Modeling of National and Regional Residential Energy Consumption and Associated Greenhouse Gas Emissions

by

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I would like to dedicate this work to my two adopted brothers who are not only my mentors, but also my dear friends. Without them none of this work would have been realized!!!

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

A/C	Air Conditioning
AB	Alberta
ADCUS	Appliance and DHW Characteristics and Usage Survey
ALC	Appliance, Lighting, and Space Cooling
ANN	Artificial Neural Network
BC	British Columbia
CANN	Cascaded Artificial Neural Network
CDA	Conditional Demand Analysis
CDD	Cooling Degree Days
CFL	Compact Fluorescent Light
CREEEM	Canadian Residential End-use Energy and Emission Model
DHW	Domestic Hot Water
EETI	Energy Efficiency Technology Impact
EGH	EnerGuide for Houses
ELCAP	End-use Load and Consumer Assessment Project
EM	Engineering Method
GHG	Greenhouse Gas
GHGIF	Greenhouse Gas Intensity Factor
GLS	Generalized Least Square
GWP	Global Warming Potential
HDD	Heating Degree Days
HEA	Household Energy Audit
HEUS	Household Energy Use Survey
HFE	Household Facility Equipment Survey
HRV	Heat Recovery Ventilator
M&M	Make and Model
MAN	Manitoba
MLP	Multi-layer Perceptron
NAC	Normalized Annual Consumption
NB	New Brunswick
NFL, NFLD	Newfoundland
NN	Neural Network
NRCan	Natural Resources of Canada
NS	Nova Scotia

OLS	Ordinary Least Square
ON, ONT	Ontario
PEI	Prince Edward Island
PQ, QUE	Quebec
PRISM	Princeton Scorekeeping Method
SAS	Saskatchewan
SH	Space Heating
SHB	Survey of Houses Built
SHEU	Survey of Household Energy Use
SMASP	Spot Measurement of Active and Standby Power
UEC	Unit Energy Consumption
VAV	Variable Air Volume

Symbols

Adult	number of adults in the household
AED	annual energy consumption of dwelling
AERS	annual energy consumption by the residential sector
AFC	annual fuel consumption
Age	age
Basement	basement size (m^2 or ft^2)
C	coefficient
Capacity	A/C cooling capacity (Btu/hr)
CD	correction factor for heating degree days
CO2EEFF	CO_2 equivalent GHG emission due to fossil fuel consumption from the house, tonnes/year
CO2EF	CO_2 emission factor
COP	coefficient of performance
CV	coefficient of variation
E	energy
ECH4	CH_4 emission, tonnes/year
ECO2	CO_2 emission, tonnes/year
EER	energy efficiency rating
ELCON	electricity consumption of the house, kWh/year
EN2O	N_2O emission, tonnes/year
GT	ground temperature
HHS	household size
Hour	total reported number of hours of usage for the fixture per year

i	type of fuel
Income	household income ($/year)
l	daily hot water usage from appliance (l/day)
Load	usage used in EnerGuide (loads/year)
Location	area where the dwelling is located (rural/urban)
$\bar{t}$	mean of the target (actual) value
N, n	sample size
NDRS	number of dwellings in the residential sector
P	current fuel price ($/kWh)
P_{-1}	lagged fuel price ($/kWh)
Province	province where the dwelling is located
q	heat quantity (J)
Q	quantity
R^2	multiple correlation coefficient of determination
S	standard deviation
Size	size (m^3 or ft^3)
t	target (actual) value
T	temperature (°C)
TCO2EE	total CO_2 equivalent GHG emission from the house, tonnes/year
Type	type of appliance or lighting fixture
UEC	unit energy consumption (kWh/household/yr) (m^3/household/yr) (l/household/yr) (GJ/household/yr)
Usage	reported usage (loads/year or hours/year)
W	weighting factor
wattage	total wattage of lighting fixture
x	variables
y	estimated value

Greek Letters

η	efficiency (%)
θ	time period of interest in year, season, or month
σ	standard error

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ABSTRACT

The objectives of this work are to develop a comprehensive and representative modeling framework for estimating energy consumption and associated greenhouse gas emissions in the residential sector suitable for a broad range of comparative analyses, and using this framework to develop an end-use energy consumption and greenhouse gas emissions model for the Canadian housing stock. These said objectives are successfully achieved and described in detail in this work.

A modeling framework was developed for modeling the residential energy consumption and associated greenhouse gas emissions, for cold (heating dominated) climates, at both regional and national levels. Detailed data requirements were analyzed, and existing data sources were identified and reviewed for suitability in energy modeling. Major inconsistencies and deficiencies in the existing data sources were also identified. New and emerging data sources were identified and their potential use on model development was reviewed. As a result, a comprehensive data collection campaign, including the integration of various existing and emerging data collection campaigns and sources, was proposed and the required total data collection costs were estimated for future data collections and model refinements.

A comprehensive and representative bottom-up engineering based model for estimating end-use energy consumption and associated greenhouse gas emissions for the Canadian low-rise single family residential stock was developed, and its detailed developmental procedure is fully documented in this work. This model is called the Canadian Residential End-use Energy Consumption and Emission Model (CREEEM). The model makes extensive use of current Canadian data sources to establish housing characteristics as well as to estimate the amount of energy consumption and associated GHG emissions at the regional, provincial, and national levels.

CREEEM was used to determine the energy consumption and GHG emissions from the Canadian housing stock by type of dwelling, by space heating fuel, by vintage and by province. The estimated total end-use energy consumption and GHG emissions for the 1993 low-rise single-family housing stock were 1000 PJ and 48 Mt, respectively. The average household end-use energy consumption and associated GHG emissions were estimated to be 141 GJ/year and 6.8 t/year, respectively. Electricity usage accounted for nearly half of the total energy consumption and GHG emissions in the residential sector.

The predictions of CREEEM were validated with 3248 annual energy billing records from 2811 houses. It was found that CREEEM's predictions could be used with confidence. The R^2 ranged from a low of 0.81 for electricity consumption on appliance, lighting and cooling (ALC) end-uses to a high of 0.90 for natural gas consumption on combined space and domestic hot water (DHW) heating end-uses.

In addition, the prediction performance of the engineering method based CREEEM was compared with two data-driven residential energy consumption models, Neural Network (NN) and Conditional Demand Analysis (CDA), recently developed by Aydinalp (2002) using the same available data sources used to develop CREEEM. This comparison showed that all three models (CREEEM, CDA and NN), on average, have comparable overall prediction performance, and they are all capable of estimating the overall residential energy consumption, with the engineering based CREEEM being the most flexible of the three in conducting a broad range of impact analyses.

In conclusion, CREEEM, having the capability and flexibility of conducting various comparative studies and assessing policy decisions, provides the most comprehensive and representative bottom-up engineering based model for estimating end-use energy consumption and associated greenhouse gas emissions in the Canadian residential sector.

Chapter One

1 Introduction

1.1 Overview: Energy Consumption and Greenhouse Gas Emissions

From the time when humans were able to control fire until the recent oil crises of 1973 and 1979, environmental and availability issues associated with the use of fossil fuels were not of much concern. There were a few exceptions[1], but generally energy was available readily and relatively cheaply. The 1973 and 1979 oil crises brought home the notion that the availability of oil and other forms of fossil fuels is not unlimited, and dependency on imported oil makes the world economy vulnerable. This understanding initiated serious efforts towards achieving "energy conservation and efficient energy use", with governments intensively promoting energy conservation to reduce inefficiency in all sectors of the economy. Then in the 1980's, the primary focus shifted to air pollution caused by the combustion of fossil fuels. In recent years, greenhouse gas (GHG) emissions associated with energy use and their potential effects on the global climate change have been a worldwide concern.

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[1] Such as the1307 proclamation of Edward II forbidding lime burners to burn coal in Southwark, England due to the air pollution that they created, and the 16th century firewood crises in England when extensive use of fire wood for years almost completely depleted the once lush forests in England.

In 1999, the end-use (secondary) energy consumption in Canada was about 7875 PJ, making Canada one of the highest per capita energy consumers in the world (NRCan, 2001). The greenhouse gases (GHG), or the carbon dioxide equivalent emissions associated with this energy consumption was about 452 Mt. About 70 Mt of this total, representing 15.5% of the total GHG emissions, were generated in the residential sector as a result of consuming 17%, or 1335 PJ, of the total secondary energy in Canada. The high share of the residential energy consumption in Canada is mostly owing to this country's northerly location and the prevalence of single family housing.

Residential energy consumption in Canada is primarily for space heating (59%), followed by domestic hot water (DHW) heating (22%), appliances and lights (18%), and finally, cooling, which is still negligibly small (0.8%) (NRCan, 2001). A graphical representation of share of major residential energy end-uses from 1990 to 1999 is depicted in Figure 1.1.

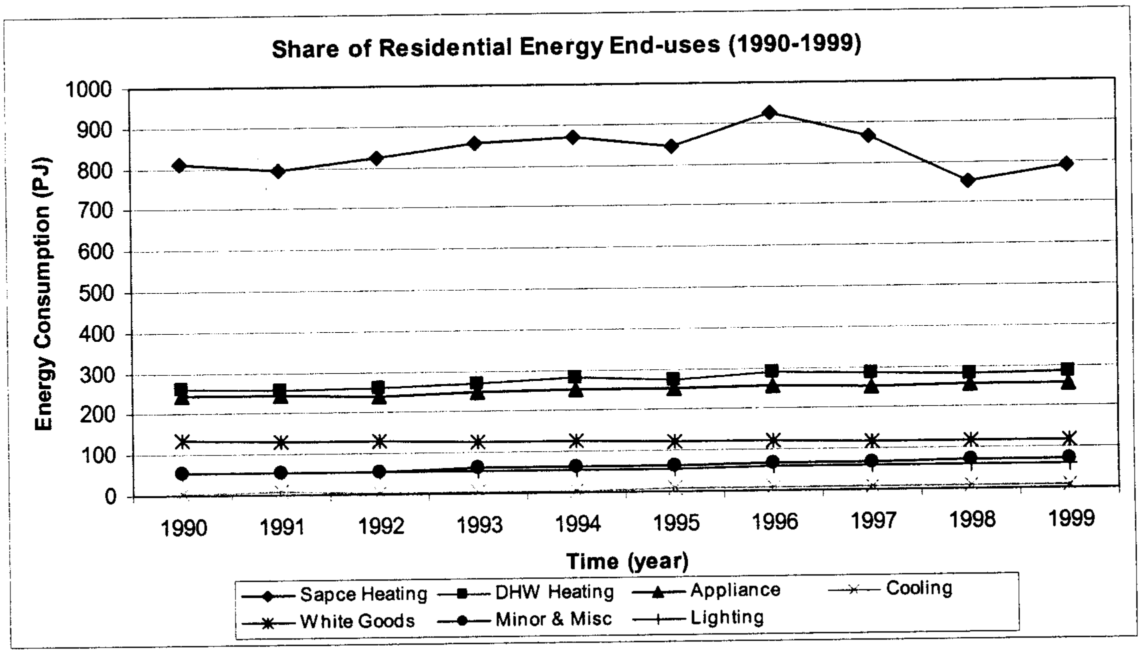

Figure 1.1: Share of residential energy end-uses trend (1990-1999) (NRCan, 2001)

End-use energy consumption and its associated GHG emissions in the residential sector could be reduced by improving building envelope characteristics (better insulation, better windows and doors, tighter buildings), and by using higher efficiency equipment (lighting, appliances, domestic hot water heaters, space heating, ventilating and air-conditioning equipment). Reducing the end-use energy consumption and switching to less carbon-intensive fuels for space and domestic hot water heating would result in reduced carbon dioxide emissions from the residential sector. However, the energy consumption pattern of consumers is a result of many complex and interrelated technical, socioeconomic, and market factors as well as consumer behavior and energy conservation consciousness. Thus, an effective and efficient energy conservation policy requires accurate and comprehensive estimates of residential energy demand parameters. These estimates are among the most important inputs for informed policy decisions. In turn, accurate estimation of energy demand parameters requires realistic modeling of the consumers' energy demand behavior, detailed data on energy consumption, and careful treatment of any technical and non-technical parameters used in the model.

With the signing of the Kyoto Protocol (UNFCCC, 1997) in December 1997, developed countries agreed working towards a legally binding greenhouse gas emission reduction of at least five percent by 2008 to 2012. Canada ratified the Kyoto Protocol in 2002, committing to a six percent reduction below the 1990 emission levels by 2010. As shown in Figure 1.2, Canada's commitment represents a reduction in greenhouse gas emissions of approximately 26 percent below what it would have been without the agreement (NCCP, 1999). To meet this commitment, Canada has to evaluate and exploit every feasible measure to reduce energy consumption and GHG emissions while maintaining its economic growth and standard of living. Thus, a comprehensive and representative residential energy end-use consumption and GHG emission model is needed to assess the feasibility of numerous potential strategies to reduce energy consumption and GHG emissions in Canada. Such a model can be used to conduct comparative evaluations and as a policy making tool to achieve Canada's overall GHG emission reduction commitment.

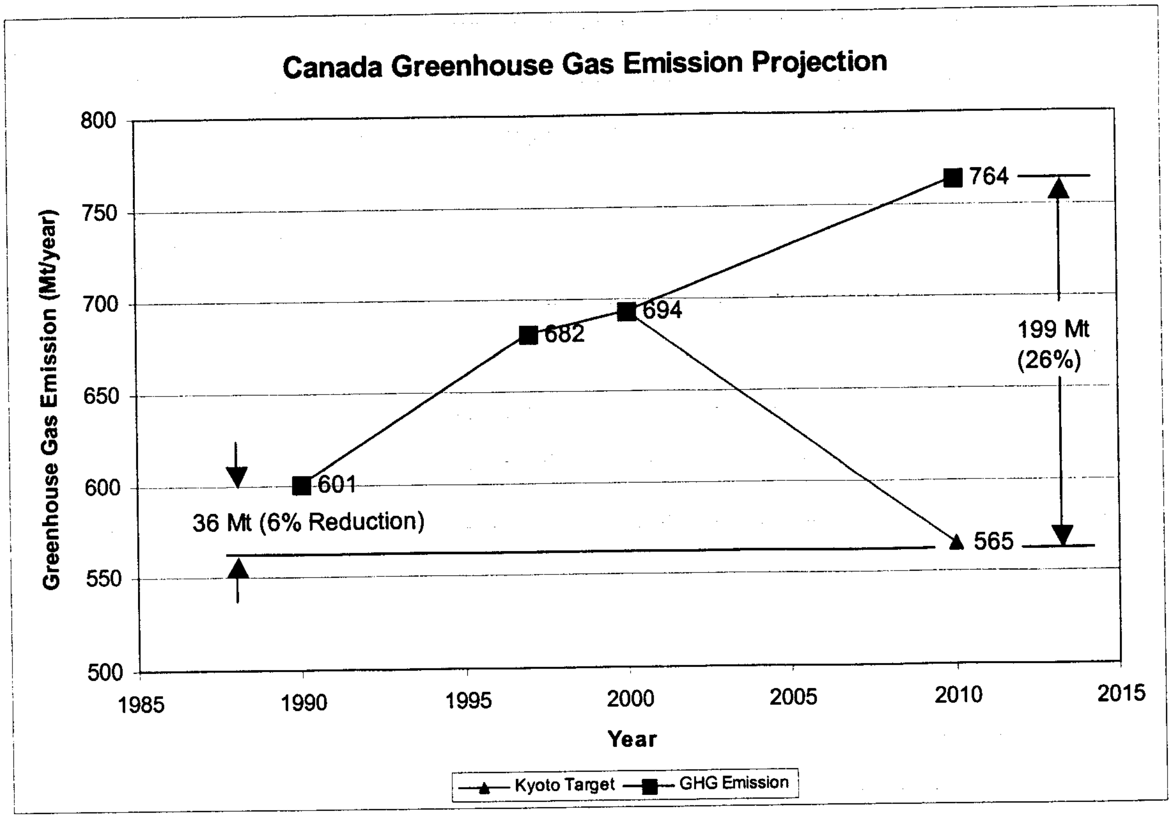

Figure 1.2: Projected Canadian carbon dioxide emission level and the Kyoto target (NCCP, 1999)

1.2 Greenhouse Effect

The sun gives energy in the form of solar radiation. Some of the radiation that reaches the earth is reflected by the earth and its atmosphere, while most of the radiation passes through the atmosphere and is absorbed by the earth's surface. The earth, in turn, releases energy in the form of long wavelength infrared radiation back into space. The outgoing infrared radiation either passes through the atmosphere or is absorbed and re-emitted in all directions by the infrared active gas molecules as depicted in Figure 1.3. Such atmospheric absorption and re-radiation of infrared energy warm the earth's surface and the lower atmosphere. The infrared active gases therefore act as a barrier to prevent some outgoing energy from escaping, retaining heat much like the glass panels of a greenhouse. This natural warming effect is generally known as the "greenhouse effect". Likewise, the gases responsible for the effect are called the greenhouse gases. Without the presence of the greenhouse gases, a significant portion of the energy that keeps the earth warm would escape into space. As a result, the earth's mean global temperature could be as much as 33°C cooler, i.e. about -18°C as opposed to 15°C, rendering the earth uninhabitable. (Henderson-Sellers and Robinson, 1986; Kellogg, 1996; Peixoto and Oort, 1992).

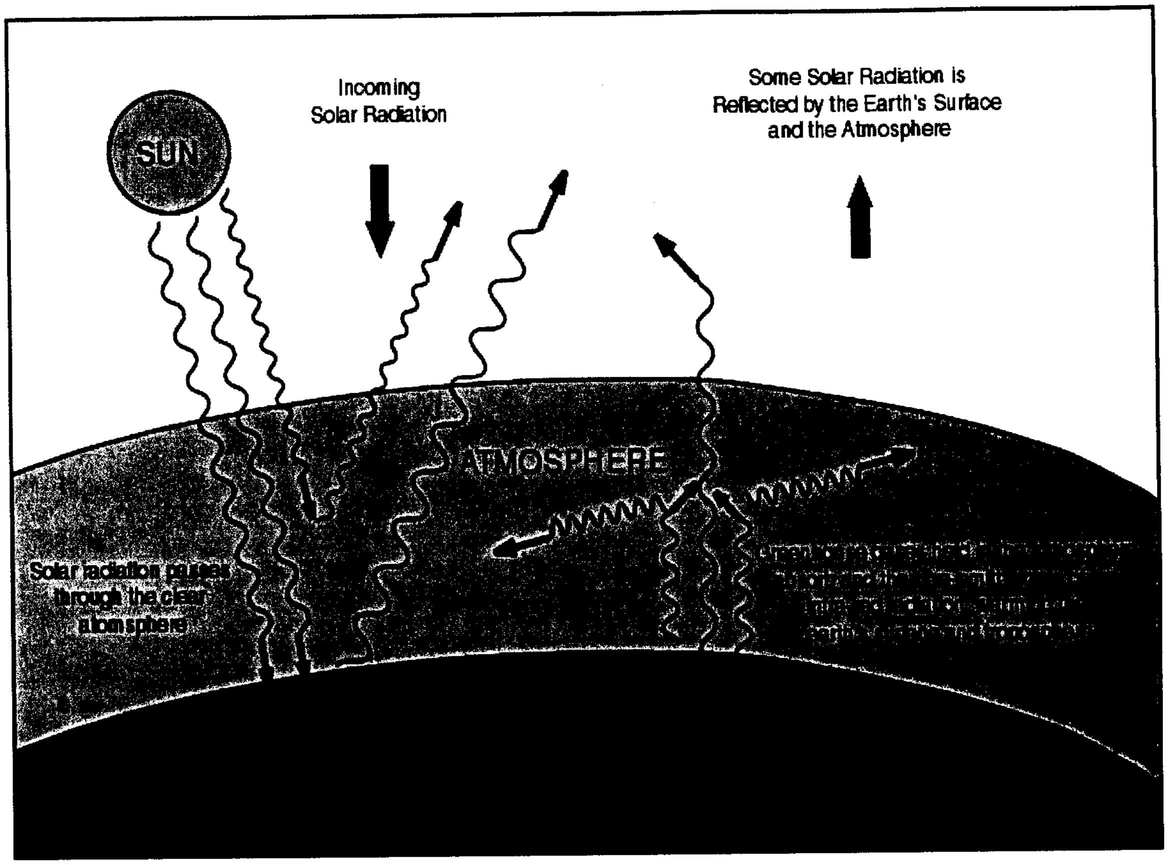

Figure 1.3: Simplified representation of greenhouse effect: adopted and simplified from Schneider (1989)

Most greenhouse gases are naturally present in the earth's atmosphere, while others are from anthropogenic (man-made) sources. Natural processes (sinks) such as ocean uptake, soil uptake, photolysis in the stratosphere, and northern hemisphere forest regrowth help remove some of the greenhouse gases from the atmosphere. Naturally occurring greenhouse gases include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ground ozone (O_3). Certain human activities have contributed to the increase in the concentration of most of these naturally occurring gases including CO_2, CH_4 and N_2O since the industrial period began about 200 years ago.

CO_2 is the main greenhouse gas emitted by human activities and is responsible for over half the enhancement of the greenhouse effect. Burning of fossil fuels (oil, natural gas, and coal), solid waste, as well as wood and wood products releases CO_2 into the atmosphere. The concentration of CO_2 in the atmosphere had increased from about 280 ppm in the pre-industrial era to about 364 ppm in 1997 (Hansen et al., 1998; Keeling and Whorf, 1998).

CH_4 is emitted during the production and transport of coal, natural gas, and oil. Other sources include decomposition of organic wastes in landfills, biomass burning, raising of livestock, and rice cultivation. Since CO_2 and water vapor are formed as a result of the removal of CH_4 from the atmosphere by reaction with the hydroxyl radical, CH_4 is regarded as making both direct and indirect contribution to the greenhouse effect. The atmospheric concentration of CH_4 had increased from about 700 ppb in pre-industrial times to about 1721 ppb in 1994 (Houghton et al., 1996).

The main anthropogenic sources of N_2O are agriculture, particularly the use of nitrogen-based fertilizers, biomass burning, and industrial processes including adipic acid and nitric acid production (Schimel et al., 1996). The main natural sources include the oceans, and tropical and temperate soils. However, emissions from natural sources are estimated to be about twice as those from human activities. The concentration of N_2O in the atmosphere had increased from about 275 ppb in the pre-industrial era to about 312 ppb in 1994 (Houghton et al., 1996).

Chlorofluorocarbons CFC-11 (CCl_3F) and CFC-12 (CCl_2F_2) were man-made compounds that were virtually undetectable in the atmosphere before 1950 (Prather et al., 1996). They are byproducts of foam production, refrigeration and air-conditioning. Since those that contain chlorine and bromine are found to be responsible for depleting the ozone layer, the emission of such substances are controlled by the Montreal Protocol (UNEP, 2000) and subsequent international agreements, resulting in dramatic reduction of their production. It is expected that the atmospheric concentration of these compounds will diminish substantially during the next century (Prather et al., 1996).

Although it is difficult to determine the persistence of anthropogenic greenhouse gases, attempts have been made to estimate their "mean residence times". It is estimated that CO_2 will remain in the atmosphere anywhere from 10 to thousands of years depending on which sink is involved (Ledley et al., 1999). CH_4 will have a mean residence time of 10 years (Prather, 1996), N_2O, 100 years (Prather, 1998), and CFC-11 and CFC-12, 50 and 102 years (Prather et al., 1995), respectively.

Other anthropogenic greenhouse gases, mainly due to industrial processes, include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) each contributed less than one percent of the total greenhouse gas equivalent emissions in 1990 according to UNFCCC (IPCC, 2000).

