in Insulation	19.4

Thus, the TIC functions for external wall insulation upgrades using 2"x4" and 2"x6"studs are given as follows:

The TIC function for the external wall insulation upgrade using 2"x4" stud:

$$TICWIU1 = (TMWA)(17.2)$$

where,

TICWIU1 = Total investment cost for external wall insulation upgrade, $

TMWA = Total main wall area, m^2

The TIC function for the external wall insulation upgrade 2"x6" stud:

$$TICWIU2 = (TMWA)(19.4)$$

where,

TICWIU2 = Total investment cost for external wall insulation upgrade, \$

TMWA = Total main wall area, m^2

A.3. TIC FUNCTION FOR THE BASEMENT UPGRADE SCENARIOS

To develop the basement insulation upgrade scenarios, several building material suppliers and house contractors from various regions of Canada were contacted to find out the most commonly used materials and methods in basement insulation upgrades. As a result, fiberglass batt insulation was identified to be the most commonly used materials in the Canadian market.

The installed costs of fiber glass insulation for basement upgrade scenarios developed from estimates obtained from contractors, suppliers and published data (Means, 1998) are given in Table A.4.

Table A.4. Installed costs for the Basement Upgrade Scenarios (Burak, 2000)

Basement	Material	Cost (\$/m2)
Basement Ceiling RSI 5 (R28)	Fiber glass batt insulation and vapor barrier	10.4
Basement Wall RSI 2.1 (R12)	2" x 4" Wood Stud, vapor barrier, fiber glass batt ins.	21.7
Basement Wall RSI 3.5 (R20)	2" x 6" Wood Stud, vapor barrier, fiber glass batt ins.	23.6

Thus, the TIC functions for the basement upgrades are given as follows:

The TIC function for the basement ceiling insulation upgrade:

TICBCIU = (TMFA)(10.4)

where,

TICBCIU = Total investment cost for the basement ceiling insulation upgrade, \$

TMFA = Total main floor area, m^2

The TIC function for the basement wall insulation upgrade using 2”x4” stud:

TICBWIU1 = (TBMWA)(21.7)

where,

TICBWIU1 = Total investment cost for basement wall insulation upgrade, \$

TBMWA = Total basement wall area, m^2

The TIC function for the basement wall insulation upgrade using 2”x6”stud:

TICBWIU2 = (TBMWA)(23.6)

where,

TICBWIU2 = Total investment cost for the basement wall insulation upgrade, $

TBMWA = Total basement wall area, m^2

A.4. TIC FUNCTION FOR WINDOW UPGRADE SCENARIOS

To develop the window upgrade scenarios, several building material suppliers and house contractors, window manufacturers from various regions of Canada were contacted to find out the most commonly used window types. As a result, standard double glazed, energy efficient double glazed, energy efficient triple glazed window types were identified to be the most commonly used windows in the Canadian market.

The installed costs of window for window upgrade scenarios developed from estimates obtained from contractors, suppliers and published data are given in Table A.5.

Table A.5. Installed costs for the Window Upgrade Scenarios (Burak, 2000)

Windows	Material	Cost ($/m2)
Standard double glazed-window		342
Energy efficient double glazed-window	with Low-E coating, Argon filled and insulated spacer	392
Energy efficient triple glazed-window	with Low-E coating, Argon filled and insulated spacer	443

Thus, the TIC functions for the window upgrades are given as follows:

The TIC function for the standard double glazed window upgrade:

TICSDWU = (TWA)(342)

where,

TICSDWU = Total investment cost for standard double glazed window upgrade, $

TWA = Total window area, m^2

The TIC function for the energy efficient double glazed window upgrade scenario:

TICEDWU = (TWA)(392)

where,

TICEDWU = Total investment cost for energy efficient double glazed window upgrade, $

TWA = Total window area, m^2

The TIC function for the energy efficient triple glazed window upgrade:

TICETWU = (TWA)(443)

where,

TICETWU = Total investment cost for energy efficient triple glazed window upgrade, $

TWA = Total window area, m^2

A.5. TIC FUNCTION FOR MECHANICAL SYSTEM UPGRADE SCENARIOS

To develop the mechanical system upgrade scenarios, several building material suppliers, space heating equipment manufacturers, domestic hot water heating manufacturers and house contractors from various regions of Canada were contacted to find out the most commonly used space heating and domestic hot water heating equipment in mechanical system upgrades. Installed costs for mechanical system upgrades are given in Table A.6.