1.3 Kyoto Protocol

The increase in the concentration of the aforementioned greenhouse gases since the start of the industrial period has given rise to concerns over potential undesirable climate changes in recent decades. In order to address such concerns and possible potential problems, the Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988. IPCC's main objective is to assess the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change. However, it does not conduct new research or monitor climate related data. It bases its assessment mainly on published and peer reviewed scientific technical literature. IPCC is open to all members of WMO and UNEP (IPCC, 2000).

IPCC completed its First Assessment Report in 1990. It played an important role in establishing the Intergovernmental Negotiating Committee for a UN Framework Convention on Climate Change (UNFCCC) by the UN General Assembly. UNFCCC was adopted in 1992 and entered into force in 1994. It provides the overall policy framework for addressing the climate change issue. Its Second Assessment Report, Climate Change 1995, provided key input to the negotiations, which lead to the adoption of the Kyoto Protocol to UNFCCC in 1997 (IPCC, 2000).

The Kyoto Protocol is an international treaty aimed at preventing potential dangerous anthropogenic interference with the climate system. A central feature of the Protocol is that all parties develop and implement policies and measures that would reduce greenhouse gas emissions. In addition, the Protocol sets binding limits on greenhouse gas emissions for developed countries that are most responsible for current levels of greenhouse gas pollution while creating significant incentives for developing countries to control their emissions as their economies grow.

The Kyoto Protocol was adopted by 150 plus nations on December 12, 1997 and opened for signature from March 16, 1998 to March 15, 1999. The Protocol commits developed countries to reduce emissions of six (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) key greenhouse gases by at least 5% by the period 2008-2012 on the basis of their 1990 emissions. On the closing date, 84 countries, including the European Community, had signed the Protocol (GCCD, 1999). However, to enter into force, it must be ratified by at least 55 countries, accounting for at least 55% of the total 1990 carbon dioxide emissions of developed countries. As of December 2002, 97 countries including Canada, Denmark, Finland, France, Germany, Italy, Japan, Norway, Sweden and United Kingdom of Great Britain and Northern Ireland, accounting approximately 40% of global GHG emissions, ratified the Kyoto agreement emissions (UNFCCC, 2002). Therefore, the Protocol is yet to be in force. Note that two – the United States and Russia - of the G8 countries have yet to ratify the Protocol. Russian President Vladimir Putin also indicated that Russia intended to ratify the Protocol soon. The United States is reluctant to support the Protocol. U.S. President George W. Bush maintained that the limits set would harm the U.S. economy and has called for a unilateral schedule of emissions reductions (Agence France-Presse, 2002). However, with Russia's proposed ratification, the Protocol would meet the threshold to take effect. Canada's greenhouse gas reduction target is 6% below 1990 levels by the period 2008-2012. This commitment represents a rather significant 26% reduction from the year 2010 projected emissions (NCCP, 1999).

1.4 Objective of the Work

Energy consumption in the residential sector, and associated GHG emissions, are influenced by, and inter-related with, many physical (such as fuel mix, climate, house envelope characteristics, types and efficiencies of space and domestic hot water heating equipment, appliance type, stock, and usage, house type and size) as well as non-physical factors (such as climate, and socio-demographic, socio-economic, and behavioral characteristics of the residents). Thus, to estimate the overall patterns of residential energy consumption and the energy related GHG emissions, as well as to clearly understand the underlining structures and mechanisms that influence the energy consumption and GHG emissions, all of these factors should be taken into consideration.

Energy consumption modeling in the residential sector is usually conducted using two general but distinct approaches; forward feeding and backward/inverse models. The first is the physical/engineering approach which involves the modeling of the thermal load of a building based on the principles of physics and thermodynamics combined with detailed data on building characteristics and weather to estimate the energy requirement for heating, cooling, domestic hot water heating, lighting and appliances. The second is the statistical approach, in which the real observed loads (usually billing records or metered consumption data) for individual households are decomposed into specific end-use energy consumption using regression based techniques. These two different approaches provide complementary advantages, but they have their own limitations. Overall review on these two methodologies in modeling residential energy consumption will be discussed in next chapter.

The objective of this work is to develop a comprehensive and representative residential end-use energy modeling framework for estimating energy consumption and associated greenhouse gas emissions in the residential sector that is suitable for a broad range of comparative analyses as well as for use as a decision making tool for policy development, and using this framework to develop an energy and greenhouse gas emissions model of the Canadian housing stock.

To achieve this objective, the model needs to have the following features and capabilities:

- Representative of the Canadian housing stock at the provincial, regional, and national levels,

- Ability to estimate energy consumption and associated greenhouse gas emissions for different residential end-uses such as space and DHW heating, cooling, and appliances,

- Flexibility to incorporate information from new data sources as they become available,
- Capability to conduct comparative techno-economic analysis for a wide range of building retrofit and fuel switching scenarios,
- Capability to assess the energetic and emissions impact of changes to the building code,
- Capability to assess the quantitative and qualitative socio-economic factors that influence different household energy end-uses.

In order to develop a modeling framework that addresses all of the aforementioned features and capabilities, the following specific tasks are to be undertaken:

- Survey existing macro modeling frameworks and modeling approaches including engineering and statistical methodologies.
- Survey existing energy end-use modeling, metering, estimating and surveying methodologies for different appliances as well as for space and DHW heating end-uses, and identify inconsistencies and gaps in available information.
- Conduct detailed engineering parametric and sensitivity studies on all major energy end-uses (such as different appliances, lighting, cooling, space and DHW heating). If necessary, propose new survey and metering activities to determine missing and/or inconsistent data.
- Survey and identify available databases and assess data quality and suitability.

- Survey and review existing building energy simulation engines for feature suitability.

- Estimate the cost associated with metering, surveying, and modeling for the development of the model framework.

- Develop a detailed bottom-up engineering method based model to estimate the end-use energy consumption and associated greenhouse gas emissions for space heating/cooling, domestic hot water heating, lighting and appliances (six major white-good appliances, i.e. refrigerator, freezer, range/oven, dishwasher, clothes washer, clothes dryer, as well as minor and miscellaneous appliances), and conduct a critical evaluation of the model and its predictions.

Chapter Two

2 Literature Review

2.1 Overview

Residential energy demand modeling was originally pioneered by Hendrik S. Houthakker in the early 1950s with his work on modeling residential electricity consumption in 42 British provincial towns using data from cross-sectional observations (Houthakker, 1951). Decades later, mainly simulated by, and thus a by-product of, the two oil crises in the 1970s, a vast and broad range of economic, socio-demographic, behavioral, physical/engineering, and various hybrid energy models have been proposed and developed. These models focused either on some sectoral or economy-wide energy demand, and employed a wide variety of modeling techniques and data. With recent concerns regarding the various potential environmental impacts caused by the consumption of fossil fuels, there is a renewed interest on energy demand modeling for impact and policy analyses.

Although there is a wide array of residential energy modeling techniques available, these can be broadly classified into two distinct groups, namely forward feeding and inverse approaches. Forward feeding approach usually utilizes fundamental physical and engineering based thermodynamic principles for estimating the energy demand required by the equipment/dwelling using detailed information available for operating, environmental, and technical characteristics. The main advantage of this approach is its ability to predict the outcome that has not been observed and/or measured. On the other hand, inverse (or data-driven) modeling techniques employ a known/measured outcome of a system under study to determine the cause and effect relationship of each desired input parameter to the outcome. Most regression based techniques, including econometric, conditional demand analysis, hybrid models, and neural network approaches, can be classified as inverse modeling approaches in which the actual observed outcome is needed and used in the development of the model. The advantages of these techniques are that the resulting models are simpler and easier to use, and usually provide a better prediction of the particular "known" system in question.

Although there are models and modeling approaches available to model the residential energy consumption at various levels of aggregation, most of the estimates of residential energy use are derived through statistical analysis of energy consumption data from utility or government sources, and they provide little or no insight into the composition of the energy use. Computer based building energy simulation tools provide a powerful means to disaggregate total household energy consumption into individual components such as envelope component loads, infiltration, internal and solar gains, and others.

2.2 Engineering/Physical Modeling

Engineering and/or physical based modeling techniques generally calculate the amount of heat entering and leaving the dwelling for a period of interest based on thermodynamic principles, and usually are capable of determining the heating/cooling loads as well as the energy consumption for different end-uses such as lighting, appliances, equipment, and so on. The time interval used is typically an hour for dynamic models while longer time intervals (such as day or month) are used for static models. These methods of calculations require detailed inputs including data on the thermal, physical and operational characteristics of the dwelling as well as location specific temperatures and other weather related (such as solar radiation, humidity, wind speed, cloud cover, etc.) data. These approaches are highly specialized for determining both static and dynamic heat transfer processes in the dwelling.

Since behavioral effects are usually relatively small compared to temperature driven effects in extreme climates, engineering/thermodynamics based energy estimation techniques provide accurate predictions for heating dominated dwellings under severe weather conditions when sufficient detailed information on building characteristics is available. Engineering/thermodynamics based models incorporate complex non-linear relationships among weather, building characteristics, and thermal loads and thus provide significant insight into the cause and effect of the building energy end-use demand (Dubin and Henson, 1985).

Engineering Method (EM) based aggregated residential end-use energy consumption models usually involve developing a housing database that is representative of the national housing stock and estimating the energy consumption of the dwellings in the database using a building energy simulation program or other engineering based techniques such as Degree-day (ASHRAE, 1976, 1981 and 1985), Variable-based Degree-day (Nall and Arens, 1979; Kusuda et al., 1981), or BIN (Erbs et al., 1983; ASHRAE, 1985) methods. Such methods require a database representative of the housing stock with detailed house description data and lengthy input data preparation time for building energy simulation. Some of the difficulties associated with the use of the EM based models are the inclusion of consumer behavior and other socioeconomic variables that have a significant effect on the residential energy use, as well as the extensive data and expertise required to develop and use such models. The most important advantage of the EM based models is their capability to evaluate a wide range of energy efficiency upgrade scenarios.

One of the early engineering based residential energy consumption models was developed by MacGregor (MacGregor, 1992, MacGregor et al., 1993). The model estimated the residential space heating energy requirements and fuel consumption in Nova Scotia for major types of dwellings and fuels used. The Nova Scotia Residential Energy Model (NSREM) was based on the "typical" dwelling characteristics that were developed based on a number of earlier surveys and data collected by government agencies and the electric utility on single- and multi-family dwellings. Three levels of "typical" building insulation and air-tightness levels were developed for each group of dwellings. Thus, there were a total of eight dwelling types (Bungalow, 2-storey, semi-detached, split-level, mobile, apartment #1, apartment #2, and apartment #3) and three insulation levels (high, medium and low), resulting in a total of 24 dwelling categories. Annual space heating energy consumption for each "typical" dwelling was estimated using the Hourly Analysis Program (HAP) Version 2.0 available from Carrier Corporation (Carrier, 1990). Overall energy consumption was then estimated based on the total number of dwellings in each dwelling group in the province according to census data. In NSREM, heat gains from occupants, appliances and lights, as well as the DHW requirements were considered and used in the model through the modeling of "typical" dwelling. The accuracy of the predicted energy consumption was evaluated based on the overall energy consumption estimate in the residential sector.

In an effort to develop a representative housing database for Canada, STAtistcially Representative HOUSING Stock (STAR HOUSING database) was first developed by Scanada Consultants Limited (1992) on behalf of Canada Mortgage and Housing Corporation (CMHC). STAR HOUSING database is a statistically representative database of the Canadian housing stock (as of 1990) that contains detailed information on housing characteristics and energy consumption. The STAR database contains information on approximately 1,000 low-rise, owner-occupied residential dwellings from across Canada collected as part of the Canadian Home Insulation Program (CHIP) during late 70s and early 80s. Hot2000 building energy simulation program was used to estimate the household energy consumption of the dwellings in the database, and the aggregated national and provincial energy use according to fuel and vintage were then extrapolated from the Hot2000 estimates with information available on the total building stock in each province and in Canada. Although the STAR database was representative of Canadian housing stock as a whole, it was not representative at the provincial and regional levels. Furthermore, it does not contain detailed information on appliance ownership and usage for enhanced detail energy analyses.

The original STAR databases was later improved and expanded (Ugursal and Fung, 1994; Ugursal and Fung, 1996). The revised version of STAR, called Modified STAR, was used to estimate the effect of appliance efficiency and usage profiles on the national residential energy consumption and the associated greenhouse gas emissions in Canada (Ugursal and Fung, 1996; Ugursal and Fung, 1998). For this study, detailed end-use estimates by appliances and lighting were developed by carrying out simulations using the hourly energy simulation program, ENERPASS (Enermodal, 1990), and the appliance usage load profiles obtained from the literature.

Farahbakhsh et al. (1997) used the data from the Modified STAR database and other sources to develop archetypes of single-family dwellings for different vintages and regions of Canada. These archetypes and the extensive data from the Survey of Household Energy Use (SHEU) (Statistics Canada, 1993a; 1993b; 1993c) on 8767 low-rise single-family dwellings from across Canada were used in the development of the Canadian Residential Energy End-use Model (CREEM) (Farahbakhsh et al., 1997; Fung et al., 2001). Hot2000 building energy simulation program was employed to estimate the household energy consumption of each house in the CREEM database, and energy estimates were then extrapolated to the provincial and national levels using information on the total housing stock. Since CREEM uses SHEU data, and SHEU is representative of the Canadian housing stock, CREEM is also representative of the Canadian housing stock. The estimates obtained using CREEM are were found to be in agreement with those from other published studies. CREEM was later used to estimate GHG emissions from residential energy consumption (Guler et al., 2000; Guler et al., 2001), and the energetic and GHG emissions impact of energy efficiency upgrade retrofits on the residential energy consumption in Canada.

A regional bottom-up engineering based residential space heating energy use model was developed by Snakin (2000) for the province of North Karelia, Finland. The model consists of calculation units that represent municipally aggregated groups of buildings with similar space heating consumption and equipment features. Although the model was based on the bottom-up engineering methodology, it ignored the heat gains from solar, occupants, and appliances, and no building energy simulation was used in estimating the overall energy consumption.

Recently, using DOE-2.1E as the simulation engine, Huang and Brodrick (2000) developed a bottom-up engineering based estimate of the aggregated heating and cooling loads of the entire US building stock. They used a large set of prototypical commercial and residential buildings developed from data obtained through the commercial and residential energy consumption surveys (RECS and CNECS) conducted by the Energy Information Administration (EIA) of the U.S. The prototypical building descriptions and the corresponding DOE-2 input files were developed between 1986 and 1992 to provide benchmark hourly building loads for the Gas Research Institute (GRI). The prototypical building descriptions include 112 single-family, 66 multi-family, and 481 commercial building prototypes. With the information on total building stock in each region, vintage, and dwelling type from EIA, the total aggregated heating and cooling energy consumption for the entire US building stock was estimated. Given the small number (112+66=178) of residential prototypical buildings used in their model to represent the entire housing stock in the US, and the use of only reported aggregated energy consumption for model calibration and validation, Huang and Brodrick (2000) reported that the overall estimated energy consumption was found to agree reasonably well with estimates from other sources, although significant differences were found for certain end-uses. The reported total residential energy consumption was found to be identical to the DOE estimates, but slightly higher than the GRI estimate.

2.3 Regression Modeling

2.3.1 Princeton Scorekeeping Method

Princeton Scorekeeping Method (PRISM) (Fels, 1986) was initially developed as a tool for reliable scorekeeping in energy conservation and building retrofit analyses. Sinden (1977) and Mayer and Benjamini (1977) developed PRISM at Princeton University for energy performance evaluation of the Twin Rivers Townhouse energy retrofit project in the 70s. PRISM has been used extensively in the US by numerous utilities, governments, and research organizations for various building energy retrofit and conservation measure analyses in different types of buildings (single and multi) with different heating systems such as electric resistance, electric heat pump, natural gas, oil and wood. (Decicco et al., 1986; Dutt et al., 1986; Fels and Goldberg, 1986; Fels, Goldberg and Lavine, 1986; Fels, Rachlin and Socolow, 1986; Fels and Stram, 1986a; Fels and Stram, 1986b; Goldberg, 1986; Goldberg and Fels, 1986; Goldman and Ritschard, 1986; Hewett et al., 1986; Hirst, 1986; Rodberg, 1986; Stram and Fels, 1986)

PRISM, primarily based on the principle of Variable Base Degree-day (VBDD) Method, uses utility meter readings from before and after the retrofit installation, together with the corresponding average daily outdoor temperatures for the same periods, to determine a weather-adjusted index of consumption (Normalized Annual Consumption - NAC), for each period. Essentially, PRISM is a two-variable (a constant and a slope) linear regression model based on variable balance point temperature degree-day method in which heating energy consumption is assumed to be linearly proportional to the difference between the actual dwelling balance point temperature and the average daily outdoor temperature. Thus, the total household energy consumption is simply comprised of two components; non-weather related baseload and the weather related space heating energy consumption due to actual degree-days.

PRISM provides an easy and convenient way of analyzing building energy consumption. However, it requires at least a whole year of 12 monthly billing records (or 6 bi-monthly) in order to generate reliable and stable NAC estimates. Another problem with PRISM arises from the fact that it is based on the assumption that the baseload consumption is constant through out the year. Such requirement of non-varying energy usage for the appliances using the same fuel makes PRISM's baseload estimate unrealistic.

2.3.2 Econometric Energy Modeling

Econometric analysis is a regression based technique that is consistent with the principle of economic theories. The demand for energy by households is thought, by many economists, to be a derived demand arising from the production of household services. The technology that provides the household services is embodied in the household appliance durables (Goett and McFadden, 1984; Dubin and Henson, 1985). To understand the residential demand for energy one must also understand the residential demand for durable equipment. Hence energy demand is both a function of the equipment stock and its rate of use. As well, fuel price changes are likely to affect both of these two determinants. This is particularly true for long-term demand estimate in which economic and market conditions play a bigger role in consumer durable acquisition. However, equipment ownership and their characteristics and operating environments play a strong role in the short-term demand.

There are numerous econometric studies on residential energy demand modeling, and they can generally be classified into two categories: aggregated and cross-sectional analyses. In the aggregated econometric studies, national household energy consumption is usually modeled as a function of nationally averaged variables such as income, gross domestic product, fuel prices, and so on (Conniffe and Scott, 1990; Badri, 1992; Al-Mutairi and Eltony, 1996). Aggregated econometric models, in general, provide very good fit between the pooled national household energy consumption and the explanatory variables. However they provide very little or no insight on how household energy is consumed. As a result aggregated econometric modeling technique has limited use on the energy end-use modeling. On the other hand, cross-sectional econometric analysis models household energy consumption on the basis of individual household characteristics that are believed to drive the energy demand (Scott, 1980; Betancourt, 1981; Donnelly and Diesendorf, 1985; Douthitt, 1989). However, cross-sectional energy demand models usually have lower regression fit due to the difficult nature in explaining consumers' behaviors on energy consumption at the household level. Nonetheless, traditional econometric analyses sought to seek the potential changes in energy demands due to changes in economic variables such as price and income (Houthakker; 1951; Taylor, 1975; Scott, 1980; Betancourt, 1981; Donnelly and Diesendorf, 1985; Douthitt, 1989; Poyer and Williams, 1993). Thus, price and income elasticity estimates were usually the main objectives of many early econometric analyses.

Houthakker (1951) was first to use cross-sectional data to analyze household electricity consumption of 42 cities in Britain. Before the development of the theoretical framework on demand analysis introduced by Taylor (1975), Houthakker (1951) empirically employed log-linear energy demand formulation to model household energy consumption by applying generalized least squares (GLS) instead of ordinary least squares (OLS) estimation in order to account for the heteroskedasticity problem[2].

In 1980, Scott (1980) introduced the "heat production function" based on the analogy of a house being treated as a firm producing heat levels according to its specific characteristics to account for the unexplained discrepancies in traditional econometric analyses. The introduced "heat production function" can be viewed analogously as the physical-engineering household characteristics that drive the demand for space heating. Both linear and log-linear functional forms were employed by Scott (1980) to estimate

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[2] Heteroskedasticity refers to unequal variance in the regression errors.

household electricity space heating energy consumption and the results showed that log-linear model provided a better overall prediction compared to that of linear model although both models provided relatively low prediction performance (R^2 of 0.422 and 0.357, respectively).

Even with its popularity, traditional log-linear model infers constant elasticity estimates over the range of variables being evaluated, thus making the use of log-linear functional form impractical and/or inflexible in most econometric analyses. Betancourt (1981) proposed three different versions of variable price elasticity log-linear functional forms, which were consistent with utility maximization theory, to analyze average and peak monthly household electricity energy consumption for six regional utilities across the US using monthly time-series data from 1972-1976. Betancourt (1981) articulated that as the share of electricity expenditures in the consumer's budget increased, the sensitivity to price changes of electricity demand increased. In addition, if weather became more extreme electricity became more of a necessity, which in turn decreased the income elasticity of demand. Thus, price elasticities were assumed to be influenced by variables such as lagged fuel price and heating and cooling degree-days in his proposed variable elasticity log-linear models. Although Betancourt (1981) found that there were no observable improvements of model predictability from the proposed variable elasticity formulation over the standard constant elasticity one, the new formulations did provide flexible mechanisms for estimating variable price elasticities over the range of observed variables that were believed to influence energy consumption.

Donnelly and Diesendorf (1985) conducted an analysis of aggregated electricity energy consumption data from a period of 1963-1992 in the Australian Capital Territory using different functional forms. Among these functional forms was a reduced modified version of variable elasticity functional form proposed by Betancourt (1981). Donnelly and Diesendorf (1985) argued that Betancourt's functional form was misspecified and produced nonunitless elasticity estimates if the exponents were not normalized. Among all functional forms tested, Donnelly and Diesendorf (1985) reported that the normalized Betancourt variable elasticity functional form provided the best fit for their time series data. However, they also reported the extreme problem of multicollinearity stemming from the introduction of the additional terms in the exponent was the reason for their inability of identifying the effect of individual explanatory variables (such as heating degree-days) on price elasticity.

More recently Douthitt (1989) applied Donnelly and Diesendorf (1985) transformation of Betancourt (1981) variable elasticity formulation to model the consumption of three different types of household space heating fuels in Canada using 370 cross-sectional audited household data collected by the Energy, Mine and Resources (EMR) during the period of 1981-1982. Douthitt (1989) used not only the traditional economic variables such as prices and income, but also a range of data on demographics and dwelling physical structure obtained from the households through an audit. Douthitt (1989) basically followed Sinden's (1977) demand specification for space heating as a function of four factors: thermal efficiency of the dwelling or thermal looseness, space heating equipment efficiency, interaction between outdoor and indoor design temperatures, and internal heat gain. Thus, the dependent variable, i.e. space heating consumption, was formulated as a log-linear function with many economical, socio-demographical and physical-engineering related variables. However, most of these additional non-economic variables were later found to be statistically insignificant and/or with a sign opposite to that expected. It was also rather interesting to note that the internal heat gain (combined appliances and occupant heat gains) variables were not significant indicators statistically, which was contrary to the conventional notion.