Table A.6. Installed costs for the Mechanical System Upgrade Scenarios (Burak, 2000)

Retrofit Scenarios	Efficiency (%)		Retail Cost ($)		Installation and removal cost ($)
Space Heating Equipment	Medium	High	Medium Eff.	High Eff.	
Oil Furnace (Stand. Eff = 60%)	80	87	1,855	2,164	300~500
Oil Boiler (Stand. Eff = 60%)	80	87	2,577	3,608	300~500
Gas Furnace (Stand. Eff = 60%)	80	92	1,339	1,964	600~1000
Gas Boiler (Stand. Eff = 60%)	80	88	1,339	1,964	600~1000
	COP		Installed Cost ($)		
Electric Air Source Heat Pump (Stand.COP = 1.4)	2.19	2.34~2.6	4,226	4,536	
DHW Equipment					
Electric 30~40 Gallon (Stand. Eff = 83%)	89	93	205	300	175
Electric 50~60 Gallon (Stand. Eff = 83%)	87	93	265	350	175
Oil 30~40 Gallon (Stand. Eff = 50%)	55	85	714*	1160*	
Oil 50~60 Gallon (Stand. Eff = 50%)	55	85	714*	1160*	
Gas 30 Gallon (Stand. Eff = 50%)	55	65	270	300	175
Gas 40 Gallon (Stand. Eff = 50%)	55	65	350	345	175
Gas 50~60 Gallon (Stand. Eff = 50%)	55	65	370	360	175

*Including installation costs

A.6. TIC FUNCTION FOR MINOR UPGRADE SCENARIOS

To develop the minor upgrade scenarios, several building material suppliers and house contractors from various regions of Canada were contacted to find out the most commonly used equipment in minor upgrades. As a result, energy-efficient fluorescent fixture, low-flow showerhead, low-flow aerator and programmable thermostats were identified to be the most commonly used equipment in the Canadian market. Installed costs of upgrade scenarios for minor retrofits are given in Table A.7.

Table A.7. Installed costs for the Minor Upgrades (Burak, 2000)

Retrofit Scenarios	Equipment	Cost ($)	Total Investment Cost Function ($)
Lighting	20 W energy efficient fluorescent fixture, 1000h	2.5 *	TIC=TNF*2.5*LF*TF
Showerhead	Low-flow showerhead	10.3	TIC=TNSH*10.3*LF*TF
Aerator	Low-flow aerator	4.1	TIC=TNAE*4.1*LF*TF
Thermostat			
Central Heating System Thermostat	Programmable Thermostat	96	TIC=TNCHT*96*LF*TF
Room Thermostat	Programmable Thermostat	75	TIC=TNRT*75*LF*TF

* The actual life of fluorescent is 10,000 h. Since incandescents have a life of 1000 h, here the cost of fluorescent is taken as1/10 than of their actual cost to reflect 10 times larger life.

Thus, the TIC functions for the minor upgrades are given as follows:

The TIC function for upgrading of lighting is given as follows:

$$TICL = (TNF)(2.5)$$

where,

TICL = Total investment cost for lighting fixtures upgrade, $

TNF = Total number of incandescent light bulbs in the house

The TIC function for upgrading of showerhead is given as follows:

$$TICSH = (TNSH)(10.3)$$

where,

TICSH = Total investment cost for showerhead upgrade, $

TNSH = Total number of showerheads

The TIC function for the aerator-faucet upgrade scenario is given as follows:

$$TICAF = (TNAE)(4.1)$$

where,

TICAF = Total investment cost for aerator and faucet upgrade, $

TNAE = Total number of aerator(s) and faucet(s) in the house

The TIC function for the room thermostat scenario is given as follows:

$$TICRT = (TNRT)(75)$$

where,

TICRT = Total investment cost for room thermostat upgrade, $

TNRT = Total number of room thermostats

The TIC function for the central heating system thermostat scenario is given as follows:

$$TICCHS = (TNHST)(96)$$

where,

TICCHS = Total investment cost for central heating system thermostat upgrade, $

TNHST = Total number of central heating system thermostat

LF= Location Factor (See Appendix B)

APPENDIX B

Location and tax factors for each province.

	Location Factors (1)	Taxes (2)
Province	Repair and Remodeling	Combined rates
NFLD	0.96	1.150
PEI	0.92	1.177
NS	0.97	1.150
NB	0.93~0.96	1.150
QUE	1.01~1.03	1.150
ON	1.04~1.12	1.150
MAN	0.99	1.140
SAS	0.92	1.140
AB	0.99	1.070
BC	1.08~1.09	1.140

1. Repair and Remodeling Cost Data 19th Annual Edition Commercial/Residential, R.S. Means Company, Inc., Massachusetts, 1998.

2. http://www.hillandco.com/Taxnews/gsthst_commodity_tax.htm

APPENDIX C

Table C.1. Electricity Generation in Newfoundland in 1993 and GHG Emission Factors (Burak, 2000)

Newfoundland 1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	0	0	N/A	N/A	N/A
US bituminous	0	0	N/A	N/A	N/A
Lignite	0	0	N/A	N/A	N/A
Light Fuel Oil	4	2 ML	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	78	24 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	1,659	409 ML	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	0	0	N/A	N/A	N/A
Hydro	38,675	N/A	N/A	N/A	N/A
Nuclear	0	N/A	N/A	N/A	N/A
Total	40,417	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.2. Electricity Generation in Prince Edward Island in 1993 and GHG Emission Factors (Burak, 2000)

Prince Edward Island 1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	0	0	N/A	N/A	N/A
US bituminous	0	0	N/A	N/A	N/A
Lignite	0	0	N/A	N/A	N/A
Light Fuel Oil	0	0	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	7	3 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	58	22 ML	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	0	0	N/A	N/A	N/A
Hydro	0	N/A	N/A	N/A	N/A
Nuclear	0	N/A	N/A	N/A	N/A
Total	65	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.3. Electricity Generation in Nova Scotia in 1993 and GHG Emission Factors (Burak, 2000)

Nova Scotia 1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	6,643	2,370 kt	2,294 t/kt	0.015 t/kt	0.05 t/kt
US bituminous	0	0	N/A	N/A	N/A
Lignite	0	0	N/A	N/A	N/A
Light Fuel Oil	13	4 ML	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	12	4 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	2,232	536 ML	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	0	0	N/A	N/A	N/A
Hydro	849	N/A	N/A	N/A	N/A
Nuclear	0	N/A	N/A	N/A	N/A
Total	9,750	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.4. Electricity Generation in New Brunswick in 1993 and GHG Emission Factors (Burak, 2000)

New Brunswick1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	996	359 kt	2,233 t/kt	0.015 t/kt	0.05 t/kt
US bituminous	0	0	2,522 t/kt	0.015 t/kt	0.05 t/kt
Sub bituminous	366	143 kt	1,739 t/kt	0.015 t/kt	0.05 t/kt
Light Fuel Oil	87	26 ML	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	4	1 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	5,156	1,207 ML	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	0	0	N/A	N/A	N/A
Hydro	2,989	N/A	N/A	N/A	N/A
Nuclear	5,323	N/A	N/A	N/A	N/A
Total	14,922	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.5. Electricity Generation in Quebec in 1993 and GHG Emission Factors (Burak, 2000)

Quebec1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	0	0	2,233 t/kt	0.015 t/kt	0.05 t/kt
US bituminous	0	0	2,522 t/kt	0.015 t/kt	0.05 t/kt
Sub bituminous	0	0	1,739 t/kt	0.015 t/kt	0.05 t/kt
Light Fuel Oil	66	19 ML	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	126	33 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	150	40 ML	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	0	0	N/A	N/A	N/A
Hydro	130,142	N/A	N/A	N/A	N/A
Nuclear	4,807	N/A	N/A	N/A	N/A
Total	135,291	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.6. Electricity Generation in Ontario in 1993 and GHG Emission Factors (Burak, 2000)