More recently Fung et al. (1999) applied a refined version of the econometric technique used by Douthitt (1989) to analyze the three major residential energy end-uses (space heating, DHW heating and appliance) for both electric and natural gas heated households using data and billing records available from the 1993 SHEU survey (Statistics Canada, 1993a). Their analysis employed not only the socio-economic and demographic variables but also the climatic, physical and appliance usage variables (such as HDD, CDD, ground temperature, heated living area, basement area, number of storey, usage of central A/C, number of lights, number of loads for clothes washer, clothes dryer and dishwasher, etc.) available from the survey. Their results showed that both short and long-run price elastcities were comparable to other similar studies, i.e. less than unity for the short-run and larger than unity for the long-run price elastcities for all three end-uses and two fuel systems investigated. They also found that the price elasticities for electricity (for all three end-uses) were higher than those of natural gas. One noticeable difference in their study was the use of total household appliance energy consumption (heat gain) as an explanatory variable in the space heating energy consumption formulation. The appliance energy consumption variable proved to be highly significant statistically and with the expected negative sign, indicating that the total appliance energy consumption was one of the dominant variables affecting the residential space heating energy consumption. However, many of the physical and appliance usage and income variables proved to be statistically insignificant mainly due to the multicollinearity problem among the explanatory variables. As a result, the impact of such variables on the overall residential energy end-use consumption could not be derived directly from the model. Further work is needed to investigate the potential use, and to enhance the benefit of such econometric modeling techniques for residential end-use energy consumption modeling.

2.3.3 Conditional Demand Analysis

Conditional Demand Analysis (CDA) is a regression based econometric technique designed to decompose household energy consumption into specific end-use components based on the assumption that total energy consumption can be expressed as a summation of energy consumed by each and every individual specific appliance present in the household. Thus, it is assumed that the energy consumption of a household is directly related to the appliance stock present in the dwelling, specific features of these appliances, dwelling characteristics, and utilization and behavioral patterns (influenced by market and weather conditions) related to the use of appliances. Thus, the regression breaks down the total consumption into specific end-uses on the basis of the association between appliance holdings and household energy consumption.

A CDA model, depending on the availability of data, can be simple or complex as required. In general, six data types are usually employed to develop a CDA model. They are 1) total household energy consumption, generally in the form of billing records; 2) household appliance holdings, features and their operating characteristics; 3) household socio-economic/demographic features; 4) dwelling physical characteristics; 5) weather data; and 6) market conditions (such as own and substitute energy prices). Information on appliance holdings, features and operating characteristics as well as household socio-economic/demographic features and dwelling characteristics are usually obtained from surveys.

Conditional Demand Analysis, CDA, was initially introduced by Parti and Parti (1980) to disaggregate total household monthly electricity billing records into appliance specific end-use consumptions for the San Diego Gas & Electric Company. The model decomposed the monthly total household electricity consumption into 16 different appliance specific end-uses using a set of twelve (one for each month of the year) cross-sectional regression analyses on billing data from 5286 households. Parti and Parti (1980) reported that their estimates of appliance energy end-uses, except those for space heating and cooling, were reasonably close to the engineering estimates, and the estimates for price and income elasticities lied within the range of estimates presented in previous studies. CDA has since gained popularity and was used extensively not only in appliance end-use modeling but also for appliance load research, particularly by utility companies where large amount of billing data could be readily available. Household end-use estimates using CDA can be found in studies done by Parti and Parti (1980), Kellas (1993), Battles (1994), Lafrance and Perron (1994), Bartels et al. (1996), Bartels and Fiebig (2000), Aydinalp (2002) and others. In 1989, Electric Power Research Institute (EPRI, 1989) provided a comprehensive summary and comparison of CDA modeling techniques for the residential energy end-use estimation. Besides estimating the household end-use energy consumption, CDA can also be used to estimate income and price elasticies (Parti and Parti, 1980; Chagnon et al. 1996), the hourly load profiles of household appliances through the day with different physical and demographic characteristics (Aigner et al., 1984; Fiebig et al., 1991; Blaney et al., 1994; Hsiao et al., 1995), assess the impacts of energy conservation measures such as changing fuel prices (Parti and Parti, 1980). However, the capability of the CDA approaches to estimate the impact of energy efficiency measures is limited to the input units included in the models and the dataset used to develop the models. Therefore, it is not possible to incorporate all of the house characteristics (e.g. wall, roof, window, etc. areas, insulation values, infiltration, solar heat gains, climatic factors, etc.) into the regression model due to the limitations in data availability. Thus, although it is theoretically possible to develop CDA models that would include parameters defining detailed house characteristics, this is difficult to accomplish in practice because of the prohibitively large data requirements to carry out the regression. Consequently, it is not possible to assess the impacts of energy conservation measures (such as increasing building envelope insulation and appliance efficiencies) using a CDA model.

Ordinary Least Square method (OLS) is the most commonly used method for CDA estimates. However, by recognizing the heteroskedasticity nature of CDA, Bartels et al. (1996) employed both Ordinary Least Square and Generalized Least Square (GLS) methods to their Australian household natural gas consumption analysis, and reported that the use GLS provided more precise estimates with lower standard errors over OLS.

In general, a robust and comprehensive CDA model, particularly one to estimate residential appliance end-use energy consumption, tends to have a large number of coefficients to estimate. In addition, some end-uses, such as refrigerator, cooking range and lighting, may have very high saturations. Thus, relatively large sample sizes are usually required for the regression estimates.

In most CDA models, particularly those with a large number of interaction terms, multicollinearity could be a serious problem. Multicollinearity is a statistical problem, caused by high correlation across explanatory variables, that limits the ability of regression to distinguish the impacts of these variables. As a result, CDA may be difficult to disentangle the influences of individual appliance or household characteristics in total energy consumption. For example, refrigerator end-use may be difficult to distinguish from the agglomerated consumption through unspecified appliances and lighting since all households are likely to own at least one refrigerator unless additional refrigerator specific explanatory variables, such as type, age and size, are used. Thus, it is not uncommon for such CDA to yield unreliable (imprecise with high standard error) and unrealistic (negative) appliance consumption estimates due to the high degree of multicollinearity. Multicollinearity problem creates a gap between the information requirements of the model and the information provided by the sample data. The way to reduce this gap (insufficient information) is to either expand the information content of the data, reduce the requirements of the model, or both. It is possible to reduce the problem of multicollinearity by expanding the sample size, as long as the configuration of appliance ownership does not have the exact pattern among individual observations. Therefore, a reduction in the CDA specification requirements is usually chosen through the use of prior information in the form of data obtained by direct metering on specific appliances (Fiebig et al., 1991; Bauwens et al., 1994; Blaney et al., 1994; Hsiao et al., 1995) or engineering estimates (Caves et al., 1987; Train, 1992).

In general, the overall fit of a CDA model depends on the model specification and data quality. Literatures on CDA analyses show that the R^2 values of these models range from low of 0.36 (Bartels et al., 1996) to high of 0.75 (Kellas, 1993); with most in the range of 0.4 to 0.7 (Parti and parti, 1980; LaFrance and Perron, 1994; Bartels et al., 1996). These values might seem low, but explaining the cross sectional data on the behaviors of individual households is a very difficult process since energy consumption is affected by many other factors (such as tastes, habits, special circumstances) that cannot be readily identified or quantified, and consequently, cannot be incorporated into the model.

Similarly, it is extremely difficult to incorporate all of the dwelling physical characteristics (such as wall, roof, window, areas, insulation values, infiltration, solar heat gains, climatic factors, etc.) into the regression model since it would create multicolinearity problem and/or require larger sample size.

CDA has been used extensively mainly by utility companies to estimate residential energy end-uses since 1980 due to its ease of implementation and the availability of in-house billing data. In Canada, Kellas (1993) used the 1991 Manitoba-Hydro survey data to estimate electricity appliance-specific end-uses by using CDA. The R^2 for the prediction was 0.75, a high value for CDA models. In addition, LaFrance and Perron (1994) used the data from 1979, 1984 and 1989 large-scale surveys from Hydro Quebec to estimate residential electricity end-uses by CDA. Their estimates showed similarities with engineering estimates, except that the space heating estimate was lower. CDA has also been reported (Battles, 1990; Battles, 1994) for use in estimating the five residential fuel (natural gas, electricity, fuel oil, kerosene, and liquefied petroleum gas) uses nationally in the US by the Energy Information Administration (EIA) using data from the Residential Energy Consumption Survey (RECS). Most recently, Aydinalp (2002) has developed a CDA model for the Canadian residential sector. Her CDA model comprises a group of three CDA formulations, one each for electricity, natural gas and oil. One of the major differences in her CDA models compared to the existing models is the incorporation of detailed information on household physical, demographical as well as equipment usage pattern characteristics. The reported R^2 of 0.66 0.92 and 0.87 for electricity, natural gas and oil consumption, respectively, were considered relatively high for published CDA models in the literature. However, Aydinalp (2002)'s CDA model still has the difficulties in disaggregating the number of appliance end-uses effectively, particularly in the electricity consumption formulation. It is also interesting to note that the heating degree-day was not found to be a significant factor in both natural gas and oil consumption models, which is in contrast with the conventional engineering notion that space heating energy demand driven mainly by the temperature difference between the outdoor and indoor.

Two validation studies (Battles, 1990; Battles, 1994) were conducted by EIA in the US to evaluate the performance of their CDA estimates using submetered appliance energy consumption data from a number of regional utilities. The studies suggested a major potential misallocation of energy consumption estimates between space conditioning and water heating; with overestimate for space conditioning (heating, central and window air-conditioning) and underestimate for domestic hot water heating. Battles (1994) suggested a few potential sources of modeling biases that caused the observed end-use estimate misallocation. They were 1) missing/insufficient variables, 2) multicollinearity among explanatory variables, and 3) regional differences in space conditioning requirements. To improve the prediction capability of their CDA Model Battles (1994) suggested that:

- missing or insufficient information such as frequency and length of use in discretionary end-uses of appliances should be included,
- more accurate weather data from the actual location of the dwelling should be used,
- submetered data should be employed to devise a "bottom-up" model to examine the potential for multicollinearity among the predictor variables, and
- regional differences should be considered or separate individual regional CDA models should be employed.

In spite of its popularity, traditional CDA modeling technique requires further refinement to improve its estimate reliability. Most of the recent research on CDA technique involve the integration of prior knowledge on appliance end-uses into the model equation to improve estimate reliability. The prior knowledge usually includes information on submetered appliance end-uses and/or engineering estimates (Caves et al., 1987; Fiebig et al., 1991; Bauwens et al., 1994; Blaney et al., 1994; Hsiao et al., 1995). It should be noted that no new CDA model has appeared in the literature in the past five years other than that published by Aydinalp (2002).

2.4 Other Modeling Techniques

Recently, Neural Network (NN) Method has been developed and applied successfully to estimate the residential energy consumption at the national level by Aydinalp and co-workers (Aydinalp et al., 2000; Aydinalp et al., 2002a; Aydinalp et al., 2002b; Aydinalp, 2002). Neural Network, or commonly known as Artificial Neural Network (ANN), is an information-processing model inspired by the way the densely interconnected, parallel structure of the brain processes information. ANNs, in other words, are simplified mathematical models of biological neural networks (Hassoun, 1995). The key element of the ANN is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements that are analogous to neurons, and tied together with weighted connections that are analogous to synapses (Hassoun, 1995).

Neural Networks are capable of finding internal representations of interrelation within raw data. They are considered to be intuitive because they learn by example rather than by following predefined rules. This characteristic, together with the relative simplicity of building and training ANNs, encouraged their applications to the task of prediction (Hassoun, 1995). Because of their inherent non-linearity, Neural Networks are able to identify the complex interactions among independent variables without the need for complex functional models to describe the relationships between the dependent and independent variables often exist in regression based modeling techniques (Hassoun, 1995).

ANNs are highly suitable for determining causal relationships amongst a large number of parameters such as seen in the energy consumption patterns in the residential sector. ANNs "learn" from examples (training data) and exhibit some capability for generalization beyond the "training" data. An ANN, also commonly referred to as a neural network (NN), is an information-processing model inspired by the way the densely interconnected, parallel structure of the brain processes information. The key element of the ANN is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements that are analogous to neurons, and are tied together with weighted connections that are analogous to synapses. Although the ANN concept was first introduced in 1943 (McCulloh and Pitts, 1943), it was not used extensively until the mid-1980's owing to the lack of sophisticated algorithms for general applications, and its need for fast and large computing resources. Since the 1980's, various ANN architectures and algorithms were developed (e.g. the multi-layer perceptron (MLP) which is generally trained with the error back propagation algorithm, Hopfield Network, Kohonen Network (Hassoun, 1995)). Consequently, ANN has been extensively used as a tool for modeling, control, forecasting and optimization in many fields of engineering and sciences such as process control, manufacturing, nuclear engineering, and pattern recognition.

In the area of energy modeling, the application of ANN has been mainly limited to utility load forecasting. There are several hundred papers in the literature on the application of ANN for utility load forecasting. These clearly show the superior capability of ANN models over conventional methods (such as time series and regression). Park et al. (1991) were the first group of researchers to use ANN for load forecasting. They used an MLP type 3-layer ANN to forecast the electrical load in the Seattle/Tacoma area, 1-hour and 24-hours ahead of time. Using past and current ambient temperatures and electrical load, their ANN model could forecast the future load with an absolute error of about 1-2% for 1-hour, and 4% for 24-hour ahead forecasts. For 24-hour load forecasting, Peng et al. (1992) used an improved ANN that used an alternate formulation of the problem in which the input is mapped to the output by both linear and non-liner terms, an improved method for selecting training cases, and a better normalization scheme. Consequently, the absolute error in their 24-hour forecasts was less than 3% for each day of the week, with some days less than 2%. Kiartzis et al. (1995) also used a 3-layer ANN with 24 output neurons, one for each hour of the day (i.e. their model could forecast the next 24-hour load profile one hour at a time). With an ANN made up of 63 input, 70 hidden and 24 output neurons, the yearly average absolute error of their forecasts was 2.66%. They expected that incorporation of additional weather information such as cloud cover, humidity, rainfall, etc. would further reduce the forecast error. Chen et al. (1996) included humidity in their ANN in addition to ambient temperature to account for the effect of humidity on air-conditioning component of the load at three types of sub-stations (residential, commercial and industrial). They used a functional link network algorithm (a combination of the time series and the back propagation algorithms) to train the network due to its higher convergence speed and accuracy. The load forecasting errors were 1.9, 2.0 and 2.9% for residential, commercial and industrial substations, respectively. AlFuhaid et al. (1997) used a cascaded ANN (CANN) to forecast half-hourly loads for the next 24-hours. The CANN approach captures the sensitivity of the non-linear influence of temperature and humidity on the load. They used a 3-layer ANN (16 input, 3 output, 8 hidden neurons) as the lower ANN, and a 4-layer ANN (107 input, 48 output, 70 hidden neurons) as the cascaded ANN. The use of the cascaded ANN approach as opposed to standard ANN reduced the absolute error from 3.4% to 2.7%.

Other than load forecasting, ANN models were used for energy modeling only by researchers at the Joint Center for Energy Management at the University of Colorado, Boulder. For example, Anstett and Kreider (1993) used ANN to predict energy use (steam, natural gas, electricity and water) in a complex institutional building. They used various network configurations, starting with a simple configuration with no hidden layers, moving progressively to more complex configurations with two or three hidden layers. They used the month, day of the month and day of the week, outdoor (high, low, average) temperatures, etc. as input parameters, and evaluated several different training algorithms. The predictive quality of the ANNs was found to be good. Later, Kreider et al. (1995) used ANN to predict the energy consumption of a complex building without knowledge of the various energies for the immediate past. This is of value when one needs to estimate what a building retrofitted with energy conservation features would have consumed had it not been retrofitted, i.e., to estimate the energy savings as a result of the retrofit. In this case, the forecasting problem is more difficult because the forecast is several months into the future rather than few hours. Using dry bulb temperature, humidity ratio, horizontal solar flux, wind speed, hour of the day, and weekday/weekend binary flag as inputs and recurrent (feedback) ANNs (with 1- or 2-hidden layers and five or nine neurons, respectively), they predicted future heating and cooling loads. They also used the ANN method to estimate the building equivalent thermal resistance (R) and building equivalent thermal capacitance (C) from time series data on energy consumption. The assumption was that the energy consumption data contains, or implicitly represents, the characteristics of the building and its usage. Their ANN was able to estimate both the R and the C with less than 1% error. Most recently, Olofsson and Andersson (2001) used the NN approach and data from daily measurements to predict the annual energy demands of six Swedish single-family dwellings.

National residential energy end-use modeling using NN conducted by Aydinalp (Aydinalp et al., 2002a; Aydinalp et al., 2002b, Aydinalp, 2002) consisted of three separate end-use NN models representing three major residential end-uses, i) space heating (SH), ii) DHW heating (DHW), and iii) appliances, lighting and cooling (ALC) energy end-use consumption.

The number and choice of input units were different for each network, and the units were selected based on the their contribution to the prediction performance of the end-use network. The actual energy consumption data for each house was used as the output (target) unit of the networks. Various network architectures, activation functions and scaling intervals were tested to identify those that produce the best predictions. Once the overall NN model was complete, it was used to predict the end-use energy consumption of all houses in the 1993 SHEU database.

For example, to develop their ALC NN model, four basic types of information with total of 55 input variables were used. The four types of information used were:

1. construction details and usage characteristics of the houses,
2. specifications and usage of space heating and cooling equipment, appliances and lighting,

3. socioeconomic characteristics of the occupants,
4. weather characteristics.

In order to determine the best network architecture for the final ALC model, five different scaling intervals, three activation functions, two scaling data types, five learning algorithms, up to three hidden layers, and up to 30 units in the hidden layers were tested using Stuttgart Neural Network Simulator (SNNS) v4.2 software (University of Stuttgart, 1993). The resultant ALC NN model with the following characteristics which provided the best predictions was then determined:

1. 55 input, 27 hidden, one output units
2. three hidden layers,
3. nine neurons in each hidden layer,
4. trained with Quickprop learning algorithm,
5. using logistic function as the hidden layer activation function and identity function as the output layer activation function,
6. all data are scaled to [-0.5 to 0.5] interval.

Aydinalp et al. (2002a) reported their ALC NN model achieved high prediction performance of $R^2 = 0.908$, and the model were capable of predicting the energy consumption of household with unusually high or low energy use provided that the input units of these households were representative of the households' energy consumption. Furthermore, their ALC NN model was able to estimate the electricity consumption of furnace fans/boiler pumps in natural gas, oil or propane-heated households, as well as the electricity consumption for central air-conditioning and second refrigerator. In addition, their ALC NN model was capable to estimate the energy consumption due to socio-economic factors with the expected results. However, their NN model failed to derive rational estimates for appliances with high saturations, i.e., main refrigerator which had 99.7% saturation rate.

Other techniques used in residential energy modeling include hybrid engineering-statistical (Train, 1992), engineering-accounting (DOE, 2000), engineering-economic (Goett and McFadden, 1984; Dubin and Henson, 1985), and the more recently, artificial neural network (ANN) approach (Aydinalp et al., 2000; Aydinalp et al., 2002a; Aydinalp et al., 2002b; Aydinalp, 2002). However, most of these models, except the ANN approach, require information and analyses provided by some type of engineering based models as an integral part of the overall model.

2.5 Comparison of Different Modeling Approaches

Although Engineering Method (EM), Conditional Demand Analysis (CDA), and Neural Network Method (NN), can be used to model residential energy consumption, each has different capabilities, advantages and disadvantages, and hence, they are useful for different purposes and uses. Among these three types of models, engineering based models provide the highest level of detail and flexibility. Consequently, Engineering based models require detailed data on the housing stock, and substantial engineering expertise is required to develop and use EM models. Because of the high level of detail and flexibility provided by EM models, they can be used to evaluate the impact of a wide range of scenarios for energy conservation on residential energy consumption and greenhouse gas emissions (Ugursal and Fung, 1996; Ugursal and Fung, 1998; Farahbakhsh et al, 1998; Guler et al., 1999; Guler et al., 2000; Guler et al., 2001). However, incorporating socioeconomic factors in an engineering based models is difficult.

Compared to EM based models, the CDA models are easier to develop and use, and do not require as detailed data. Since CDA models are regression based, the number of dwellings in the database is required to be larger, and the models do not provide much detail and flexibility. As a result, they have limited capability to assess the impact of energy conservation scenarios. It is, however, possible to include socioeconomic parameters in the model if such data are available and used in the development of the model.

Based on the research and development work done on NN based models so far, it can be inferred that in terms of their data requirements, flexibility of assessing the impacts of a variety of energy conservation scenarios, and the ease of development and use, NN based models are somewhere in between the EM and CDA based models. Furthermore, current NN models, similar to CDA models, have difficulties in estimating energy consumption on highly saturated end-uses such as main refrigerator (Aydinalp et al., 2002a). This is to be expected since it is not possible for NN algorithm to isolate the energy consumption when saturation is very high, such as 99.7% for main refrigerator. However, to be able to make definitive conclusions on the feasibility of using NN method for residential energy modeling, further development and testing work is needed.

Chapter Three

3 Modeling Framework

3.1 Overview

The modeling framework developed in this work uses a causal (bottom-up) approach based on engineering principles augmented by social, behavioral and economic factors. It is mainly based on the notion that energy is used by physical appliances/equipments such as space heaters and refrigerators. Factors such as human behavior, life-style, attitudes, culture, income, and intentions do not directly consume energy. However, social, behavioral, and economical factors influence how the physical equipment and appliances are operated. Therefore, these factors indirectly influence energy consumption and, thus, will also be considered in the overall modeling framework.

3.2 Purpose

The main purpose of this work is to develop a flexible, representative and comprehensive bottom-up engineering based residential end-use energy consumption and emission modeling framework for estimating energy consumption and associated greenhouse gas emissions in the residential sector that is suitable for a broad range of comparative analyses as well as for use as a decision making tool for policy development. Given the fact that total energy consumption and its associated emissions in the residential sector are the results of complex interrelated end-use demands derived from different domestic services (such as space conditioning, bathing, cooking, cleaning, lighting, entertaining, and so on) in the households, to estimate such demands, and hence the overall energy consumption, one must understand the different types of equipments and the way they are used in delivering such services, and model their energy consumption demands accordingly.

Traditional national residential end-use energy models are either aggregated econometric or accounting based models that lack in details and are unable to account for interactions among different end-uses. These models usually provide little or no insight into the regional perspective and the inherent interconnected nature of residential energy end-uses. Thus, such models could not provide enough details on the impact of different energy efficiency measures and fuel switching scenarios on overall energy consumption and associated GHG emission at both national and regional levels.

The primary objective of the modeling framework is first to assess the availability of existing data and/or databases for modeling suitability, and then to propose and devise new data collection protocol if deemed necessary. Also, a flexible bottom-up engineering based modeling framework will be developed using which detailed sensitivity analysis of different scenarios could be performed and evaluated at the national and regional levels.

3.3 Capability Required

The proposed modeling framework should be representative of the housing stock, and provide flexibility to accept new information regarding new housing and appliance stocks, building and equipment standards, and service demands from new and emerging sources. The framework should provide general guidelines for data requirement and national/regional representation, as well as capabilities for parametric and sensitivity analyses.

3.3.1 Representativeness

Realistic national and regional analysis of residential energy consumption requires data representative of regional and national household characteristics. Sample design for household survey and metering projects should reflect such representativeness of the housing stock.

The purpose of sample design is to determine a selected group of households that will be representative of a larger group. The sample design for a study is conducted based on its objectives regarding the desired target population, sample frame, population characteristics, accuracy expectations and resource limits of the study.

The sample design requires the calculation of number of houses needed to be surveyed and/or monitored in order to achieve statistically representative data. The required sample size and the required precision of the end-uses are proportional. Thus, there is a strong interaction between sample size, precision, and confidence level of the study (Schrock, 1997).