Ontario 1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	5,637	2,010 kt	2,522 t/kt	0.015 t/kt	0.05 t/kt
US bituminous	11,929	4,129 kt	2,501 t/kt	0.015 t/kt	0.05 t/kt
Lignite	1,398	902 kt	1,491 t/kt	0.015 t/kt	0.05 t/kt
Light Fuel Oil	183	52 ML	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	0	0 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	60	31 ML	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	3,922	1,131 Mm^3	1,880 t/Mm^3	0.0048 t/Mm^3	0.02 t/Mm^3
Hydro	39,275	N/A	N/A	N/A	N/A
Nuclear	78,489	N/A	N/A	N/A	N/A
Total	140,894	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.7. Electricity Generation in Manitoba in 1993 and GHG Emission Factors (Burak, 2000)

Manitoba1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	0	0	N/A	N/A	N/A
US bituminous	0	0	2,501 t/kt	0.015 t/kt	0.05 t/kt
Lignite	226	181 kt	1,521 t/kt	0.015 t/kt	0.05 t/kt
Light Fuel Oil	2	1 ML	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	27	9 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	0	0	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	1	0.451 Mm^3	1,880 t/Mm^3	0.0048 t/Mm^3	0.02 t/Mm^3
Hydro	26,891	N/A	N/A	N/A	N/A
Nuclear	0	N/A	N/A	N/A	N/A
Total	27,147	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.8. Electricity Generation in Saskatchewan in 1993 and GHG Emission Factors (Burak, 2000)

Saskatchewan1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	0	0	N/A	N/A	N/A
US bituminous	0	0	N/A	N/A	N/A
Lignite	11,227	8,739 kt	1,342 t/kt	0.015 t/kt	0.05 t/kt
Light Fuel Oil	7	2 ML	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	0	0	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	0	0	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	421	155 Mm^3	1,880 t/Mm^3	0.0048 t/Mm^3	0.02 t/Mm^3
Hydro	4,051	N/A	N/A	N/A	N/A
Nuclear	0	N/A	N/A	N/A	N/A
Total	15,285	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.9. Electricity Generation in Alberta in 1993 and GHG Emission Factors (Burak, 2000)

Alberta1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	654	532 kt	1739 t/kt	0.015 t/kt	0.05 t/kt
US bituminous	0	0	N/A	N/A	N/A
Sub bituminous	41,320	23,689 kt	1701 t/kt	0.015 t/kt	0.05 t/kt
Light Fuel Oil	0	0	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	20	7 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	0	0	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	3,820	1,177 Mm^3	1,880 t/Mm^3	0.0048 t/Mm^3	0.02 t/Mm^3
Hydro	1,808	N/A	N/A	N/A	N/A
Nuclear	0	N/A	N/A	N/A	N/A
Total	47,622	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.10. Electricity Generation in British Columbia in 1993 and GHG Emission Factors (Burak, 2000)

British Columbia 1993 Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	Emission Factor CO2 (2)	CH4 (2)	N2O (2)
Canadian bituminous	0	0	N/A	N/A	N/A
US bituminous	0	0	N/A	N/A	N/A
Sub bituminous	0	0	N/A	N/A	N/A
Light Fuel Oil	0	0	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	60	18 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	0	0	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	3,553	880 Mm^3	1,880 t/Mm^3	0.0048 t/Mm^3	0.02 t/Mm^3
Hydro	42,238	N/A	N/A	N/A	N/A
Nuclear	0	N/A	N/A	N/A	N/A
Total	45,851	N/A	N/A	N/A	N/A

(1) Source: Electric Utility Thermal Plants, Fuel and Combustion in 1993; Electric Power Statistics, Statistics Canada, Cat-No: 57-202.
(2) Source: Environmental Protection Series, Canada's Greenhouse Gas Emissions Estimates for 1990, Report EPS 5/AP/4 Environment Canada, December 1992.

Table C.11. GHG Emissions in Newfoundland from Electricity Production, 1993 (BURAK, 2000)

Newfoundland 1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	N/A	N/A	N/A	N/A
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	N/A	N/A	N/A	N/A
Light Fuel Oil	6	0	0	6
Diesel	66	0	3	69
Heavy	1,263	0	2	1,265
Natural Gas	N/A	N/A	N/A	N/A
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	1,334	0	5	1,339

Table C.12. GHG Emissions in Prince Edward Island from Electricity Production, 1993 (Burak, 2000)

Prince Edward Island 1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	N/A	N/A	N/A	N/A
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	N/A	N/A	N/A	N/A
Light Fuel Oil	N/A	N/A	N/A	N/A
Diesel	8	0	0	9
Heavy	68	0	0	68
Natural Gas	N/A	N/A	N/A	N/A
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	76	0	0	77

Table C.13. GHG Emissions in Nova Scotia from Electricity Production, 1993 (Burak, 2000)

Nova Scotia 1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	5,437	1	37	5,474
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	N/A	N/A	N/A	N/A
Light Fuel Oil	11	0	0	11
Diesel	11	0	0	11
Heavy	1,655	0	2	1,658
Natural Gas	N/A	N/A	N/A	N/A
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	7,114	1	39	7,155

Table C.14. GHG Emissions in New Brunswick from Electricity Production, 1993 (Burak, 2000)

New Brunswick1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	802	0	6	807
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	249	0	2	251
Light Fuel Oil	74	0	0	74
Diesel	3	0	0	3
Heavy	3,727	1	5	3,733
Natural Gas	N/A	N/A	N/A	N/A
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	4,854	1	13	4,868

Table C.15. GHG Emissions in Quebec from Electricity Production, 1993 (Burak, 2000)

Quebec1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	N/A	N/A	N/A	N/A
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	N/A	N/A	N/A	N/A
Light Fuel Oil	54	0	0	54
Diesel	90	0	4	94
Heavy	124	0	0	124
Natural Gas	N/A	N/A	N/A	N/A
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	267	0	4	272

Table C.16. GHG Emissions in Ontario from Electricity Production, 1993 (Burak, 2000)

Ontario 1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	5,069	1	31	5,101
US bituminous	10,327	1	64	10,392
Sub bituminous	1,345	0	14	1,359
Light Fuel Oil	147	0	0	147
Diesel	N/A	N/A	N/A	N/A
Heavy	96	0	0	96
Natural Gas	2,125	0	7	2,132
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	16,984	2	109	19,227

Table C.17. GHG Emissions in Manitoba from Electricity Production, 1993 (Burak, 2000)

Manitoba1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	N/A	N/A	N/A	N/A
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	275	0	3	278
Light Fuel Oil	3	0	0	3
Diesel	25	0	1	26
Heavy	N/A	N/A	N/A	N/A
Natural Gas	1	0	0	1
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	304	0	4	308

Table C.18. GHG Emissions in Saskatchewan from Electricity Production, 1993 (Burak, 2000)

Saskatchewan1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	N/A	N/A	N/A	N/A
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	11,728	3	135	11,866
Light Fuel Oil	6	0	0	6
Diesel	N/A	N/A	N/A	N/A
Heavy	N/A	N/A	N/A	N/A
Natural Gas	292	0	1	293
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	12,025	3	136	12,164

Table C.19. GHG Emissions in Alberta from Electricity Production, 1993 (Burak, 2000)

Alberta1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	925	0	8	934
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	40,295	7	367	40,670
Light Fuel Oil	N/A	N/A	N/A	N/A
Diesel	19	0	1	20
Heavy	N/A	N/A	N/A	N/A
Natural Gas	2,210	0	7	2,217
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	43,449	8	384	43,841

Table C.20. GHG Emissions in British Columbia from Electricity Production, 1993 (Burak, 2000)

British Columbia 1993	GHG Emissions (kt)			Total GHG emission (kt)
Energy Source	CO2	CO2 Eqv.CH4	CO2 Eqv.N2O	(in tonnes of equivalent CO2)
Canadian bituminous	N/A	N/A	N/A	N/A
US bituminous	N/A	N/A	N/A	N/A
Sub bituminous	N/A	N/A	N/A	N/A
Light Fuel Oil	N/A	N/A	N/A	N/A
Diesel	49	0	2	52
Heavy	N/A	N/A	N/A	N/A
Natural Gas	1,653	0	5	1,659
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	1,703	0	8	1,711

APPENDIX D

USE OF WEIGHTING FACTORS

As it was stated in the Introduction section, CREEM is based on the 1993 SHEU (Statistics Canada, 1993) data collected from 8767 houses across Canada. To create CREEM, an input data file for each house in SHEU was developed using the data in SHEU and additional data from other sources. The development of CREEM and its validation are described in detail elsewhere (Farahbakhsh et al., 1998, Farahbakhsh et al., 1997a; Farahbaksh 1997).