The most commonly used sampling techniques are simple random sampling and stratified sampling Shrock (1997). Random sampling is useful when the characteristics of the population are collected as a whole and the categories within the sample with predefined statistical accuracy are not under consideration. Eq. 3.1, proposed by Shrock (1997), can be utilized to determine the required sample size for a given population:

$$n = \frac{N^2 S_x^2}{\sigma_x^2 + N S_x^2} \qquad \text{Eq. 3.1}$$

where n= Sample size

N= Population size

σ_x^2= Squared standard error of the design variable in the sample

S_x^2 = Squared standard deviation of the design variable in the population

As can be seen from Eq. 3.1, in order to reduce the sample size, either the desired standard error of the sample or the standard deviation in the samples should be reduced. One of the methods that can be used to reduce the standard deviation in the sample is to stratify a population before the sample design stage. A sample can be stratified by dividing the population into groups/segments, such as province or region, which are fairly homogeneous with respect to the design variables, and by drawing a random sample from each group/segment. This process reduces the standard deviation within each group (Schrock, 1997). A simplified representation of such required representativeness of the housing stock is shown in Figure 3.1.

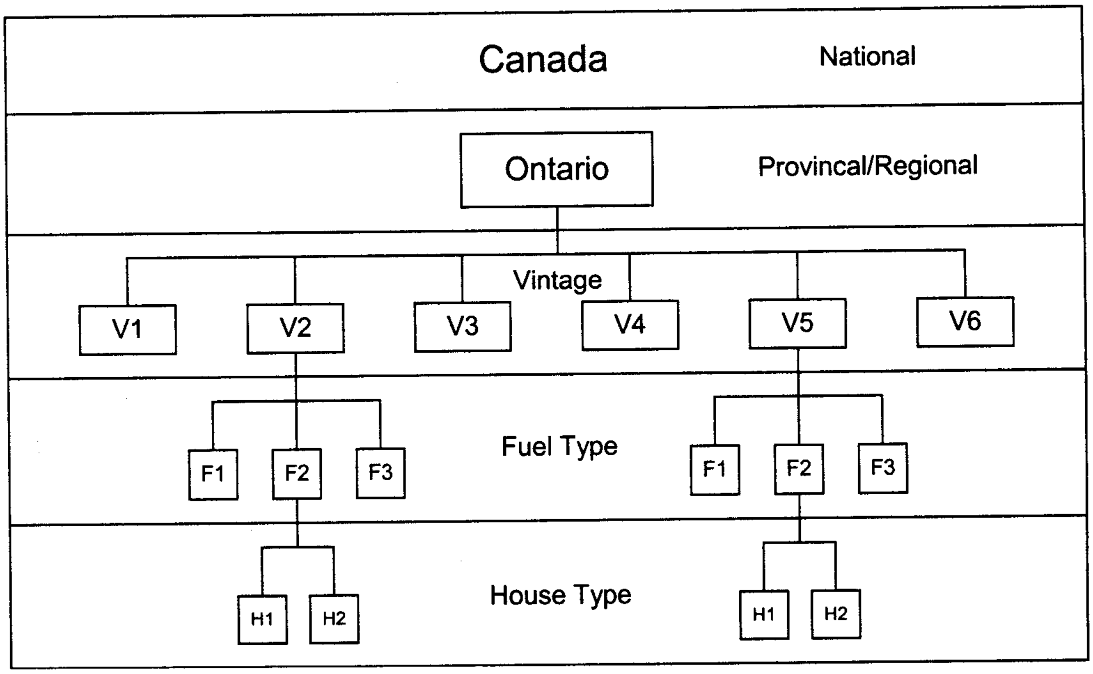

Figure 3.1: Proposed national, provincial and regional classification of households

3.3.2 Parametric Studies

The proposed residential end-use energy consumption modeling framework should have flexibility in conducting impact analyses of various parameters influencing both individual and overall household energy consumption. Impact analyses for various levels of saturation of energy efficiency technologies on overall residential energy consumption as well as GHG emissions can be modeled under such modeling framework. It would provide mechanisms for analyzing the impact of future energy efficiency standards on building envelop, heating equipment and appliances. Such analyses may include impact analyses for different levels of saturation of (i) compact fluorescent light (CFL), (ii) energy efficient appliances such as refrigerator, freezer, clothes washer and dishwasher, (iii) high efficiency condensing furnace/heater and/or heat pump systems, (iv) increased levels of insulation and air-tightness, (v) energy efficient windows, and (v) fuel switching scenarios.

3.3.3 Sensitivity Analyses

The proposed modeling framework should provide not only the capability to conduct systematic parametric analyses to assess residential energy consumption, but should also provide a flexible methodology to conduct sensitivity analyses. The sensitivity analyses that could be performed under the proposed modeling framework include impacts of different (i) space and DHW heating equipment efficiencies, (ii) dwelling thermal and air-tightness characteristics, (iii) appliance ownership and usage, as well as (iv) heating fuel types, on regional and national energy consumption and associated greenhouse has emissions. Such sensitivity analyses not only provide insights on the impacts of different factors influencing the overall residential energy consumption, but also provide an understanding of the boundaries of uncertainty for the model estimates. As a result, the sensitivity analyses could provide the needed mechanism for assessing the model's confidence level.

3.4 Model Architecture

The general outline of the proposed bottom-up engineering based model architecture is shown in Figure 3.2. For each household in the database, first the individual appliance end-use energy consumption and DHW requirement is modeled based on the information specific to the household. Appliance end-uses such as lighting (indoor and outdoor), major appliances (refrigerator, freezer, oven/range, dishwasher, clothes washer and clothes dryer) as well as minor and miscellaneous appliances (such as TV, VCR, computer, stereo equipment, and so on) are considered and modeled individually at the household level. Information on the appliance end-uses and the placement (indoor, outdoor, living area, basement, crawlspace, garage) of the appliances, as well as the DHW requirement are then used as input to the building energy simulation program to estimate the whole house energy use, with the incorporation of information on dwelling and heating equipment characteristics and environmental conditions.

Individual whole house energy consumption values estimated by the building energy simulation program are used to project the provincial and national level of energy consumption and associated greenhouse gas emissions using the household weighting factors representing the housing stock, and the greenhouse gas emission intensities based on fuel type and province. The resulting aggregated national energy consumption and GHG emissions can then be classified into lower levels of disaggregation based on province, end-use, fuel type, house type, and vintage.

To model the energy consumption in the residential sector using the engineering method, a database of dwellings that is representative of the residential sector is needed. In a representative database, each dwelling represents a certain number of dwellings in the residential sector, i.e.

$$NDRS = \sum_{i=1}^{n} W_i \qquad \text{Eq. 3.2}$$

Where NDRS = number of dwellings in the residential sector

W_i = weighting factor for dwelling i in the database

n = number of dwellings in the database

Thus, if the annual energy consumption of each dwelling in the database can be estimated, the total annual energy consumption of the residential sector can be calculated from:

$$AERS = \sum_{i=1}^{n} AED_i \times W_i \qquad \text{Eq. 3.3}$$

Where AERS = annual energy consumption by the residential sector

AED_i = annual energy consumption of dwelling i

The Engineering Model involves the estimation of the annual energy consumption of each dwelling in the database using a building energy simulation program, and then extrapolating the energy consumption of the dwellings in the database to the entire residential sector using Eq. 3.3.

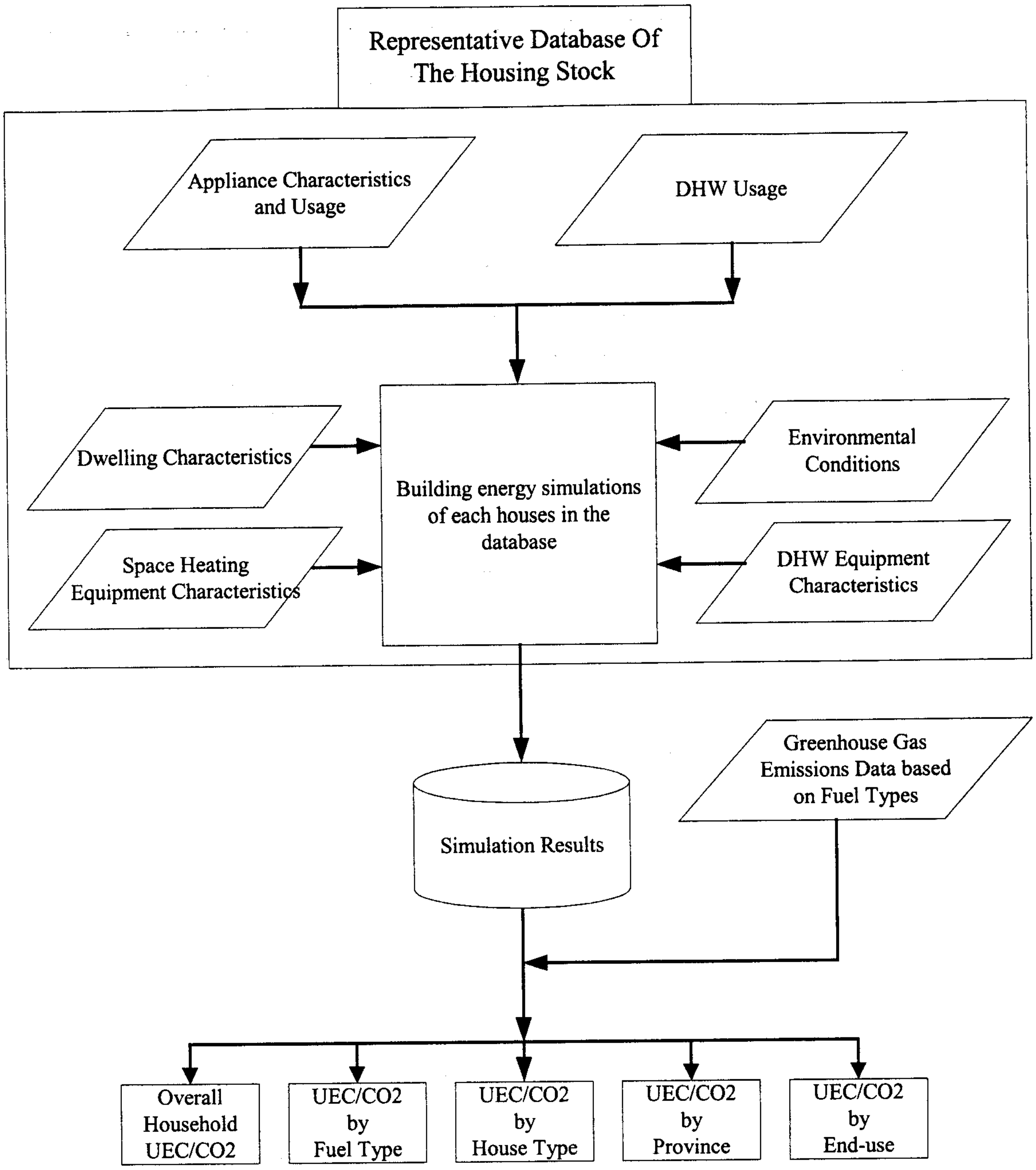

Figure 3.2: Overall model architecture

3.5 Modeling Approach

Since the proposed modeling framework involves a macro-based analysis of energy consumption rather than a micro-based physical modeling technique, a detailed parametric study on the cause and effect relationship of various variables that influence household energy consumption is highly desirable. As illustrated in Figure 3.3, overall household energy consumption is influenced by a large number of complex and interrelated factors from both the external and internal environment of the household. The model assumes that external factors such as climate, dwelling and equipment characteristics, as well as appliance usage patterns of a household are location and household specific, therefore they are fixed for a given household.

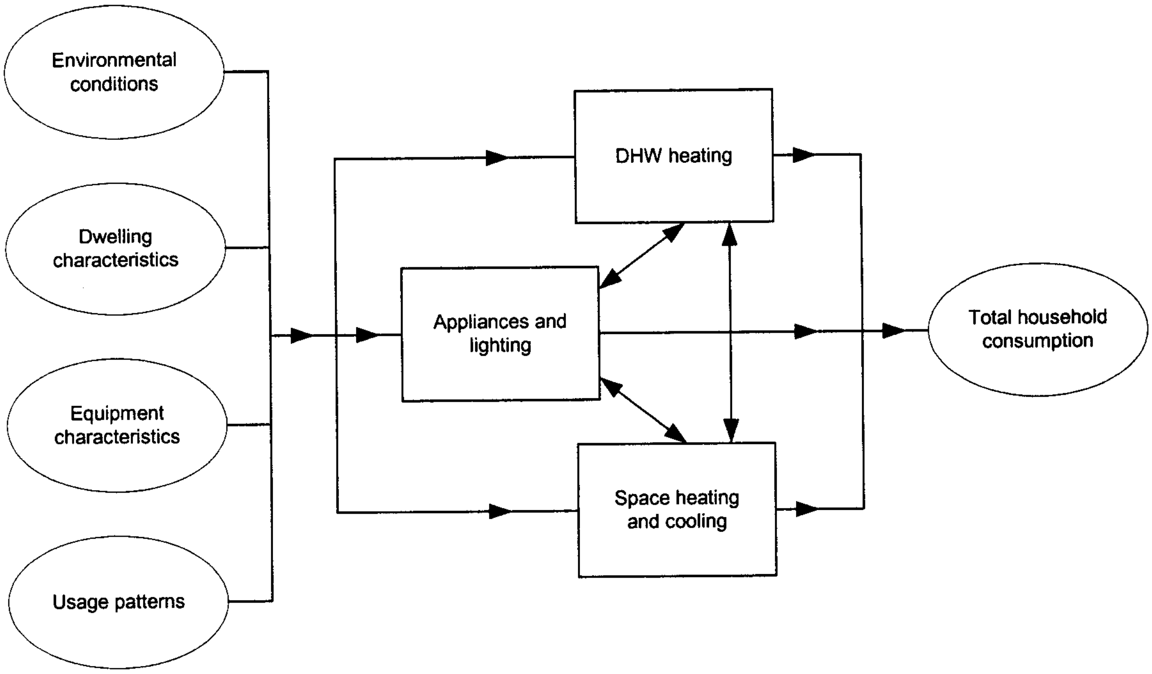

Figure 3.3: Schematic of interrelated factors influencing household energy consumption

The demands for i) electricity derived from appliance and lighting usage and ii) DHW requirements derived from appliance usage and personal usage, are proposed to be estimated separately. The energy demands for these two categories of end-uses not only directly influence their share of the total household energy consumption but also influence the space conditioning requirement. Heat gains from appliances, DHW and occupants would reduce space heating requirement in the heating season while they increase the space cooling requirement during the cooling season (Palmiter and Kennedy, 1983; Corum, 1986). Thus, both appliance and DHW end-uses directly and indirectly influence the total household energy consumption.

3.5.1 Appliance and Lighting End-uses

Because of the indirect effect of appliance energy consumption on the space conditioning requirement of a dwelling, knowledge on energy consumption from appliances and lighting is critical in estimating both space conditioning requirements as well as total household energy consumption. Obviously, appliance end-use estimates from direct metering studies are more accurate and preferred in any energy consumption modeling. However, information on appliance end-uses is scarce. Two most notable large scale appliance end-use metering projects in North America were the End-use Load and Consumer Assessment Project (ELCAP) by the Pacific Northwest Laboratory (Pratt et al., 1989) and the Electric Power Research Institute's Patterns of Energy Use by Electrical Appliances project (EPRI, 1979). In spite of the wealth of knowledge on the major appliance end-uses from these two metering projects, the information contained are dated and may not be directly applicable to the Canadian residential sector due to the obvious differences in climate, culture, life style, and socio-demographical characteristics between the two countries. Nonetheless, information provided by these major metering projects could provide some insights on appliance end-uses.

3.5.1.1 Lighting End-uses

Among different electricity end-uses, lighting consumption is probably the least understood component due to the difficulty and tedious nature in measuring such end-use in a household. In addition, lighting can be used in both indoor and outdoor environments in which heat gains may or may not directly contribute to the space-conditioning loads. Thus, in order to estimate lighting energy consumption, both indoor and outdoor usages must be considered in the modeling. Lighting energy consumption has been estimated with modest success by using self-reported survey on the number of lighting fixtures, wattage of fixtures and number of hours of usage by a number of research groups (Kelsey and Richardson, 1992; Bartlett, 1993; Nielsen, 1993; Market Facts, 1993; Fung and Ugursal, 1995; Fung and Ugursal, 1998). The energy consumption for lighting can be expressed (Fung and Ugursal, 1995; Fung and Ugursal, 1998) as:

$$\begin{aligned} UEC_{light,indoor} &= \sum Type_i \times Wattage_i \times Hour_i \\ UEC_{light,outdoor} &= \sum Type_i \times Wattage_i \times Hour_i \qquad \text{Eq. 3.4} \\ UEC_{light,total} &= UEC_{light,indoor} + UEC_{light,outdoor} \end{aligned}$$

Where $Type_i$ = Type of lighting fixture; incandescent, halogen, fluorescent, etc.

$Wattage_i$ = Total wattage of lighting fixture

$Hour_i$ = Total reported number of hours of usage for the fixture per year

3.5.1.2 Major Appliance End-uses

Major appliances (white goods) such as refrigerator, freezer, range/oven, dishwasher, clothes washer and dryer, contribute a large portion of the total household appliance electricity demand. These major appliance end-uses can be classified as discretionary and non-discretionary usages. Discretionary end-uses include appliances such as range/oven (cooking equipment), dishwasher, clothes washer and clothes dryer since energy consumption of such appliances are highly dependent on their usage. On the other hand, energy consumption of non-discretionary appliance end-uses such as refrigerator and freezer are highly dependent on their operating environments, i.e., ambient air temperature of the kitchen (or other locations of the dwelling where the appliances are located) rather than how often the doors are opened and how the appliances are loaded with food (Meier, 1997). Based on their ELCAP end-use monitoring project in the Pacific Northwest of the U.S., Pratt et al. (1993) reported that the variation of the amount of average energy consumption of refrigerators and freezers was relatively small compared to that of discretionary end-uses. They found that average metered monthly non-discretionary end-uses did not fluctuate during the heating season where indoor temperatures of homes were maintained at constant level by the space heating equipment. In addition, Meier (1997) and Meier and James (1997) reported, based on the findings of a number of studies, that energy consumption estimates for refrigerators and freezers obtained using laboratory labels (such as EnerGuide in Canada and Energy Guide Label in the U.S.[3]) were on average slightly higher than field metered energy consumption although there were wide variations in the estimates and observations for individual units. Thus, they concluded that it was possible to confidently predict field energy use by using energy label estimates. Therefore, UEC estimates of refrigerators and freezers can be obtained through the knowledge of such appliances' Make and Model Number[4] and the corresponding EnerGuide label consumption as follows:

$$\begin{aligned} UEC_{refrigerator} &= EnerGuide_{refrigerator,M\&M} \\ UEC_{freezer} &= EnerGuide_{freezer,M\&M} \end{aligned} \qquad \text{Eq. 3.5}$$

Similarly, discretionary appliance end-use consumption can be estimated from the Make and Model information combined with the corresponding EnerGuide label information and the reported usage since the energy consumption reported on the label of such

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[3] EnerGuide and Energy Guide Label are appliance energy consumption labeling systems used in Canada and United States, respectively.

[4] Make and Model Numbers of appliances refer to the appliance manufacturer and the product code.

appliances is based on a certain number of operation cycles per year. Thus, energy consumption of range or cooktop/oven, dishwasher, clothes washer and clothes dryer can be expressed as:

$$
\begin{aligned}
UEC_{range} &= EnerGuide_{range,M\&M} \times Usage_{range} / Load_{range,default} \\
UEC_{dishwasher} &= EnerGuide_{dishwasher,M\&M} \times Usage_{dishwasher} / Load_{dishwasher,default} \\
UEC_{clotheswasher} &= EnerGuide_{clotheswasher,M\&M} \times Usage_{clotheswasher} / Load_{clotheswasher,default} \\
UEC_{clothesdryer} &= EnerGuide_{clothesdryer,M\&M} \times Usage_{clothesdryer} / Load_{clothesdryer,default}
\end{aligned}
$$

Eq. 3.6

Where $UEC_{appliance}$ = Unit energy consumption of particular appliance under reported usage

$EnerGuide_{appliance,M\&M}$ = EnerGuide labeled UEC for a particular appliance of a particular Make and Model

$Usage_{appliance}$ = Reported usage in number of loads per year for such appliance

$Load_{appliance,default}$ = Number of loads per year used in EnerGuide label estimates

3.5.1.3 Minor and Miscellaneous Appliance End-uses

Besides lighting and major white good appliances, minor and miscellaneous appliances constitute a substantial portion of the total household electricity consumption. Estimates of such minor and miscellaneous appliance electricity consumption range from 1,866 kWh/year/household (or 23% of the total residential electrical appliance energy consumption) (Fung et al., 1997b) for Canada in 1993 to 25% (235 TWh) of the total residential electricity end-use for the U.S. in 1995 (Sanchez et al., 1998). Appliances such as microwave oven, television (TV), video cassette recorder (VCR), computer, and other home entertainment and office related electronic devices have become more prevalent, and are continuously increasing their share of energy consumption in homes. Thus, inclusion and accurate estimate of energy consumption by these appliances is paramount in overall residential energy consumption modeling and forecasting.

Due to the nature of their design and power demand characteristics, most minor and miscellaneous appliance energy consumption can, and should be divided into three components, namely active, low and standby power consumption[5] (Meier and Huber; 1997; Molinder, 1997; Nagakami et al., 1997; IEA, 1999; Aulenback et al., 2001; Fung et al., 2003). In most of these appliances (such as VCR), standby power consumption can be a major contribution to their total energy consumption (Rosen and Meier, 1999; Rosen and Meier, 2000a; Rosen and Meier, 2000b; BRANZ, 2002; Fung et al, 2003). Therefore, energy consumption of such appliances can be estimated if power demand and the amount of time of each consumption component of the end-uses are known:

$$\begin{aligned} UEC_{minor/miscelleneous} &= Wattage_{stanby} \times Hour_{standby} + Wattage_{low} \times Hour_{low} \\ &+ Wattage_{active} \times Hour_{active} \end{aligned} \qquad \text{Eq. 3.7}$$

Where $Hour_{standby}$ = Total number of hours per year appliance stays in standby mode

$Hour_{low}$ = Total number of hours per year appliance stays in low power/idle mode

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[5] Most appliances have more than one operational mode, and these modes usually have different power requirements. There is a wide range of appliance types, and a wide range of features is available for any one appliance. Consequently, researchers have used definitions for standby power that are somewhat different (Meier and Huber, 1997; Molinder, 1997; Nagakami et al., 1997; IEA, 1997; Aulenback et al., 2001; Fung et al., 2003). The definitions used in this work for the standby power mode categories are consistent with the IEA definition (IEA, 1997; Fung at al., 2003), and are given below:
Active power is the power requirement of the appliance in the mode in which the appliance is used for its intended use. Normally, the appliance draws the most power in this mode.
Low power differs depending on the appliance. For appliances with an energy saving or low power mode, such as computer monitors, computers, printers, and scanners, low power is the power requirement of the appliance in the energy saving mode. If there is more than one such mode, the low power measurement is taken in the low power mode with the lowest power requirement. For VCR's and stereo components, low power is the power requirement in the mode in which the appliance is only being partially used; for example, this is the mode when a VCR is on, but not playing a tape or recording, or when a computer is turned on, but is in a power saving mode.
Standby power is the power requirement of the appliance when the appliance is not functioning, or is off, or in a standby mode waiting to perform an intended function. The appliance should be turned off with the remote control if the appliance has one. Examples of this mode are when a television is turned off, or when a fax machine is not transmitting data.