SHEU database is representative of the Canadian housing stock, and each house in SHEU is representative of a number of houses in the housing stock. Thus, each house in SHEU has associated with it a "weighting factor"[3] that identifies the number of houses in the Canadian housing stock that a given house in SHEU is representative of.

Since CREEM is based on the SHEU database, and each house in CREEM corresponds to a house in SHEU, the weighting factors given in SHEU are used here to extrapolate the results of CREEM to the Canadian housing stock. The weighting factors are used to determine, for the entire Canadian housing stock, the annual energy savings as well as the total cost of undertaking the upgrade as shown below.

$$BCEP_P = \sum_{i=1}^{N} \left(BCEP_i \times WF_i\right)$$

$$BCEP_{CHS} = \sum_{p=1}^{10} BCEP_p$$

$$EPWU_p = \sum_{i=1}^{N} \left(EPWU_i \times WF_i\right)$$

$$EPWU_{CHS} = \sum_{p=1}^{10} EPWU_p$$

$$ERAVWU_p = BCEP_p - EPWU_p$$

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[3] By definition, weighting, is a procedure for applying a factor or weight to the results of a sample to adjust a disproportionate sample, to correct for a misestimate of the size of a cluster or strata, to adjust for different response rates or to make population estimates (Patton et al., 1993).

$$ERAVWU_{CHS} = BCEP_{CHS} - EPWU_{CHS}$$

$$TCU_p = \sum_{i=1}^{N} (TCU_i \times WF_i)$$

$$GHGRPDI_p = \frac{ERAVWU_p}{TCU_p}$$

$$TCU_{CHS} = \sum_{p=1}^{10} TCU_p$$

$$GHGRPDI_{CHS} = \frac{ERAVWU_{CHS}}{TCU_{CHS}}$$

where,

10 = Number of provinces

BCEP = Base case emissions production

EPWU = Emissions production with upgrade

ERAVWU = Emissions reduction with upgrade

GHGRPDI = GHG emissions reduction per dollar investment

N = Number of houses in CREEM that are from province p

TCU = Total cost of upgrade

WF = Weighting factor from SHEU database

Subscripts:

CHS = Canadian housing stock

i = House i in CREEM

p = Province

Some questions in the SHEU database have "Don't Know" and "Not Stated" as responses. For example, Question 42, which is about the age of refrigerators has the following responses:

Q. 42: Age of main refrigerator?

	Unweighted	Weighted
Not Applicable	33	45992
1 year or less	732	871701
2 years	573	738822
3 years	556	547825
4 years	499	441187
5 years	653	648864
6 – 7 years	850	839907
8 – 10 years	1726	1810816
11 – 15 years	2001	1754508
16 – 20 years	1326	975005
21 years or more	835	707423
Don't Know	973	780138
Not Stated	225	197030

To extrapolate the results of CREEM to the entire Canadian housing stock for parameters that are associated with such questions, the weighting factors were modified to reflect only those houses that have informative responses by excluding the houses with "Don't Know" and "Not Stated" responses. The modified weighting factors were calculated as shown below, and they were used in place of the standard weighting factors for parameters associated with "Don't Know" and "Not Stated" responses:

$MFW_i = WF_i (TNHS/(TNHS-NHN))$

where,

MFW = Modified weighting factor

TNHS = Total number of houses represented by all responses

NHN = Number of houses that have “Don’t Know” and “Not Stated” responses

APPENDIX E

Table E.1. End-use Unit Energy Consumption (UEC) comparisons for refrigerators - kWh/day (Burak, 2000)

	Type 1		Type 2		Type 3		Type 4		Type 5		Type 6	
AV	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**
6.4	1.05	1.96	1.25	3.50	1.58	5.46	1.29	2.56	1.38	2.30	1.73	3.13
6.5-12.4	1.27	2.26	1.51	3.60	1.77	5.10	1.56	2.90	1.66	2.93	1.99	3.50
12.5-16.4	1.42	2.70	1.69	3.80	1.90	4.56	1.74	3.43	1.86	3.83	2.17	4.03
16.5-20	1.55	3.03	1.84	3.93	2.01	4.16	1.90	3.83	2.03	4.56	2.33	4.43

AV: Adjusted Volume = refrigerator volume (in cubic feet) + 1.63*freezer volume (in cubic feet)
Type 1: Refrigerators and Refrigerator-Freezers with manual defrost
Type 2: Refrigerator-Freezers - automatic defrost with: Top mounted freezer w/o through the ice service
Type 3: Refrigerator-Freezers - automatic defrost with: Side mounted freezer w/o through the ice service
Type 4: Refrigerator-Freezers - automatic defrost with: Bottom mounted freezer w/o through the ice service
Type 5: Refrigerator-Freezers - automatic defrost with: Top mounted freezer w/ through the ice service
Type 6: Refrigerator-Freezers - automatic defrost with: Side mounted freezer w/ through the ice service
UEC (1): UEC to comply with the minimum aplliance efficiency standards for 1993 -2001
UEC (2): Average UEC of the 1993 Canadian housing calculated by CREEDAC
* Wenzel, T.P., Koomey, J.G., Rosenquist, G.J., Sanchez, M. (1997) Energy Data Sourcebook for the US Residential Sector. Lawrence Berkeley National Laboratory, Report No. LBL-40297.
** Fung, A., Farahbakhsh, H., Ugursal, I., (1997) Unit Energy Consumption (UEC) Of Major Household Appliances in Canada Final Report

Table E.2. End-use Unit Energy Consumption (UEC) comparisons for freezers- kWh/day (Burak, 2000)

End-use Unit Energy Consumption (UEC) comparisons for freezers -kWh/day

	UPM		UAD		CHT	
AV	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**
7	0.92	1.50	1.35	1.73	0.64	1.93
11	1.11	1.66	1.63	2.06	0.85	2.03
16	1.22	1.93	1.80	2.46	0.97	2.13
21	1.36	2.13	2.00	2.80	1.12	2.23
23	1.38	2.33	2.26	3.16	NA	2.33

AV: Adjusted Avolume = 1.73*freezer volume (in cubic feet)
UPM: Uprigt freezers with manual defrost
UAD: Upright freezers with automastic defrost
CHT: Chest freezers and all other freezers
UEC (1): UEC to comply with the minimum aplliance efficiency standards for 1993 -2001
UEC (2): Average UEC of the 1993 Canadian housing calculated by CREEDAC
* Wenzel, T.P., Koomey, J.G., Rosenquist, G.J., Sanchez, M. (1997) Energy Data Sourcebook for the US Residential Sector. Lawrence Berkeley National Laboratory, Report No. LBL-40297.
** Fung, A., Farahbakhsh, H., Ugursal, I., (1997) Unit Energy Consumption (UEC) Of Major Household Appliances in Canada Final Report

Table E.3. End-use Unit Energy Consumption (UEC) comparisons for clothes washer-kWh/day (Burak, 2000)

	Mini		Standard	
Type	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**
Type1	1.48	1.76	2.01	2.96
Type2	1.48	N/A	2.01	2.96
Type3	1.48	2.56	2.01	2.73
Type4	1.48	N/A	2.01	2.73
Type5	1.48	3.40	2.01	3.53
Type6	1.48	2.66	2.01	3.50

Type Classification: Based on availability of wash and rinse temperature settings as per Energuide classification: (first entry: wash; second entry: rinse)

Type 1: warm/cold
Type 2: hot/cold, warm/cold
Type 3: hot/cold,warm/cold, cold/cold
Type 4: hot/cold, warm/cold, warm/warm, cold/cold
Type 5: hot/warm, hot/cold, warm/warm, warm/cold, cold/cold
Type 6: hot/hot, hot/warm, hot/cold, warm/warm, warm/cold, cold/cold
UEC (1): UEC to comply with the minimum aplliance efficiency standards for 1993 -2001
UEC (2): Average UEC of the 1993 Canadian housing calculated by CREEDAC
* Wenzel, T.P., Koomey, J.G., Rosenquist, G.J., Sanchez, M. (1997) Energy Data Sourcebook for the US Residential Sector. Lawrence Berkeley National Laboratory, Report No. LBL-40297.
** Fung, A., Farahbakhsh, H., Ugursal, I., (1997) Unit Energy Consumption (UEC) Of Major Household Appliances in Canada Final Report