$Hour_{active}$ = Total number of hours per year appliance stays in active mode

$$Hour_{standby} + Hour_{low} + Hour_{active} = 8760(hours/year)$$

3.5.2 Domestic Hot Water

Energy demand for domestic hot water is derived from the hot water consumption for such household activities as bath, shower, clothes washing, cooking, dish washing and other cleaning purposes. The temperature and amount of hot water demand at the end-use level for such services are highly dependent on the type of uses and these two quantities determine the amount of hot water required from the DHW heater. Most water end-use services require a moderate temperature range for practical and safety reasons. Services such as shower, bath, and kitchen and lavatory sink uses require temperature around 41°C (105 – 107°F) (Hopp and Darby, 1980). Actually, the delivered water temperature at the end-use level for such services is generally between 37°C and 45°C. Cooler than body water temperature may make uncomfortable feeling while higher than 45°C water temperature may cause potential burns.

Existing studies on DHW end-uses concentrate mainly on either the total electricity consumption by the water heating equipment or the total amount of hot water delivered by the equipment (EPRI, 1979; Perlman and Mills, 1985; Gladhart and Weihl, 1986; Kempton, 1988; Pratt et al., 1989; Warwick, 1995; Bouchelle et al., 2000). These studies report high seasonality of DHW energy usage in terms of electricity consumption and hot water volume from the hot water heater. However, these studies ignore the fact that hot water demands at the end-use service level (such as shower, bath, or sink uses) at or below 45°C with mixture of hot water from the hot water heating equipment and the cold water from the water mains. The hot water temperature from the hot water heating equipment is usually fixed for an individual household and usually set at approximately

55°C (usually between 50°C and 60°C) from the factory, while cold water temperature from the water mains is highly dependent on season and location of the household.

In addition, water usage pattern analyses conducted by Gladhart and Weihl (1986) in nine households located in the state of Michigan showed no noticeable changes, statistically, in mean water event (frequency of use) or end-use durations from season to season at individual household level. However, they have observed that there were some seasonal variations in average hot water volume demands for bathing and laundry. These observed seasonal variations in hot water volume demand did not show any definite seasonal trend for such end-uses. Their study also showed that most households took more frequent baths/showers with shorter duration in the summer than in the winter months. This behavior has a compensating effect on the overall end-use water (mixture of cold and hot water) demand for bathing/shower. As a result, detailed metering of both quantities and delivered water temperatures of such water end-uses is needed to further understand the overall DHW energy consumption.

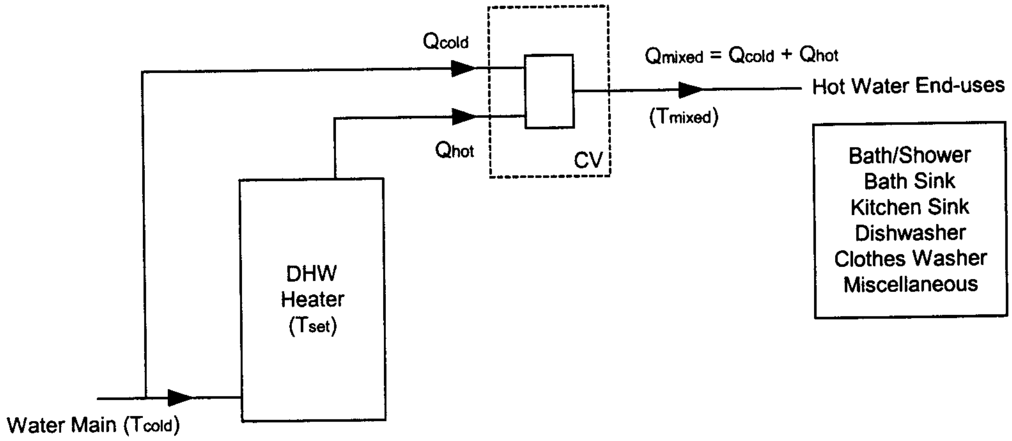

Figure 3.4: Schematic diagram of quantity and temperature flow diagram of residential hot water usage

The relationship among different variables affecting hot water requirement can be obtained by applying mass and energy balance on the control volume of the water end-use. Figure 3.4 presents the quantity and temperature flow diagram of residential hot water usage. The governing equation for DHW end-use can be expressed as:

$$\begin{aligned} &(Q_{cold} \times T_{cold}) + (Q_{hot} \times T_{set}) = T_{mixed} \times Q_{mixed} \\ &and \\ &Q_{mixed} = Q_{cold} + Q_{hot} \end{aligned} \qquad \text{Eq. 3.8}$$

where Q_{cold} = Quantity of cold unheated tap water usage for particular end-use

Q_{hot} = Quantity of hot water usage from DHW heater for particular end-use

Q_{mixed} = Quantity of total water usage for particular end-use

T_{cold} = Temperature of cold unheated tap water

T_{set} = Temperature of hot water from DHW heater

T_{mixed} = Temperature of mixed water delivered for particular end-use

Variables such as quantity and temperature of delivered water, Q_{mixed} and T_{mixed}, are highly dependent upon end-uses, household and personal preferences, and possibly seasons. Temperatures of delivered water usually fall between a very narrow range of 37 and 45°C, while temperature of cold and hot water, T_{cold} and T_{set}, are site specific and they can be obtained through meteorological records and equipment settings.

DHW demands can be estimated from Eq. 3.8 once all water end-use specifics about a household are known. The energy consumption for such DHW demand can be estimated based on the household specific DHW heater characteristics (such as size, insulation level, energy conversion efficiency and standby loss), placement (heated or unheated portion of the dwelling) and locale (ground/main water temperatures). The main determinant is the amount of hot water requirement, Q_{hot}, by the household. Thus, the quantity of hot water required for water end-use services can be expressed as:

$$Q_{hot} = \frac{Q_{mixed}(T_{mixed} - T_{cold})}{T_{set} - T_{cold}} \qquad \text{Eq. 3.9}$$

Household hot water usage such as dishwasher and clothes washer end-uses can be derived from self-reported usage and information on appliance characteristics obtained from household surveys. On the other hand, hot water requirement estimates from bath/shower and kitchen and lavatory sink uses require detailed information on the frequency, duration, fixture flow rate, and desired water temperature. Such information is scarce and unavailable at present. However, one can estimate the total amount of hot water requirement by adding up all hot water end-uses if data can be obtained from surveys and metering studies:

$$Q_{hot,total} = \sum_{i=1}^{n} Q_{hot,i} \qquad \text{Eq. 3.10}$$

Energy consumption or fuel usage for hot water heater is influenced by the fuel type, conversion efficiency, standby and stack losses of the heating equipment as well as the quantity and temperature of desired hot water. Schematic of energy and mass flow diagram for residential DHW heater is illustrated in Figure 3.5. Conversion efficiency (including stack loss) is affected by fuel and equipment type as well as outdoor temperature, while standby loss is influenced by the size and insulation level of the equipment as well as the temperature difference between tank water and ambient/room air. Energy requirement for the delivered hot water can be calculated based on the amount of hot water and the required temperature rise, $T_{set} - T_{cold}$. Thus, the unit energy consumption of DHW can be formulated as:

$$\begin{aligned} UEC_{DHW} &= E_{in} = \sum_{wholeyear} \{E_{cs} + E_{sb} + E_{DHW}\} \\ E_{cs} &= f(type, fuel, T_{outdoor}) \\ E_{sb} &= f(size, insulation, T_{set}, T_{room}) \\ E_{DHW} &= f(Q_{hot}, T_{set}, T_{cold}) \end{aligned} \qquad \text{Eq. 3.11}$$

Where UEC_{DHW} = Annual unit energy consumption of DHW

E_{cs} = Energy losses due to conversion and stack losses for each period

E_{sb} = Energy losses due to standby for each period

E_{DHW} = Energy requirement for the required amount of hot water at the desired temperature, T_{set}, for each period

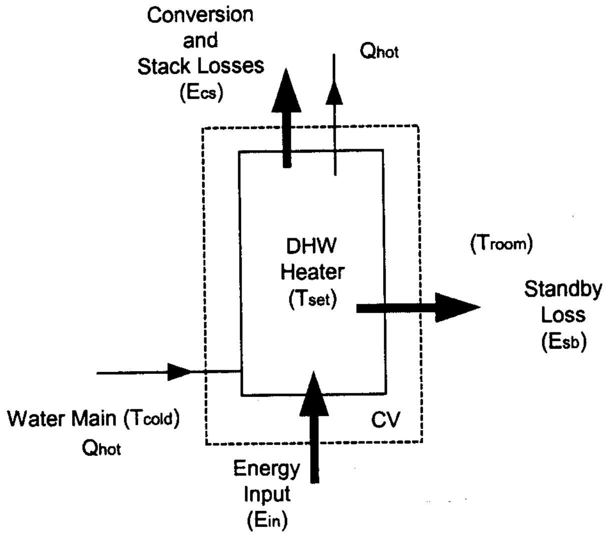

Figure 3.5: Schematic diagram of control volume for residential DHW heater

Since outdoor, ambient/room, and cold water temperatures are seasonal, and location and placement specific for each individual household, annual unit energy consumption for DHW heater can be rewritten based on the seasonal or monthly changes in temperatures as:

$$UEC_{DHW} = E_{in} = \int_{wholeyear} \{E_{cs}[T_{outdoor}(\theta)] + E_{sb}[T_{room}(\theta)] + E_{DHW}[T_{cold}(\theta)]\}d\theta \qquad \text{Eq. 3.12}$$

where θ is time period of interest in year, season, or month.

3.5.3 Space Conditioning

Space conditioning (both heating and cooling) requirements are mainly driven by solar and internal heat gains, dwelling characteristics, heating and cooling equipment characteristics and efficiencies, as well as both indoor and outdoor environments such as preferred indoor temperature and local climate. With sufficient information on (i) internal heat gains from occupants, appliances and lighting and DHW standby, (ii) dwelling, space conditioning equipment and their operating characteristics, and (iii) local climatic conditions, one can estimate the annual energy consumption of a dwelling using a variety of building energy simulation software.

A simple representation of different heat flows in a dwelling during the heating season is shown in Figure 3.6. With the illustrated heat flow shown in Figure 3.6, the space heating requirement from the furnace, $q_{furnace}$, in maintaining a desired indoor temperature can be written as:

$$q_{furnace} = \sum q_{heatloss} - \sum q_{heatgain} \qquad \text{Eq. 3.13}$$

where $q_{furnace}$ = Space heating requirement

$q_{heatloss}$ = Total heat loss

$= \lfloor q_{roof} + q_{window} + q_{door} + q_{wall} + q_{belowgradewall} + q_{slab} + q_{infiltration} + q_{ventilation} \rfloor$

$q_{heatgain}$ = Total heat gain

$= \lfloor q_{solar} + q_{appliance} + q_{light} + q_{DHW\_standby} + q_{occupant} \rfloor$

Thus, the space heating energy consumption, $UEC_{spaceheating}$, can be calculated based on the equipment efficiency as:

$$UEC_{spaceheating} = UEC_{furnace} = \int_{wholeyear} \left(\frac{q_{furnace}}{\eta_{furnace}} \right) d\theta \qquad \text{Eq. 3.14}$$

where $UEC_{spaceheating} = UEC_{furnace}$ = Annual unit energy consumption for space heating

$q_{furnace}$ = Space heating requirement

$\eta_{furnace}$ = Efficiency of the heating equipment

θ = Time in month, season or year

The quantities for various heat gains and heat losses are dependent on (i) household ownership and usage pattern of appliances, (ii) equipment size and characteristics, (iii) dwelling physical characteristics, and (iv) local climate and season.

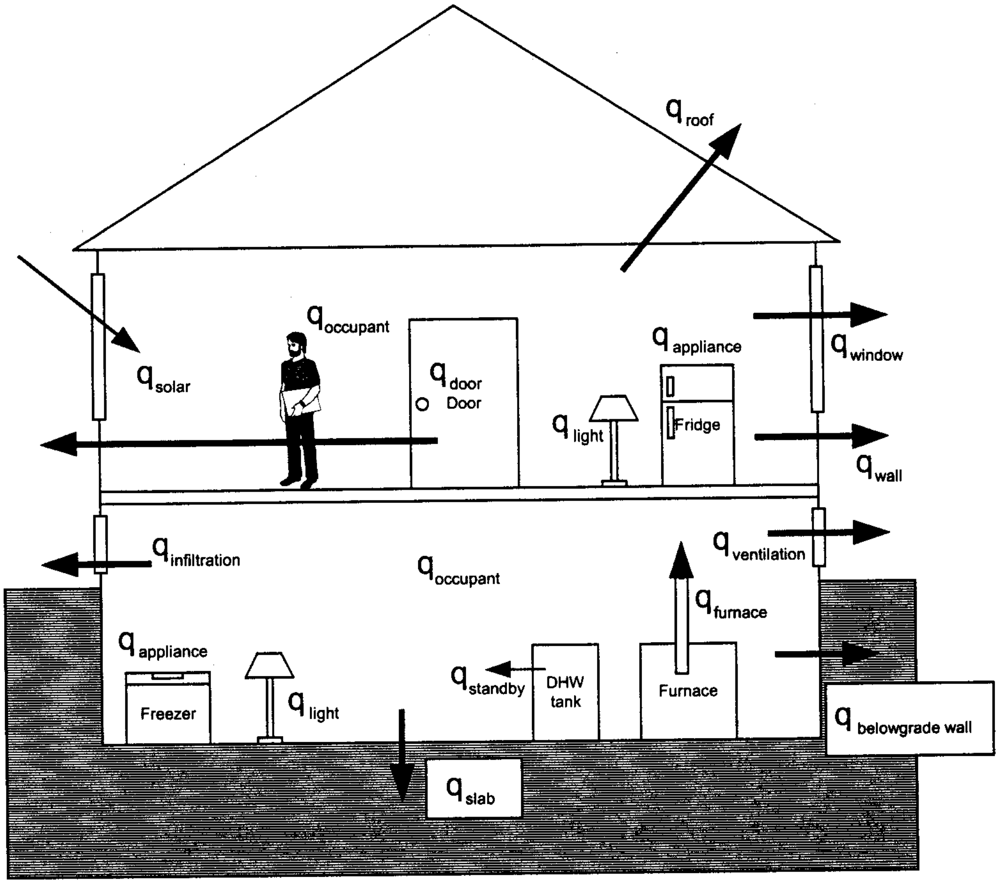

Figure 3.6: Schematic diagram of heat flow of a dwelling (heating season)

Similarly, space cooling energy consumption, $UEC_{spacecooling}$, can be calculated based on the cooling equipment coefficient of performance and the space cooling energy requirement as:

$$UEC_{spacecooling} = UEC_{A/C} = \int_{wholeyear} \left(\frac{q_{A/C}}{COP_{A/C}} \right) d\theta \qquad \text{Eq. 3.15}$$

where $UEC_{spacecoolting} = UEC_{A/C}$ = Annual unit energy consumption for space cooling

$q_{A/C}$ = Space cooling requirement

$COP_{A/C}$ = Coefficient of performance of the cooling equipment.

Contrary to the heating mode, excess heat (and moisture) must be extracted from the dwelling to provide comfortable indoor conditions during the cooling season. Thus, all internal and solar heat gains in a dwelling in addition to the heat gains through building envelop via heat transmission as well as infiltration and ventilation must be removed by the cooling equipment. By applying an energy balance, the cooling load requirement, $q_{A/C}$, can be summarized as:

$$q_{A/C} = \sum q_{heatgain} - \sum q_{heatloss} \qquad \text{Eq. 3.16}$$

3.6 Modeling Resource Requirements

Bottom-up engineering based modeling of end-use energy consumption such as the one proposed in this work requires extensive resources in terms of data for model development, computation power for programming, and building energy simulation. Therefore, first the data requirement for the proposed model will be presented. Existing databases will be reviewed for modeling suitability, and new survey and/or metering requirements will then be identified to provide the missing information. Secondly, a brief review on suitable building energy simulation software will be presented and a suitable simulation engine for the proposed model will be proposed. Thirdly, the databases required to develop the model will be analyzed. And finally, the costs of the required survey and metering studies, and the modeling will be presented.

3.6.1 Data Requirements

A flexible and relational database architecture is necessary and usually required to handle large amounts of interrelated information needed for the proposed residential model framework that includes a large volume of data on social, economical, demographical, structural, weather, and equipment/appliance characteristics and usage patterns. The overall data structure for the proposed model framework is illustrated in Figure 3.7. A minimum of four sets of databases is required for providing the required data and information regarding the households that represent the housing stock. These databases include (i) Dwelling characteristics database, (ii) Weather and environmental conditions database, (iii) Equipment characteristics database, and (iv) Usage patterns database. In addition, databases for information on i) market conditions, ii) household socio-econo-demographical characteristics, iii) detailed metering end-use consumption, and iv) whole house billing records should also be created for model evaluation and validation purposes, as well as for econometric and behavioral based studies. Finally, information from a detailed end-use metering project could provide further insight and validation for the model. However, such detailed information on metered end-uses is not essential for model development and is very costly to obtain. Figure 3.7 illustrates the proposed database requirements and their causal relationships.

The most comprehensive and representative survey on household energy use in Canada is the Survey of Household Energy Use (SHEU) (Statistics Canada, 1993a and 1997). This survey was first conducted by Statistics Canada for Natural Resources Canada (NRCan) in 1993 using a combination of mail-in and telephone interview techniques. The 1993 SHEU database contains detailed information on household socio-demographical characteristics as well as equipment and appliance features and some usage patterns on more than 10,000 households from ten provinces (Newfoundland, Prince Edward Island, Nova Scotia, New Brunswick, Quebec, Ontario, Saskatchewan, Manitoba, Alberta and British Columbia) across Canada. SHEU 1993 also contains self-reported usages for certain appliances, such as dishwasher, clothes washer and clothes dryer. The second SHEU survey (SHEU 1997) was conducted in 1997 and contained detailed information on a total of 4,414 low-rise, single-family dwellings in ten provinces across Canada. In contrast to the telephone interview technique used in the SHEU 1993, SHEU 1997 was conducted through in-person interview with the household members who were the most familiar with the characteristics of the house and its equipment, with the aid of a computer. In essence, SHEU 1997 was an improvement over the SHEU 1993. However, SHEU 1997 contained fewer questions on building physical characteristics as well as appliance ownership, characteristics and usage compared to SHEU 1993. Thus, it is proposed that SHEU 1993 would serve as the foundation on which the model will be based upon.

SHEU survey used the “stratification technique” (Statistics Canada, 1993a) to ensure that each household in the database represents a number of houses in the housing stock with similar features and characteristics, and that the SHEU database is representative of the Canada housing stock.

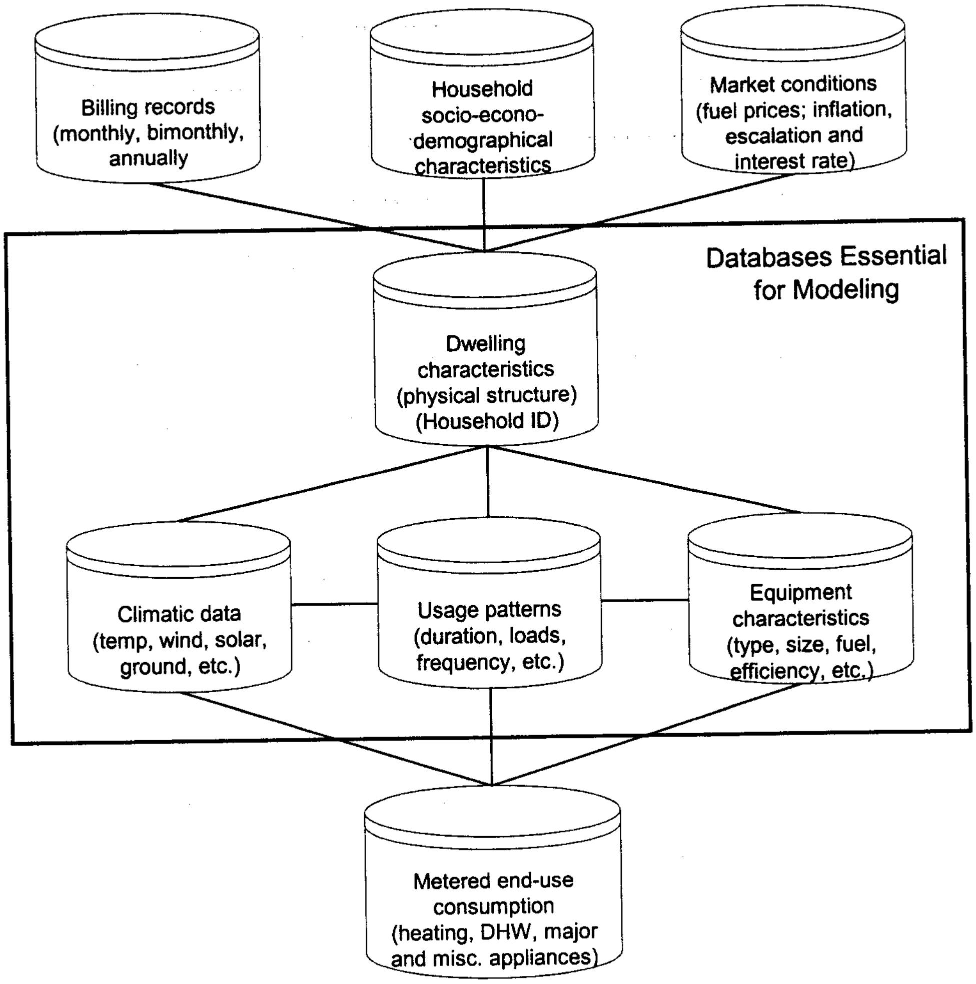

Figure 3.7: Graphical representation of data requirements for the modeling framework

3.6.2 Proposed Data Collection Strategy

In order to model detailed household end-use energy consumption, one must obtain all the necessary variables that govern different household end-uses as illustrated in the previous sections. Major residential end-uses include space heating, domestic water heating, and appliances. Contrary to space heating energy consumption, appliance and DHW usages are mainly discretionary and subject more to the behavioral deterministic variables than the physical factors. Thus, information on detailed dwelling characteristics, heating equipment characteristics, DHW usage, as well as appliance ownership, characteristics and usage should be collected and available for the proposed bottom-up engineering based end-use energy consumption modeling.

Data on household energy consumption can be collected through a combination of 1) mail-in/phone survey, 2) energy auditing, and 3) end-use metering. Each data collection methodology has its own advantages and disadvantages, and each serves a different purpose. Conventional household surveys provide the least expensive of the three data collection methodologies. General household surveys usually provide adequate general information about the households and appliance ownership, but they often provide inadequate or imprecise information on technical details for the dwelling construction and equipment specifications required for engineering based modeling. Thus, information from the general household energy use survey should be augmented by other targeted surveys, and auditing and metering campaigns. It should be noted that obtaining accurate and meaningful survey data is a tedious and time-consuming process. A brief but complete combination of survey and metering campaign for the proposed and future residential energy end-use modeling framework is illustrated in Figure 3.8. The suggested survey and metering campaign shown in Figure 3.8 is based on the data requirement for the proposed modeling framework with consideration of the existing survey and metering data available in Canada.

The proposed surveys and metering campaign illustrated in Figure 3.8 include the following generalized campaigns:

- General Household Energy Use Survey (HEUS): This general mail-in/phone household energy use survey would provide general information on household socio-demographics, dwelling and heating equipment characteristics, appliance ownership, and energy billing records. Survey of Household Energy Use (SHEU) is a similar survey of this nature, and survey data is available for the 1993 and 1997 housing stock.

- Appliance and DHW Characteristics and Usage Survey (ADCUS): This survey would provide detailed appliance characteristics, specification (such as EnerGuide Make and Model number), and self-reported usages. Currently, there is no such survey available, it is proposed that this survey be incorporated in the future SHEU survey or EnerGuide for Houses (EGH) home audit campaign for data augmentation.

- Household Energy Audit (HEA): Household energy audits conducted by professional energy auditors would provide detailed engineering data (such as insulation level, air leakage rate, heating equipment efficiencies) that are crucial to model development. It is recommended to carry out an audit to obtain such data because it is difficult to obtain these data accurately by conventional surveys. EnerGuide for Houses (EGH) initiative is a similar home energy audit campaign currently implemented by the Canadian Federal Government.

- On-site Spot Measurement of Active and Standby Power (SMASP): Spot measurement of appliance active and standby power consumption campaign is required mainly for the collection of power requirements by numerous minor and miscellaneous appliances that are common in today's households. Information on both ownership and power consumption for these minor and miscellaneous appliances are generally not available from the general household survey and EnerGuide estimates. Data from a recent spot measurement campaign is available for the province of Nova Scotia (Aulenback et al., 2001; Fung et al., 2003) and similar data for different regions of Canada should be collected through future campaigns.

- Detailed End-use Metering: Detailed end-use metering campaigns provide detailed long-term energy consumption data for different residential end-uses. Such detailed end-use consumption data are not generally required if compatible and suitable information is available for the proposed modeling framework. However, such a metering project would provide i) detailed information on how and when different appliances/equipment are being utilized, and their usage related to other potentially related factors such as climate, economics, culture, behavior, and demographics, and ii) data for model evaluation and validation. Currently there is no such metering campaign being planned.

The information presented in Figure 3.8 includes (i) the type of survey and metering campaigns, (ii) the approximate number of households required, and (iii) the estimated cost of each proposed campaign. Since energy auditing and metering campaigns are costly to administer, particularly where intended households are scattered in wide geographic areas, the proposed data collection for such campaigns are divided into six regions instead of 13 provincial/territorial jurisdictions in Canada. The suggested six regions for the proposed metering campaigns are the West (British Columbia), Prairies (Alberta, Saskatchewan and Manitoba), Ontario, Quebec, Atlantic (New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador), and the North (Yukon, Northwest Territories and Nunavut).

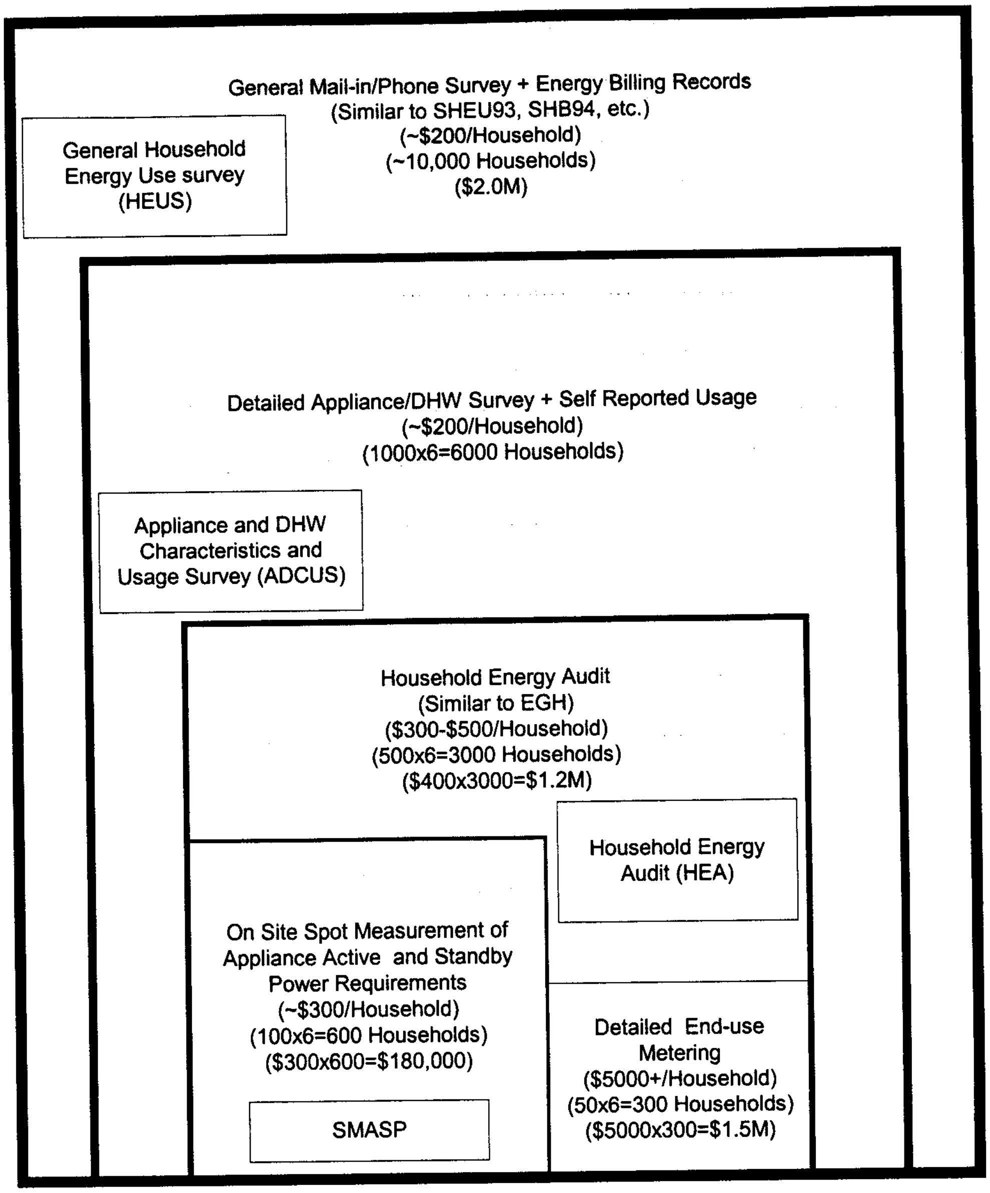

Figure 3.8: Proposed data collection scheme

3.6.3 Cost of Data Collection

With the general information about the data requirement for the proposed model presented in the previous sections, data collection cost could be estimated based on the information available from existing surveys and metering.

3.6.3.1 General Household Energy Use Survey

The total cost of conducting SHEU survey (similar to the proposed General Household Energy Use Survey) was approximately $2,000,000 (Bourbeau, 1997) or $200 (in 1993$) per house.

Since the proposed appliance and DHW characteristics and usage survey (ADCUS) can be conducted as i) a part of the large national survey in SHEU, ii) a part of home energy auditing initiative in EGH, iii) a part of appliance active and standby power requirement metering project, or iv) as an independent web based interactive survey, the incremental cost of collecting such data would be relatively small compared to the primary survey that it is attached to.

3.6.3.2 Home Energy Auditing

A large scale home energy audit program, the EnerGuide for Houses (EGH) Initiative, was launched in Canada in April 1998. The initiative was subsidized by Natural Resources Canada. EGH is a Government of Canada program established to provide homeowners with independent expert advice concerning the energy efficiency level of their homes. The program was developed by the Office of Energy Efficiency at Natural Resources Canada (NRCan) in cooperation with the Canada Mortgage and Housing

Corporation to expand the energy evaluation industry, and to improve the energy efficiency level of Canadian housing (NRCan, 2001b). Participation in the program was voluntary, and interested homeowners contacted EGH representatives in their areas to arrange the energy audit. EGH program calculated a measure of energy efficiency called "EnerGuide Rating" for each of the houses audited. As of December 2000, EGH program has acquired data from approximately 20,000 houses across Canada. The cost of such home energy audit was estimated to be between $300 and $500 per house (NRCan, 2001c) with the total annual budget of $3,000,000.

Howell-Mayhew Engineering Inc. (1995) estimated that 12 man-hours are required to complete a detailed whole-house energy audit. Thus, the cost would be approximately $900 per house if $75 per hour of labor cost is assumed. Similarly, Fung and Ugursal (1999) have estimated the cost of collecting data through detailed household energy and environmental audit to be approximately between $1,000 and $1,500 per house. The higher reported estimated cost was due to the fact that home audits from these two projects were more involved and supposed to collect extra information on environmental and indoor air quality compared to the EGH home energy audit.

3.6.3.3 Spot Measurement of Appliance Active and Standby Power

The cost of an on-site appliance spot measurement of active and standby power consumption project is estimated to cost between $250 and $300 per house (Fung, 2000). In a study conducted by Aulenback et al. (2001) to measure appliance active and standby power consumption, the total cost of such spot metering project was approximately $20,000 (in 2000$) for collecting data on appliance active and standby power consumption from 75 houses.

3.6.3.4 Appliance End-use Metering

Direct residential metering is usually conducted in one of the three ways. The first method is metering at the whole house level using existing electro-mechanical power/gas/water meters provided by the utility. The second method is a refined version of the former system in which data is collected at a much shorter time interval (i.e., higher data sampling rate), usually in the order of 10 seconds, in order to obtain a very detailed energy/gas/water consumption load profile (Mayer et al., 1999; EPRI, 1997; Shin et al., 1996; Mayer and DeOreo, 1995). With field collected appliance usage "signatures" for each individual end-use, the collected high-resolution whole house level usage profiles can be disaggregated into different end-use specific usage profiles by using customized signal processing and/or rule-based pattern recognition algorithms (Mayer et al., 1999; EPRI, 1997; Shin et al., 1996; Mayer and DeOreo, 1995). These "appliance signatures" include power demands for electric appliances, natural gas flow rates for gas appliances and water flow rates, usage durations, and total flow volumes for water end-uses. Projects such as the Non-intrusive Submetering of Residential Gas Appliances from Tokyo Gas (Shin et al., 1996), the Residential End Uses of Water Study (REUWS) from American Water Works Association (Mayer et al., 1999), and the Non-intrusive Appliance Load Monitoring System (NIALMS) (Shin et al., 1996) and others from Electric Power Research Institute (EPRI, 1997), Quantum Consulting, and Farinaccio and Zmeureanu (1999) all used a similar methodology to disaggregate residential end-uses from metered whole house energy/water demand data. However, up till now, this method of end-use disaggregation has only been demonstrated to be effective and accurate enough for use with household water end-use monitoring due to difficulties in separating individual end-use demand in situations where more than one appliance may be in use at the same time, and because electric and gas appliances generally have variable energy demand when operating under different conditions and/or settings.

The third method is a full-fledge end-use metering campaign using transducers and a data logging/acquisition system. In the past, direct appliance end-use metering was complicated and costly due mainly to the high cost and intrusive nature of the computerized data logging and acquisition equipment, and limited computational processing and electronic data storage resources. End-use energy consumption was usually metered at the circuit level with customized voltage and ampere transducers coupled with a microprocessor based data acquisition system. Data were usually collected and integrated at an hourly (or 15 minutes) rate to limit the amount of memory and data storage required. The collected data were either stored in an on-site computer for later retrieval, and/or uploaded at regular intervals to a remote centralized data collection computer through telephone lines using a built-in modem. Nightly uploading of collected data was usually preferred for large-scale long-term metering projects to minimize the number of site visits required. The major drawbacks of such metering projects are 1) the intrusive nature of the equipment used, 2) the fact that only end-use on each circuit level (not the individual appliance) could be metered and 3) the relatively low resolution of the sampling rate (usually one hour).

More recently, a new direct metering approach was employed in France by Sidler (1995 and 2000). In each of the three metering projects, a metering/data logging system called DIACE was used. DIACE is designed and manufactured by Landis and Gyr (http://www.landisgyr.com) specifically for these metering projects. The DIACE system employs a group of pocket-sized in-line watt meters which are connected to individual appliances in series. These pocket-sized watt meters scan the wattage used by each appliance every 10 seconds and then integrate the total every 10 minutes. A “collector”, usually located close to the telephone line in the house, regularly interrogates these pocket-size watt meters and downloads their integrated 10-minute energy consumption data through the household power lines. Every night the “collector” uploads the collected data to a remote centralized data storage system through the telephone line using the built-in modem. With such a system, each individual appliance end-use can be measured directly without the interference of other appliances connected to the same circuit. In addition, the DIACE system used in the French projects is flexible, compact and non-intrusive compared to the older systems used by the ELCAP project (Pratt et al., 1993) and other similar projects from Florida Solar Energy Center (FSEC) (Bouchelle et al., 2000; Bouchelle and Parker, 2000; James et al., 1997; Merrigan et al., 1983; Merrigan and Parker, 1993; Parker et al., 1996; Parker et al., 1997; Parker et al., 2000; Parker et al., 2001). However, the cost of the DIACE system used in the French studies is not available in the literature.

The reported cost estimates on metering equipment vary broadly, mainly depending on the vintage of the project and the number of variables measured. Older reported equipment cost estimates were ranging from US$5,000 to US$10,000 each. An equipment cost estimate was obtained for the FSEC projects (Parker et al., 1996) through Danny Parker of Florida Solar Energy Center. The equipment was of an older type with a full-fledge data acquisition system (CR10 data logger from Campbell Scientific - http://www.campbellsci.com/) with power transducers connected directly to the circuit breakers. The cost of equipment alone (with only two power transducers) was approximately US$2,500, and each additional power transducer cost US$220. Thus, if one would require to measure up to 16 different end-uses per house (which is thought to be the minimum number of end-uses from today's equipment laden households), the total equipment cost per house would be approximately US$5,600. In addition to this, there would be an additional cost of installation of the equipment. However, it should be noted that this estimate is from one study. It is probable that less expensive data acquisition systems could be realized if a project was at hand, and equipment manufacturers were asked to provide quotations.

The cost of a typical data collection project involving a detailed all end-use metering protocol was estimated by Eto et al. (1991) and Bowman et al. (1994) to be between US$4,000-US$10,000 per house. The cost of metering equipment was estimated to be approximately US$5,000 per house by Parker et al. (1996) for most of the metering projects conducted by the FSEC during the 80s and 90s. And the most recently reported whole house end-use metering equipment cost was approximately US$3,500 or CAD$5,400 (NZ$7,000) used by the New Zealand Household Energy End-use Project

(HEEP) (BRANZ, 2002). In addition to the direct cost of metering equipment, Sandusky et al. (1993) reported approximately US$700 and US$75-$125 per site/household for site recruitment and nuisance payment, respectively, were required for their comprehensive End-use Load and Consumer Assessment Program (ELCAP) end-use metering project.

Considering the potentially large number of household appliances used in today's homes, metering equipment with the combination of the traditional full-fledge micro-processor based metering equipment (Parker et al., 1996; BRANZ, 2002) and the French DIACE system (Sidler, 1995 and 2000) would be required for the proposed end-use metering campaign. The traditional circuit level metering equipment are candidates for major end-uses such as electric space heating, DHW heating, air-conditioning, clothes dryer, oven/range where dedicated circuits are generally required. On the other hand, DIACE system is more suitable for the minor and miscellaneous appliances or appliances that do not require a dedicated circuit. Appliances in this category would include dishwasher, clothes washer, refrigerator, freezer, TV, VCR, computer, audio equipment, and so on. With rapid progression on modern electronics and communication equipment, and considering the economies of scale, the estimated equipment cost associated with the proposed end-use metering project would probably be under $5,000 per house.

3.6.3.5 Overall Data Collection Cost

In order to obtain the required information for the understanding of different residential energy end-uses and the development of a comprehensive and representative bottom-up engineering based residential energy model, the proposed combination of survey and metering campaigns proposed in Section 3.6.2 is required. The total cost of collecting and metering the proposed detailed data on the socio-economic and behavioral variables of the households, physical structure and heating equipment characteristics of the dwellings, as well as the features, power requirements and usage patterns of major, minor and miscellaneous appliances would be approximately $500 per dwelling or five million dollars if information from a total of 10,000 households across Canada was to be acquired for the analysis. Since only a subset of the 10,000 would be subjected to the more costly metering and home energy auditing campaigns, the total cost of all the proposed survey, metering and auditing campaigns would be divided by the total of 10,000 households. The estimated total and per household data collection costs for different surveys and metering projects proposed for the analysis are depicted in Figure 3.8. As can be seen from Figure 3.8, large portion of the total estimated data collection cost is coming from the two end-use metering projects. The expensive nature of direct metering is mainly due to the high cost of equipment and the long duration needed for such data collection activities. Data collected from detailed end-use metering is crucial in providing insights to better understand different household energy end-uses as well as in determining the accuracy of the final model. Active involvement by all levels of governments, utilities, universities, non-profit organizations, and the public during all stages of the campaign, and careful planning and administration may reduce the cost of data collection.

3.6.4 Simulation Tools

In order to accurately estimate the overall household energy consumption one would require modern building energy simulation tools. The level of detail and complexity of building description, and the accuracy of estimation of modern building simulation software vary considerably. Increasing accuracy usually increases data requirements on building and equipment descriptions and climatic variables, thus requiring extensive data collection (which can be expensive), and long simulation time. On the other hand, low building simulation prediction confidence increases uncertainty level in the overall model. Thus, building energy simulation software selection is critical in balancing between overall model prediction accuracy and resource requirements. The following sections provide brief descriptions of the most commonly used simulation engines.

3.6.4.1 Hour-by-Hour Simulation Programs

3.6.4.1.1 ESP-r

Environmental System Performance (University of Strathclyde, 2002), ESP-r, allows an in-depth appraisal of the factors which influence the energy and environmental performance of buildings (DOE, 2001a). The ESP-r system has been the subject of sustained development since 1974 with the objective of simulating building performance in a manner that a) is realistic and adheres closely to actual physical systems, b) supports early-through-detailed design stage appraisals, and c) enables integrated performance assessments in which no single issue is unduly prominent (Aasem et al., 1994; DOE, 2001a, University of Strathclyde, 2002).

ESP-r attempts to simulate the "real world" building environment as rigorously as possible, and to a level which is consistent with current best practice in the international building simulation community. By addressing all aspects simultaneously, ESP-r allows the modeler to explore the complex relationships between a building's form, fabric, air flow, plant and control. ESP-r is based on a finite volume, conservation approach in which a problem (specified in terms of geometry, construction, operation, leakage distribution) is transformed into a set of conservation equations (for energy, mass and momentum) which are then integrated at successive time-steps in response to climate, occupant and control system influences. ESP-r comprises of a central Project Manager around which are arranged support databases, a simulator, various performance assessment tools and a variety of third party applications for CAD, visualization and report generation.

With ESP-r functionality, simple models and operating regimes composed in a few minutes can be extended, in steps, to encompass the simultaneous solution of fabric (in 1/2/3 dimensions), air flow (network and/or coupled, transient computational fluid dynamics (CFD)), electrical power, embedded renewable sources, plant system components, indoor air quality, and lighting. Building energy and flow simulations can be undertaken at time step of one minute to one hour, and system simulations can be from fractions of a second to an hour.

In addition to the state of the art standard simulation features, ESP-r has the capability to simulate many innovative or leading edge technologies including daylight utilization, natural ventilation, combined heat and electrical power generation and photovoltaic facades, CFD, multi-grid generation, and control systems. ESP-r specialist features require detailed knowledge of the particular subject. ESP-r is widely recognized and used for building simulations and researches, and it is one of the standard simulation programs for the International Energy Agency (IEA) Building Energy Simulation Test (BESTEST) procedure (Judkoff and Neymark, 1995a and 1995b). Although robust, ESP-r is still primarily intended as a research tool. ESP-r is made available at no cost under an Open Source license from University of Strathclyde (ESP-r is available for free from http://www.esru.strath.ac.uk/Programs/ESP-r.htm).

3.6.4.1.2 DOE/Blast/EnergyPlus

DOE was developed in the 1970s by the Simulation Research Group of the US Department of Energy (DOE). DOE-2 building energy analysis program was designed to assist engineers and architects in predicting the energetic performance of their building and mechanical system designs under actual weather conditions. Program development was guided by several objectives: the description of the building entered by the user was to be readily understood by non-computer scientists; the calculations were to be based upon well-established algorithms; the program was to permit the simulation of commonly available heating, ventilating, and air-conditioning equipment; the costs of running the program were to be minimal; and the predicted energy use of a building was to be acceptably close to measured values (Buhl et al., 1979; Diamond et al., 1986).

DOE-2 is an hour-by-hour, multiple zone whole-building energy analysis program that can predict energy performance and life-cycle cost of operation. It is based on the ASHRAE endorsed Transfer Function method as the basis for the zone heat transfer model. DOE-2 is widely recognized as the industry standard and is one of the standard simulation programs for the International Energy Agency (IEA) Building Energy Simulation Test (BESTEST) procedure (Judkoff and Neymark, 1995a and 1995b). In addition, DOE-2 serves as the basis for most building regulations, codes, and standards in the US. DOE-2 currently costs US$575.00 for use in Canada.

Building Loads Analysis and System Thermodynamics (BLAST) building simulation program was developed by the US Army Construction Engineering Research Laboratories (CERL) to investigate the energy performance of new or retrofit building design options of almost any type and size (BLAST Support Office, 1992). In addition to performing peak load (design day) calculations necessary for mechanical equipment design, BLAST also estimates a facility's annual energy performance which is essential for the design of solar and total energy (such as cogeneration) systems and for determining compliance with design energy budgets.

BLAST analysis program encompasses three major subprograms which compute hourly requirements of the space loads, calculates demands (hot water, steam, gas, electrical, chilled water) of the building and air-handling systems, and computes the annual fuel and electrical power consumptions. The heart of BLAST's space loads prediction is the room heat balance. For each hour simulated, BLAST performs a complete radiant, convective, and conductive heat balance for each surface of each zone described and a heat balance on the room air. This heat balance includes transmission loads, solar loads, internal heat gains, infiltration loads, and the temperature control strategy used to maintain the space temperature. BLAST performs hourly simulations of buildings, air handling systems, and central plant equipment in order to provide mechanical, energy and architectural engineers with accurate estimates of a building's energy needs. The zone models of BLAST, which are based on the fundamental heat balance method, are the industry standard and endorsed by ASHRAE for heating and cooling load calculations. BLAST output may be utilized in conjunction with the Life Cycle Cost in Design (LCCID) program to perform an economic analysis of the building/system/plant design. BLAST currently costs US$1500.00.

BLAST is widely recognized and used by the US military for its buildings and it is one of the standard simulation programs for the International Energy Agency (IEA) Building Energy Simulation Test (BESTEST) procedure (Judkoff and Neymark, 1995a and 1995b).

EnergyPlus (Strand et al., 2000; Crawley et al., 2000; Crawley et al., 2001) is the newest generation of building energy simulation program that builds on the most popular features and capabilities of BLAST and DOE-2. EnergyPlus includes innovative simulation capabilities including time steps of less than an hour, modular systems simulation modules that are integrated with a heat balance-based zone simulation from BLAST, and input and output data structures tailored to facilitate third party interface development. Other planned simulation capabilities include solar thermal, multi-zone airflow, and electric power simulation including photovoltaic systems and fuel cells.