Table E.4. End-use Unit Energy Consumption (UEC) comparisons for clothes dryer-kWh/day (Burak, 2000)

	Mini (Electric)		Standard (Electric)		Standard (Gas)	
Type	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**
Type1	1.09	1.63	2.65	3.13	2.95	N/A
Type2	1.09	1.43	2.65	N/A	2.95	N/A
Type3	1.09	1.66	2.65	3.03	2.95	N/A
Type4	1.09	2.20	2.65	2.83	2.95	N/A
Type5	1.09	3.13	2.65	3.23	2.95	N/A
Type6	1.09	1.16	2.65	3.00	2.95	N/A
Type7	1.09	1.86	2.65	2.80	2.95	N/A
Type8	1.09	N/A	2.65	N/A	2.95	N/A

Type Calssification: Based on drying options:

Type 1: Manual timer, Auto shut-off, Perma-press
Type 2: Manual timer, Auto shut-off
Type 3: Manual timer, Perma-press
Type 4: Manual timer
Type 5: Auto shut-off, perma press
Type 6: Auto shut-off
Type 7: Perma-press
Type 8: No options
UEC (1): UEC to comply with the minimum aplliance efficiency standards for 1993 -2001
UEC (2): Average UEC of the 1993 Canadian housing calculated by CREEDAC
* Wenzel, T.P., Koomey, J.G., Rosenquist, G.J., Sanchez, M. (1997) Energy Data Sourcebook for the US Residential Sector. Lawrence Berkeley National Laboratory, Report No. LBL-40297.
** Fung, A., Farahbakhsh, H., Ugursal, I., (1997) Unit Energy Consumption (UEC) Of Major Household Appliances in Canada Final Report

Table E.5. End-use Unit Energy Consumption (UEC) comparisons for dishwasher-kWh/day (Burak, 2000)

	Mini			Standard		
	Drying Option			Drying Option		
Types		YES	NO		YES	NO
	UEC (1)*	UEC (2)**	UEC (2)**	UEC (1)*	UEC (2)**	UEC (2)**
Type1	1.42	3.2	3.3	1.91	3.20	3.3
Type2	1.42	3.06	3.2	1.91	3.30	3.43

Type Classification:
Type 1: Built-in
Type 2: Portable
UEC (1): UEC to comply with the minimum aplliance efficiency standards for 1993 -2001
UEC (2): Average UEC of the 1993 Canadian housing calculated by CREEDAC
* Wenzel, T.P., Koomey, J.G., Rosenquist, G.J., Sanchez, M. (1997) Energy Data Sourcebook for the US Residential Sector. Lawrence Berkeley National Laboratory, Report No. LBL-40297.
** Fung, A., Farahbakhsh, H., Ugursal, I., (1997) Unit Energy Consumption (UEC) Of Major Household Appliances in Canada Final Report

Table E.6. End-use Unit Energy Consumption (UEC) comparisons for cooking appliances- kWh/day(Burak, 2000)

	Electric		Gas	
Type	UEC (1)*	UEC (2)**	UEC (1)*	UEC (2)**
Type1	1.46	2.33	4.49	2.33
Type 2	N/A	N/A	N/A	N/A
Type 3	N/A	N/A	N/A	N/A
Type 4	N/A	N/A	N/A	N/A
Type 5	0.36	N/A	N/A	N/A

Type Classification:
Type 1: Regular (self-clean) stove/oven (range)
Type 2: Regular (non self-clean) stove/oven (range)
Type 3: Built-in oven with separate cook top (self-clean)
Type 4: Built-in oven with separate cook top (non-self-clean)
Type 5: Microwave
UEC (1): UEC to comply with the minimum aplliance efficiency standards for 1993 -2001
UEC (2): Average UEC of the 1993 Canadian housing calculated by CREEDAC
* Wenzel, T.P., Koomey, J.G., Rosenquist, G.J., Sanchez, M. (1997) Energy Data Sourcebook for the US Residential Sector. Lawrence Berkeley National Laboratory, Report No. LBL-40297.
** Fung, A., Farahbakhsh, H., Ugursal, I., (1997) Unit Energy Consumption (UEC) Of Major Household Appliances in Canada Final Report