EnergyPlus offers accurate, detailed simulation capabilities through complex modeling capabilities. Input is geared to the object oriented model way of thinking. Successful interfacing using IFC standard architectural model has been demonstrated. Extensive testing (comparing to available test suites) is still being done during development and results will be available. Recently, Henninger and Witte (2001) conducted a comprehensive IEA BESTEST analysis of the newly released non-beta version (version

1.0.0.023) of EnergyPlus and found that energy consumption predicted by EnergyPlus lied well within the estimates from other established simulation programs. EnergyPlus is expected to be the replacement of the two most widely used building energy simulation programs in the US, i.e., BLAST and DOE-2. EnergyPlus version 1.0 is free for download. (EnergyPlus is available from http://www.eere.energy.gov/buildings/energy_tools/energyplus.)

3.6.4.1.3 ENERPASS

ENERPASS (EnerModal, 1995) was developed by the EnerModal Engineering Limited of Kitchener, Ontario. ENERPASS is a detailed building energy simulation program for residential and small commercial buildings. It calculates the annual energy use for space heating, cooling, lighting, water heating, and fan energy. The calculations are performed on an hourly basis using hourly measured weather data. ENERPASS can model up to seven building zones and provides hourly temperature and humidity predictions for each zone. It costs US$299. A wide range of HVAC systems can be modeled including make-up air units, heat recovery ventilators (HRV), rooftop units, variable air volume (VAV), four-pipe fan coil, and dual duct. ENERPASS is considered to be the easiest to use hour-by-hour simulation program. It is structured for fast data entry, and performs the hourly calculation of building temperature, energy consumption, peak demand loads and daylighting parameters. Additional advantages are connected with the automatic check for data errors and the possibility to customize the program for special applications such as batch simulations of a large number of dwellings. A typical residential building model can be generated in one to two hours with simulation run-time of less than one minute in today's Pentium based microcomputers (Ugursal and Fung, 1994). In IEA validation studies ENERPASS results compare favorably with other hour-by-hour based computer programs such as BLAST and DOE-2 (DOE, 2001b).

3.6.4.2 Bin Methods

3.6.4.2.1 Hot2000

Hot2000 (NRCan, 1996) is an easy-to-use energy analysis and design software for low-rise residential buildings. Shortly after its initial development based on HOTCAN, Hot 2000 has been further developed and used extensively by the Natural Resources Canada in close cooperation with the Canadian Home Builders' Association (CHBA) for the promotion and evaluation of Canada's voluntary low-energy residential building standard, R-2000. Classified as a Bin model, Hot2000 uses average monthly weather data for all calculations. Hot2000 utilizes current heat loss/gain and system performance models found in more advanced hour-by-hour simulation engines. The evaluation takes into account the thermal effectiveness of the building and its components, the passive solar heating owing to the location of the building, and the operation and performance of the building's ventilation, heating and cooling systems. Heat balance method is used in the attic, main floor and basement sections of the dwelling separately. Advanced features such as heat balance model for ground-coupled basement, and Alberta Air Infiltration Model (AIM-2) (Walker and Wilson, 1990; Bradley, 1993) are also employed. The program aids in the simulation and design of buildings for thermal effectiveness, passive solar heating and the operation and performance of heating and cooling systems. Hot2000 can perform whole-house energy analysis very quickly (usually requires only a second or less on a modern microcomputer) (Ugursal and Fung, 1994), thus, making Hot2000 a good candidate for energy simulation with a large group of houses. The program also takes into account of thermal bridging through studs in assemblies, and it can model five fuel types and many different HVAC systems (including heat recovery ventilators and heat pumps). Hot2000 has been validated extensively against hourly simulation programs and monitoring of real houses (Ma, 1990; Li, 1991; MacInnes; 1993; Howell-Mayhew Engineering, 1995; Nisson, 1996; Haltrecht and Fraser; 2001). A major weakness of

Hot2000 is that it cannot size HVAC equipment and model energy analysis room-by-room. The latest interactive version of Hot2000 is available free of charge from http://www.buildingsgroup.nrcan.gc.ca/software/hot2000_e.html.

Hot2000 is considered (Nisson, 1996) to be the best validated and probably the most widely used residential energy analysis program. It has been well validated by both detailed building energy metering data empirically, and the three other more advanced hour-by-hour reference simulation programs (Blast, DOE and SERIRES) (Haltrecht and Fraser, 1997) in accordance to the International Energy Agency's (IEA) simplified Building Energy Simulation Test (HERS BESTEST) procedure (Judkoff and Neymark, 1995a and 1995b).

With the balance between the level of detail in modeling the dwelling energy consumption and the resources required, Hot2000 building simulation program is the most suitable to be used as the energy simulation engine in the proposed model. Hot2000 provides not only sufficient level of accuracy in energy prediction for low-rise residential dwellings in comparison to other more complex hour-by-hour simulation engines, but it is also time and resource efficient which is an important consideration when thousands of dwellings are to be simulated.

3.7 Cost of Modeling

The resources, and thus costs, involved in the modeling of detailed residential energy consumption entail 1) data collection, 2) database development, 3) model development, 4) simulation, and 5) reporting. The cost of data collection was estimated in Section 3.6. The costs of database development, modeling and reporting are relatively minor in comparison to the cost of data collection. Pratt et al. (1993) described in detail the experiences with one of the most comprehensive residential end-use metering project in the US, the ELCAP project, conducted by the Pacific Northwest Laboratory for the Bonneville Power Administration. They reported that they had collected more than thousands of megabytes (MB) worth of multi-year hourly submetered appliance end-use energy consumption and weather data on more than 400 residences from the ELCAP project during the 1980s. This sheer volume of data was noted to be difficult to manage even with two Digital DEC MicroVAX II Mini computers in that era. However, such volume of data is not believed to pose any potential problem with today's desktop computers in which multi-gigabytes (GB) of data can easily be manipulated with off-the-shelve relational database software. The author's own experience at Canadian Residential Energy End-use Data and Analysis Centre (CREEDAC) is that modern personal computers with practically unlimited data storage capacity, fast microprocessor and resident memory (RAM), provide the necessary capacity to deal with gigabytes of data and data manipulation without significant problem.

Modeling and simulation can be automated using existing desktop computer equipment and software with customized programming. Detailed household data from multiple databases can be retrieved and manipulated with special computer programs that generate individual house input files for energy simulation. Batch simulation of household energy consumption can then be proceeded once the required input files are generated. The most time and resource intensive process is the development of the needed customized programming that transforms raw household data from different databases into household input files required by the building simulation software.

Again, reporting can also be automated with customized computer programming that can transfer the raw result from the simulation software into more presentable aggregated end-use consumption by region, fuel and house types, vintage, and so on.

Thus, based on the overall cost of such modeling, simulation and reporting for the proposed bottom-up engineering based residential energy modeling framework would be about two orders of magnitude (in tens of thousands of dollars) smaller than the cost of survey and metering data collection. And the subsequent simulation would only be a fraction of that, in the range of thousands of dollars.

Chapter Four

4 Development of CREEEM

4.1 Overview

In this chapter, a detailed review of the development of the Canadian Residential End-use Energy and Emission Model (CREEEM) is presented. CREEEM is a versatile end-use energy and emissions model of the Canadian housing stock, and it is primarily based on the Engineering Method. It contains 8767 house files that represent the Canadian housing stock, and it uses the Hot2000 building energy simulation program as its simulation engine. It can evaluate the impact of a wide range of potential energy saving measures on the residential end-use energy consumption and the associated carbon dioxide emissions.

To develop CREEEM, data from the 1993 Survey of Household Energy Use (SHEU) (Statistics Canada, 1993a) was used as the core of the model since the SHEU database contains the most comprehensive information on the Canadian housing stock.[6] The SHEU data were augmented with data from other and more recent surveys and sources, and a Hot2000 input file was developed for each one of the 8767 houses in the SHEU database. By conducting Hot2000 simulations using typical (approximately 30 year average) weather files for each house, "typical" energy consumption for each house in the database are estimated. Based on the energy consumption estimates, GHG emission estimates are calculated. The national residential energy consumption and associated GHG emissions are estimated by extrapolating the CREEEM estimates using weighting factors given in SHEU.

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[6] A detailed analysis of the distribution of households in the 1993 SHEU database and the Canadian housing stock is given in Appendix A.

The development of CREEEM as well as the accuracy of its predictions of household energy consumption and associated greenhouse emissions are presented and discussed in this chapter. A critical evaluation of the proposed model, as well as summary conclusions obtained using CREEEM are presented at the end of the chapter.

4.2 Detailed Model Development

The flow chart showing the detailed methodology used in the development of CREEEM is shown in Figure 4.1. As mentioned in the previous chapter, SHEU 1993 (Statistics Canada, 1993a) is the basis for CREEEM. In 1993, Statistics Canada in collaboration with Natural Resources Canada conducted the Survey of Household Energy Use (SHEU) (Statistics Canada, 1993a). SHEU is a comprehensive combination of mail and telephone survey consisting of about 380 questions regarding the various aspects of residential energy consumption. The SHEU 1993 survey contains data on 10,982 households in Canada. Thus, information available from SHEU 1993 that is suitable for the development of CREEEM is used along with supplementary information from other sources such as the EnerGuide database (NRCan, 1993; 1996) and Expanded STAR (Ugursal and Fung, 1994; Ugursal and Fung, 1996) databases.

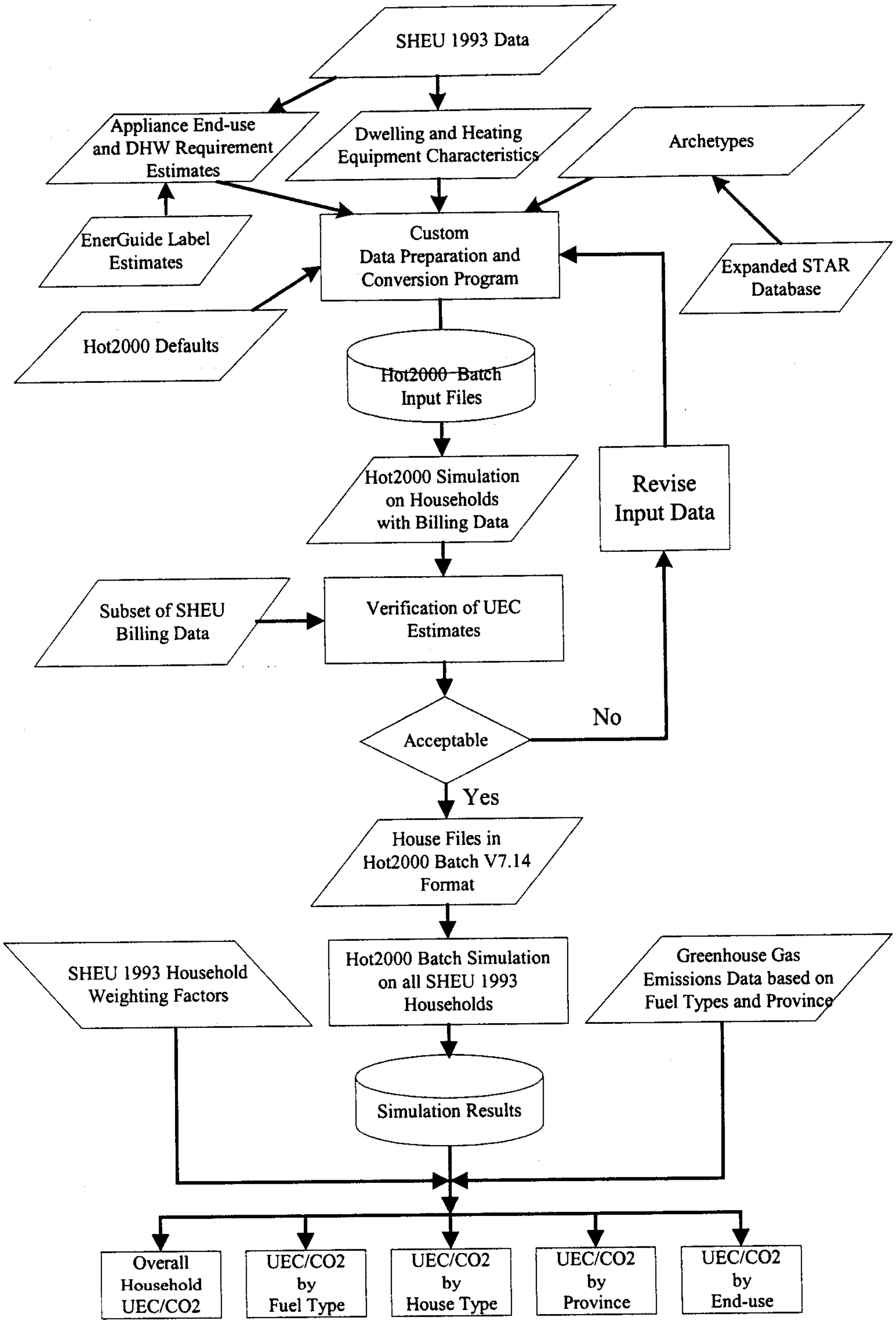

Figure 4.1: Flow chart of CREEEM

Appliance and lighting energy end-uses and DHW requirement for each household in CREEEM are estimated separately using the information available on appliance characteristics and usage patterns available in the SHEU and EnerGuide databases. Since the information in the SHEU database on building thermal characteristics is not sufficient to develop the input files for the Hot2000 program, 16 house archetypes were developed using the data from other databases containing information on the Canadian housing stock (Scanada, 1992; NRCan, 1994; Ugursal and Fung, 1994; Ugursal and Fung, 1996) and minor contributions from other sources. The archetypes are based on vintage (pre-1941, 1941-1960, 1961-1977, 1978 and later) and regional location (Western Canada, Prairies, Central Canada, Atlantic Canada), and they provide typical house characteristics for each archetype house (Farahbakhsh et al., 1998). Thus, the information from the SHEU database was augmented with archetype descriptions, as well as appliance energy end-use and DHW requirement estimates, and a Hot2000 input file was developed for each one of the 8767 low-rise single-family dwellings in the SHEU database.

Table 4.1 summarizes the source of information for each input data stream (i.e. "card") of the Hot2000 Batch input file. As can be seen from this table, 26 percent of an input file came from SHEU, 23 percent from archetype descriptions, 9 percent from Hot2000 defaults and other sources, with some assumptions made based on engineering judgement. The remaining 42 percent were mostly insignificant information such as specific information on the city, etc. A detailed description of the input data used in each "card" of the Hot2000 house description files is given in Appendix B.

Table 4.1: Contribution of different sources to the creation of Hot2000 Batch input files

Hot2000 Input Card	SHEU93	User Input Including Assumptions	Statistics on STAR + 200 Houses	Hot2000 Defaults and Other Sources	Total
A	4	6	0	0	10
B1	0	3	0	0	3
B2	0	4	0	0	4
B3	0	4	0	0	4
B4	6	5	2	0	13
C1	15	11	11	1	38
C2	6	5	1	1	13
Ceiling	3	2	4	0	9
Attic/Roof	2	5	7	0	14
Main Walls	1	6	1	1	9
Door	0	4	2	0	6
Exposed Foor	1	2	2	0	5
Main Floor	2	2	1	0	5
Basement	7	22	8	0	37
Windows	2	2	6	0	10
D1.1	12	5	1	3	21
D1.2	4	2	4	5	15
D1.3	3	9	8	2	22
D2.1	0	3	0	1	4
D3	5	2	3	1	11
D4	0	2	0	0	2
D5.1	0	1	4	4	9
D5.2	2	10	0	0	12
D6	0	2	0	0	2
D7	3	6	1	3	13
G1	1	4	4	1	10
G2	1	2	0	6	9
Total	80	131	70	29	310
Contribution (%)	26	42	23	9	

User Input:	*This includes the columns which describe some insignificant information, such as date of data entry, or number of user defined windows. It also includes the assumption made due to insufficient information.*
Statistics:	*This category includes the column input based on the statistics done on houses in the "200-House Aduit" database and the Modified STAR database.*
Hot2000 Defaults:	*This includes the inputs based on the Hot2000 default values or other sources.*

Once the input data files were developed for all 8767 house files in the SHEU database, Hot2000 simulations were run using weather files for the location of each house. The weather files represent long term (approximately 30 year) averages of weather data obtained by Environment Canada. Thus, the simulation results are estimates of the "typical" or "average" energy consumption that can be expected in an "average" year.

Actual energy billing data obtained from fuel suppliers and utility companies for a complete year are available for 2811 of the 8767 houses in the SHEU database. These billing data were used to verify the accuracy of the annual unit energy consumption (UEC) estimates obtained from the simulations of the 2811 house files. To do this, the UEC estimates were compared with the actual billing data, and some systemic errors in the input files were identified from these comparisons. After several cycles of simulation and input file improvement, an acceptable level of agreement was achieved between the actual billing data and the Hot2000 estimates. The refinements identified from the verification process were applied to the rest of the 8767 house files as necessary to eliminate systemic errors and improve the accuracy of the simulation results. Thus, the refined 8767 Hot2000 house files, which are representative of the Canadian housing stock, constitute CREEEM.

The impact of any energy saving measure can be estimated by modifying the 8767 input files to reflect the measure, and conducting a Hot2000 simulation on CREEEM. The difference in the energy consumption of the houses in their original state and with the modifications reflects the energy savings potential of the measure. The reduction in GHG emissions can be estimated using the same approach. The overall results can further be analyzed by disaggregating the energy consumption and GHG emissions according to province, end-use, fuel type, dwelling type, and dwelling vintage.

4.2.1 Estimation of Appliances and Lighting Energy Consumption

The methods used to estimate the average unit energy consumption (UEC) values, per Canadian household, associated with lighting, and major, minor and miscellaneous household appliances are presented in the following sections.

4.2.1.1 Lighting Energy Consumption

For each household in the SHEU 1993 database, the following data on lighting are available:

- Number of halogen light bulbs; indoors and outdoors;
- Number of fluorescent light bulbs; indoors and outdoors;
- Total number of incandescent light bulbs indoors, outdoors and in the garage; and,
- Number of incandescent light bulbs in the kitchen, living/dining area, bedrooms/closets, family room, bathroom, hallways, basement, attic, and in other areas inside the house.

To estimate the lighting energy consumption using the SHEU data, information on two key parameters are needed: i) average wattage of each type of lighting (incandescent, fluorescent and halogen) used in residences, and ii) average number of hours of usage for each type of lighting. In a study published by Lawrence Berkeley Laboratories (Hanford et al., 1994), the average number of hours of usage for an incandescent light bulb is given to be 2.1 hours/day, and the average wattage of an incandescent light bulb is given to be 67.1 W/bulb. For fluorescents, the average wattage is 41.1 W/bulb and the average daily use is 3.8 hours/day. Following discussions with researchers at Natural Resources Canada (Miller, 1995; Moisan, 1995) and Ontario Hydro (Bartoszek, 1995) and based on the results of a study conducted by Market Facts (Market Facts, 1993), it was decided to estimate the lighting energy consumption using an average of 2.7 hours/day usage (corresponding to 1,000 hours/year) as well as 2.1 hours/day usage (corresponding to 766 hours/year). Also, since there is no data on halogens, the same numbers are used for halogens as those given for fluorescents in the Lawrence Berkeley Laboratories study (average wattage of 41.1 W/bulb and the average use of 3.8 hours/day). In addition, Aydinalp (2002) derived the average annual household lighting energy consumption from the CDA model using the same SHEU database used in CREEEM, to be 50.2 kWh/year/bulb, suggesting that average of 2.1 hours of usage of light bulb with an assumed wattage of 67 W/bulb.

The calculation procedure is straightforward (Fung and Ugursal, 1995; Fung and Ugursal, 1998): from the SHEU database, the number of bulbs for each category is obtained. Then, this value is multiplied by the average wattage of the type of bulb, the average number of hours of usage per day and the number of days per year to give annual electricity consumption, i.e.:

$$\begin{aligned} UEC_{light,indoor} &= \sum (Type_i \times Wattage_i \times Hour_i / day) * 365 \\ UEC_{light,outdoor} &= \sum (Type_i \times Wattage_i \times Hour_i / day) * 365 \qquad \text{Eq. 4.1} \\ UEC_{light,total} &= UEC_{light,indoor} + UEC_{light,outdoor} \end{aligned}$$

The analysis was carried out for both scenarios, i.e. based on 2.7 and 2.1 hours/day of usage. The overall lighting energy consumption was found to be 1767 kWh/year/household for the high and 1387 kWh/year/household for the low incandescent bulb usages, respectively. In comparison, Kelsey and Richardson (1992) estimated, based on the survey of 1,009 households, the average household lighting energy consumption for Northern California to be 1,270 kWh/year. Based on this comparison, and further discussions with researchers at Natural Resources Canada, the 2.1 hour/day of incandescent bulb usage was adopted for the model and the UEC estimates presented in the rest of this work are based on this value.

The average electricity consumption per household for each category is then calculated by summing the electricity consumption of all households in that category and then dividing the total by the number of households.

The average number of bulbs of each type of lighting (i.e., incandescent, fluorescent and halogen) per household for each province and for Canada are given in Table 4.1. These are categorized according to the location of usage, i.e., indoors, outdoors and the total of indoors and outdoors. Data on the distribution of incandescent lights among the different rooms of a dwelling are available elsewhere (Fung and Ugursal, 1995; Fung and Ugursal, 1998). Using the data in Table 4.2, the average wattage and the average number of hours of usage given above, the annual electricity consumption values were calculated and the results are given in Table 4.3.

The total annual residential lighting electricity consumption estimates for all households in each province and in Canada are given in Table 4.4. As shown in the table, the total electricity consumption in Canada for residential lighting is estimated to be about 14.4 TWh, or 52 PJ, representing about 3.8% of the total annual residential end-use energy consumption in Canada. This is in agreement with 53.6 PJ (within 3.9%) estimated by Natural Resources Canada using a top-down approach (NRCan, 2001).

It should be noted that the estimate of household lighting UEC could be further improved and refined if energy surveys not only provide the type and number of lighting fixtures, but also provide the approximate wattage and hours of usage for each type of fixture.

Table 4.2: Average number of bulbs of each typing of lighting

Province	Average No. of Bulbs Per Household								
	Halogen			Fluorescent			Incandescent		
	Indoor	Outdoor	Total	Indoor	Outdoor	Total	Indoor	Outdoor	Total
NFLD	0.08	0.05	0.1	0.88	0.04	0.9	20.0	2.2	22.4
PEI	0.52	0.08	0.6	1.30	0.10	1.4	19.7	2.2	22.4
NS	0.16	0.11	0.3	1.48	0.20	1.7	20.8	2.4	23.8
NB	0.21	0.14	0.4	1.45	0.12	1.6	21.2	2.5	24.4
QUE	0.91	0.11	1.0	1.29	0.17	1.5	17.7	2.4	20.5
ONT	0.32	0.13	0.5	2.43	0.22	2.6	24.0	2.5	27.4
MAN	0.20	0.10	0.3	2.23	0.16	2.4	20.4	2.1	23.6
SAS	0.18	0.12	0.3	2.92	0.19	3.1	22.3	2.4	25.9
AB	0.21	0.17	0.4	2.72	0.17	2.9	23.2	2.3	26.5
BC	0.26	0.18	0.4	2.77	0.31	3.1	24.1	2.7	27.7
Canada	0.27	0.12	0.4	2.01	0.17	2.2	21.5	2.4	24.6

Table 4.3: Average annual lighting energy consumption per dwelling

Province	Average Annual Lighting Energy Consumption (kWh/year/household)									
	Halogen			Fluorescent			Incandescent			Total Dwelling
	Indoor	Outdoor	Total	Indoor	Outdoor	Total	Indoor	Outdoor	Total	
NFLD	3.9	2.2	6.1	41.8	2.0	43.8	1026	113	1151	1201
PEI	24.5	3.8	28.3	61.5	4.9	66.5	1015	113	1153	1248
NS	7.7	5.1	12.8	70.1	9.4	79.5	1070	125	1222	1314
NB	10.2	6.7	16.9	68.7	5.8	74.5	1092	126	1254	1346
QUE	43.2	5.4	48.6	61.4	7.9	69.2	909	122	1056	1174
ONT	15.3	6.3	21.7	115.4	10.3	125.7	1236	131	1407	1554
MAN	9.7	4.7	14.4	106.1	7.6	113.8	1048	110	1214	1343
SAS	8.6	5.5	14.1	138.5	8.9	147.4	1146	122	1330	1491
AB	10.0	8.0	18.0	129.3	8.0	137.4	1192	118	1364	1520
BC	12.2	8.7	21.0	131.4	14.6	145.9	1241	141	1424	1591
Canada	12.9	5.6	18.5	95.3	8.1	103.4	1103	122	1265	1387

Table 4.4: Total annual lighting energy consumption

Province	Lighting UEC (kWh/yr/dwelling)	Number of Dwellings	Total Consumption (TWh/yr)	Total Consumption (PJ/yr)
NFLD	1201	186,070	0.22	0.80
PEI	1248	45,736	0.06	0.21
NS	1314	336,080	0.44	1.59
NB	1346	260,915	0.35	1.26
QUE	1174	2,710,836	3.18	11.46
ONT	1554	3,810,478	5.92	21.32
MAN	1343	402,524	0.54	1.95
SAS	1491	368,270	0.55	1.98
AB	1520	934,816	1.42	5.11
BC	1591	1,303,492	2.07	7.46
Canada	1387	10,359,217	14.37	51.74

4.2.1.2 Energy Consumption by Appliances

In the literature on their energy consumption characteristics, household appliances are typically classified into two groups: major appliances and minor/miscellaneous appliances (Ugursal and Fung, 1993). Major appliances include cold food storage equipment (freezers, refrigerator/freezers, refrigerators), primary cooking equipment (ranges, ovens, cooktops), clothes dryers, clothes washers, dishwashers and window/room air conditioners. Minor appliances include all other electrical appliances used in households.

Three national surveys were conducted by Statistics Canada that include extensive data on the major household appliance stocks in Canada. These are the 1993 SHEU survey (Statistics Canada, 1993a), and the 1994 and 1995 Household Equipment Surveys (NRCan, 1995; 1996). The annual energy consumption under normal usage for every type (i.e. every make and model) of major household appliance sold in Canada is available from the EnerGuide Database for Household Appliances (NRCan, 1993).

Therefore, the UEC values for major household appliances were derived using the survey data with the EnerGuide UEC estimates. A brief overview of the methodology used in estimating the major appliance UEC's is presented below. Detailed reviews are presented elsewhere (Fung et al., 1996a, 1996b, 1997a).

In contrast to the availability of data on major appliance ownership and UEC, there is little data on the ownership and UEC of minor and miscellaneous appliances in Canada. The available data are presented and discussed further below.

4.2.1.2.1 Major Appliances - UEC of 1993 Stock Appliances

Data on several key characteristics of refrigerators, freezers, clothes washers, clothes dryers, dishwashers, and electric ranges/ovens as well as window air-conditioners were collected in the 1993 SHEU survey. For example, for refrigerators, data on size, type (number of doors, mixed of refrigerator and freezer, automatic defrost, and automatic ice maker through door) and age were obtained. In addition, the actual make and model numbers of a subset of appliances were also obtained. These data are available in a separate database called the 1993 SHEU Appliance Make and Model (M&M) database (Statistics Canada, 1993a). The numbers of appliances for each class of appliance in the M&M database are as follows:

- Refrigerators: 3014
- Freezers: 1027
- Clothes washers: 1109
- Clothes dryers: 1553
- Dishwasher: 1124
- Range/oven: 1647

To estimate the UEC of 1993 stock of appliances, first the M&M database was used to estimate the UEC of various types of appliances (Fung et al., 1997a). For this purpose, the UEC of each appliance in the M&M database was obtained from the EnerGuide database. Then, the appliance characteristics of each appliance obtained from the 1993 SHEU database was matched with the EnerGuide UEC, and a regression analysis was carried out to develop UEC equations for each type of each appliance, such as "refrigerator and refrigerator-freezer with manual defrost". The appliance type classification for each of the six major appliances was based on the EnerGuide appliance classification categorization (NRCan, 1993). Thus, regression equations of the following form were developed using SPSS (SPSS, 1996) statistical software. For example, the resulting regression equation for Type 1 (refrigerator and refrigerator-freezer with manual defrost) refrigerator is:

$$UEC_{Type1,Refrigerator} = C_1(Age) + C_2(Size) + C_3 \qquad \text{Eq. 4.2}$$

Where $UEC_{Type1,Refrigerator}$ =Energy Consumption for Type 1 Refrigerator (kWh/year)

C_i= Coefficients; C_1= 10.8; C_2= 30.9; C_3= 423.2

Using this process for each class of major appliance, regression equations were developed to estimate UECs based on appliance characteristics.

For clothes washers, clothes dryers and dishwashers, SHEU database includes data on usage in terms of number of loads per week. For these, the UECs estimated using the regression equations were modified taking into account the number of actual loads as follows:

$$UEC = UEC_{regression} \times Usage_{actual} / Load_{default} \qquad \text{Eq. 4.3}$$

Where: UEC = Actual appliance unit energy consumption (kWh/year)

$UEC_{regression}$ = Appliance unit energy consumption estimate from derived regression equation

$Usage_{actual}$ = Actual reported usage (loads/year)

$Load_{default}$ = Predefined (default) number of loads used in EnerGuide (loads/year)

Since there is no information on window (room) air-conditioners in EnerGuide, data published by the Association of Home Appliance Manufacturers (AHAM) (AHAM, 1996) were used in calculating the UEC of window air-conditioners. The data available from 1993 SHEU database and the Energy Efficiency Rating (EER) of window air-conditioners expressed in terms of their age and capacity were used in the following formula:

$$UEC_{window-A/C}(kWh/yr) = \frac{Capacity(Btu/h) \times Usage(Hours/year)}{EER(Btu/Wh) \times 1000(Wh/kWh)} \qquad \text{Eq. 4.4}$$

Where $UEC_{window-A/C}$ = Unit energy consumption of window A/C (kWh/year)

$Capacity$ = Reported window A/C capacity (Btu/hr)

$Usage$ = Reported usage during the cooling season (hours/year)

EER = Energy efficiency rating from AHAM (1996) data based on age and capacity of window A/C (Btu/Whr)

Table 4.5: Window A/C EER versus age (AHAM, 1996)

Window A/C Age	EER (AHAM, 1996)
1	8.88
2	8.80
3	8.73
4	8.48
5	8.23
6	7.93
7	7.50
8	7.00
9	6.35
10	5.98

The resulting regression equations for the major household appliances are given in Table 4.6, and the average UECs estimated using these equations are given in Table 4.7. The general form of the equation used to estimate the UEC of major appliances can be expressed as:

$$UEC_{Major-Appliance} = \sum_{n=1}^{n} [(Variable_n) * (Coefficient_n)] + \text{constant} \qquad \text{Eq. 4.5}$$

Table 4.6: Major appliance UEC regression equations

Appliance			Variable 1	Coefficient 1	Variable 2	Coefficient 2	Variable 3	Coefficient 3	Constant	R^2
Refrigerator	Type1	Ref and ref-freezer w/ manual defrost	Age	10.8	Size	30.9			423.2	0.470
	Type2	Ref-freezer, auto defrost, top-freezer	Age	32.8	Size	12.8			884.3	0.777
	Type3	Ref-freezer, auto defrost, side-freezer	Age	22.0	Size	-37.7			1995.4	0.575
	Type4	Ref-freezer, auto defrost, bottom-freezer	Age	17.8	Size	36.5			541.7	0.687
	Type5	Ref-freezer, auto defrost, top-freezer, ice	Age	53.2	Size	65.1			-42.0	0.692
	Type6	Ref-freezer, auto defrost, side-freezer, ice	Age	52.8	Size	37.7			425.7	0.741
Freezer	Type1	Upright, manual defrost	Age	14.3	Size	16.3			340.8	0.867
	Type2	Upright, auto defrost	Age	21.5	Size	27.3			311.4	0.722
	Type3	Chest and other	Age	1.6	Size	7.5			638.8	0.204
Clothes Washer	Type1	Warm/cold for wash/rinse cycle	Age	7.4	Water-Level	165.1	Standard	421.9	422.3	0.634
	Type3	Hot/cold, warm/cold, cold/cold	Age	-3.5	Water-Level	-121.3	Standard	64.2	1065.1	0.323
	Type5	H/W, H/C,W/W, W/C, C/C	Age	15.1	Water-Level	-199.2	Standard	39.5	1329.2	0.477
	Type6	H/H, H/W, H/C, W/W, W/C, C/C	Age	0.8	Water-Level	93.0	Standard	299.9	865.9	0.721
Clothes Dryer	Type1	Manual timer, Auto-off, Perma-press	Age	4.8	Mini/Large	-544.8	Standard	-0.7	1102.8	0.870
	Type2	Manual timer, Auto-off	Age	15.6	Mini/Large	549.6	Standard	626.4	454.8	0.928
	Type3	Manual timer, Perma-press	Age	6.0	Mini/Large	-486.0	Standard	14.4	1041.6	0.825
	Type4	Manual timer	Age	-8.4	Mini/Large	-244.8	Standard	-15.6	1088.4	0.559
	Type5	Auto-off, Perma-press	Age	30.0	Mini/Large		Standard	46.8	931.2	0.747
	Type6	Auto-off	Age	34.8	Mini/Large	762.0	Standard	669.6	187.2	0.928
	Type7	Perma-press	Age	15.6	Mini/Large	488.4	Standard	424.8	572.4	0.777
Dishwasher	Type1	Built-in	Age	18.6	Dry	-41.2	Standard	-4.9	1029.1	0.647
	Type2	Portable	Age	26.6	Dry	-50.4	Standard	90.0	936.8	0.805
Range/Oven	Type1	Self-clean range	Age	1.2	SelfClean-Use	23.4	Convection	4.2	765.0	0.307
	Type2	Non self-clean range	Age	-0.1			Convection	20.2	788.3	0.080
	Type3	Self-clean oven w/ separate cooktop	Age	8.6	SelfClean-Use	85.7	Convection	9.1	350.1	0.304
	Type4	Non Self-clean oven w/ sep. cooktop	Age	5.6			Convection	-7.5	366.5	0.238

Table 4.7: Average UEC's of major household appliances in the 1993 SHEU database

Appliance	Number in SHEU	UEC (kWh/year)
Refrigerator	9462	1,308
Freezer	7117	792
Clothes washer	7623	932
Clothes dryer	7107	658
Dishwasher	3790	828
Range/oven	8264	786
Cooktop	510	427
Window A/C		
1st unit	354	490
2nd unit	38	370
All combined		477

It can be seen from Table 4.6 that the multiple correlation coefficient (R^2) is low for some of the appliances (e.g. chest and other freezers). There are several reasons for this: (i) appliances with similar features, age and size from all manufacturers are grouped together, (ii) some groups have only a few units in them, (iii) some groups, such as "chest and other freezers" contain a wide range of appliance types. However, it can be concluded that UECs can, on average, be reasonably estimated using the characteristics of an appliance.

4.2.1.2.2 Major Appliances - UEC of 1994 and 1995 New Appliances

Market Facts of Canada Limited conducted the 1994 and 1995 Household Equipment Surveys (HES 1994 and HES 1995) for Natural Resources Canada in February 1995 and January 1996 (NRCan, 1995 and 1996). The data collected in HES 1994 and 1995 are similar to the data collected on appliances in the 1993 SHEU. Therefore, the methodology presented in the previous section was used to estimate the major appliance UECs based on the data collected in these surveys. Detailed review of the methodology can be found elsewhere (Fung et al., 1996a and 1996b). The resulting regression equations for the major household appliances for the 1995 new equipment are given in Table 4.8.

Table 4.8: Major appliance UEC regression equations for 1995 new equipment

Appliance		Refrigerator	Freezer	Clothes Washer	Clothes Dryer	Dishwasher	Range/Oven
Variable	1	Type1	Chest	Large	Large	Built-in	Built-in
Coefficient	1	-745.1	0.0	0.0	-140.8	0.0	0.0
Variable	2	Type2	Up/frostfree	Standard	Standard	Port./full size	FreeStand
Coefficient	2	636.6	215.6	-59.2	-154.9	101.8	226.9
Variable	3	Type3	Up/Manual	Compact	Compact	P./counter top	SelfClean
Coefficient	3	-778.7	95.3	-155.8	-480.5	63.0	-12.7
Variable	4	Type4	Up/Unspec	Stacked	Stacked	Heat on/off	Convection
Coefficient	4	-833.6	0.0	-130.8	-97.3	-25.0	0.0
Variable	5	Type5	Size	Rinse-hot	Manual timer	Energy saver	
Coefficient	5	-769.5	13.2	-70.4	13.0	-132.5	
Variable	6	Type6		Rinse-warm	Auto off	Size	
Coefficient	6	0.0		-18.4	-12.1	36.2	
Variable	7	Size		Rinse-cold	Permapress		
Coefficient	7	-0.4		90.1	-22.5		
Variable	8	Ice		Water level			
Coefficient	8	38.0		98.8			
Constant		1472.3	225.7	957.4	1138.8	868.1	515.9
R^2		0.345	0.634	0.291	0.479	0.242	0.543

The UEC estimates for the new stock major appliances in the HES 1994 and HES 1995 are presented in Table 4.9 along with the UEC estimates for the 1993 stock appliances. As can be seen from Table 4.9, newer appliances consume less energy.

The annual energy consumption estimates by major appliances in the 1993 Canadian housing stock calculated based on the data given in Table 4.7 are presented in Table 4.10. The overall appliance energy consumption by major appliances in 1993 is estimated to be 4524 kWh/year/household.

Table 4.9: Comparison of average major appliance UEC estimates for 1993 stock, 1994 and 1995 new equipment

Appliance	Average UEC (kWh/year)		
	1993 Stock	1994 New Equipment	1995 New Equipment
Refrigerator	1,308	700	715
Freezer	792	480	410
Clothes washer*	932	890	540
Clothes dryer*	658	530	475
Dishwasher*	828	660	500
Range/oven	786	770	720

*UECs include actual reported usage for clothes washer, clothes dryer and dishwasher

Table 4.10: List of estimated major appliance UECs

Major Appliances

Appliances	Saturation (Unit/Home) (%)	UEC (kWh/year)	Total Energy Use (kWh/year)
Refrigerator	116.7	1308.0	1.58E+10
Freezer	79.0	792.0	6.48E+09
Clothes Washer	83.3	932.0	8.04E+09
Clothes Dryer	75.9	658.0	5.17E+09
Dishwasher	37.4	828.0	3.21E+09
Range (Oven+cooktop)	92.5	786.0	7.53E+09
Oven*	7.3	***401.0***	3.02E+08
Cooktop	7.3	427.0	3.22E+08
		Total	**4.69E+10**
		Average	**4524**

Shaded HFE (Stat Can, 1993)

Bold Italic = EETI (Ugursal and Fung, 1994)

4.2.1.2.3 Minor and Miscellaneous Appliances - UEC

As pointed out earlier, there is limited data on the ownership and UEC of minor and miscellaneous appliances in Canada. The SHEU database contains data on the ownership of a limited number of minor and miscellaneous appliances[7], while UEC estimates exist for minor and miscellaneous appliances obtained from a recent small-scale spot metering campaign carried out in Nova Scotia (Fung et al., 2003). Due to this general lack of information on minor and miscellaneous appliances, the information collected in a literature review from primarily American sources (Ugursal and Fung, 1994), as well as the limited appliance saturation data available from the SHEU 1993 summarized in Table 4.11 and Table 4.12 are used in this work.

Table 4.11: List of estimated minor appliance UECs

Minor Appliances

Appliances	**Saturation (Unit/Home) (%)**	**UEC (kWh/year)**	**Total Energy Use (kWh/year)**
Microwave	78.8	***180.0***	1.47E+09
Color TV	126.6	***412.4***	5.41E+09
Black & White TV	21.8	***249.4***	5.64E+08
Central A/C	9.7	865.0	8.71E+08
Window A/C	10.1	477.4	4.97E+08
Furnace Fan	52.2	***543.3***	2.94E+09
Lighting	100.0	1387.0	1.44E+10
Radio	225.0	***70.5***	1.64E+09
		Total	**2.78E+10**
		Average	**2680**

Shaded HFE (Stat Can, 1993)

Bold Italic = EETI (Ugursal and Fung, 1994)

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[7] Minor appliances available in the SHEU include: microwave oven, color TV, B&W TV, central A/C, window A/C, furnace fan, lighting, radio. Miscellaneous appliances available in the SHEU include: VCR, CD player, stereo, computer, electric blanket, water bed heater, portable humidifier, portable dehumidifier, car block heater, interior car warmer, water cooler, aquarium, bathroom exhaust fan, kitchen exhaust fan, central electronic air filter, central humidifier, central dehumidifier, portable heater, central ventilation, HRV, central vacuum cleaner, sump pump, pool heater, hot tub, sauna, central heat pump, ceiling fan, and portable fan.

The UEC estimates for minor and miscellaneous appliances are compared with the results of a recent spot metering study conducted in Nova Scotia (Aulenback et al., 2001; Fung et al., 2003) in Table 4.13. In the Nova Scotia study, conducted from January to April 2001, spot measurements of appliance active and standby power requirements were made, and estimates of hours of usage for each appliance were obtained from homeowners in 75 houses. It can be seen from Table 4.13 that the minor/miscellaneous appliance UECs used in CREEEM are in general agreement with those from the Nova Scotia study, except for TVs, clocks and radios. The larger discrepancy in these appliances may due to the fact that electronic equipment technology and usage patterns change over time. For example, newer electronic clocks and radios may require less power to operate than the older models, and the current per TV usage hours may be lower due to the higher saturation of TVs and computers in home now (2001) than before (before 1994). The reported average number of hours of TV usage for the most used TV in the Nova Scotia study was 5 hours/day, while for the second and third TV sets, the usage was 2.6 hours/day. In 1999, the hours of TV usage for the most used TV reported by Rosen and Meier (1999) was 6 hours. Also, the B&W TV usage is simply phased out and replaced by color TV sets.

These results indicate that the timely and regular updates of the energy consumption characteristics and usage patterns of minor and miscellaneous appliances are crucial for overall residential energy consumption modeling.

Using these data, the overall annual energy consumption by minor and miscellaneous appliances in the 1993 Canadian housing stock are estimated to be 2680 and 1421 kWh/year/household, respectively.

Table 4.12: List of miscellaneous appliance UECs

Miscellaneous Appliances

Appliances	Saturation (Unit/Home) (%)	UEC (kWh/year)	Total Energy Use (kWh/year)
VCR	86.2	***40.0***	3.57E+08
CD Player	30.5		
Stereo	72.9	***50.0***	3.78E+08
Computer	20.2	***130.0***	2.73E+08
Electric Blanket	10.7	***142.6***	1.59E+08
Water Bed Heater	18.4	***1250.0***	2.39E+09
Portable Humidifier	17.5	***140.5***	2.55E+08
Portable Dehumidifier	14.0	***382.2***	5.54E+08
Car Block Heater	50.3		
Interior Car Warmer	7.6		
Water Cooler	2.0		
Aquarium	5.5	***548.0***	3.13E+08
Bathroom Exhaust Fan*	62.4	***15.0***	9.69E+07
Kitchen Exhaust Fan	57.0		
Central Electronic Air Filter	5.4	***216.0***	1.20E+08
Central Humidifier	11.1		
Central Dehumidifier	1.5		
Portable Heater	8.5	***173.0***	1.53E+08
Central Ventilation	7.9		
HRV	2.7		
Central Vacuum*	12.4	***42.2***	5.42E+07
Sump Pump	13.5		
Pool (pump)*	2.9	***1269.0***	3.81E+08
Electric Pool Heater	0.2		
Hot Tub	4.1	***2300.0***	9.72E+08
Sauna	0.5		
Central Heat Pump	1.4		
Ceiling Fan	65.3	***110.0***	7.44E+08
Portable Fan	70.1	***135.5***	9.84E+08
Clock	***95.7***	***18.8***	1.86E+08
Electric Mower			
Garbage Disposal	***34.5***	***26.7***	9.55E+07
Grow-lights & Acc.	***4.0***	***800.0***	3.31E+08
Attic Fan	***41.6***	***290.0***	1.25E+09
Fry Pan (skillet)	***56.5***	***182.4***	1.07E+09
Iron	***59.5***	***121.4***	7.48E+08
Coffee Maker	***60.1***	***97.1***	6.05E+08
Toaster	***90.8***	***40.0***	3.76E+08
Hair Dryer	***77.7***	***19.2***	1.55E+08

Continued

Table 4.12: List of miscellaneous appliance UECs, Continued

Blender	***70.9***	***12.2***	8.96E+07
Sewing Machine	***67.9***	***11.0***	7.73E+07
Mixer	***76.6***	***10.7***	8.49E+07
Shaver	***49.1***	***1.2***	6.10E+06
Instant Hot Water	***1.0***	***160.0***	1.66E+07
Crockpot	***32.1***	***139.0***	4.62E+08
Window Fan	***10.0***	***120.0***	1.24E+08
Heat Tape	***4.0***	***100.0***	4.14E+07
Broiler	***17.9***	***96.3***	1.79E+08
Toaster Oven	***21.6***	***93.0***	2.08E+08
Plate Warmer	***15.4***	***92.2***	1.47E+08
Circulating Fan	***9.0***	***91.5***	8.53E+07
Griddle	***10.3***	***46.0***	4.89E+07
Trash Compactor	***2.6***	***40.0***	1.09E+07
Waffle Iron	***33.1***	***21.6***	7.40E+07
Heat Lamp	***7.2***	***15.0***	1.12E+07
Floor Polisher	***6.0***	***15.0***	9.32E+06
Wok/Fondue Set	***5.5***	***9.0***	5.17E+06
Heating Pad	***5.7***	***8.4***	4.99E+06
Knife/Slicer	***39.0***	***6.2***	2.50E+07
Tooth Brush	***8.5***	***5.3***	4.69E+06
Can Opener	***34.0***	***3.9***	1.37E+07
Massager	***1.3***	***1.2***	1.65E+05
Ice Cream Maker	***9.9***	***0.7***	7.16E+05
Juicer	***5.3***	***0.6***	3.32E+05
Ice Crush	***7.0***	***0.5***	3.60E+05
Opener/Sharpener	***33.1***	***0.2***	6.86E+05
Sharpener	***4.8***	***0.2***	9.90E+04
Hot Comb	***45.7***		
Tape Deck	***38.2***		
Curler	***37.6***		
Popcorn Popper	***32.7***		
Slide/Movie Projector	***28.7***		
Flood Lights	***28.2***		
Food Grinder	***26.4***		
Curling Iron	***21.5***		
Water Pic	***7.9***		
Amp'r (Huitar/Organ)	***7.7***		
Roaster		***156.7***	
Deep Fryer		***83.0***	
Kettle		***75.0***	
Rotisserie		***73.0***	
Sandwich Grill		***28.7***	
Cooker/Fryer		***23.0***	
Baby Food Warmer		***22.0***	
Egg Cooker		***13.7***	
		Total (kWh/year)	**1.47E+10**
		Average (kWh/year)	**1421**

Shaded HFE (Stat Can, 1993)

Bold Italic = EETI (Ugursal and Fung, 1994)

Table 4.13: Comparison of minor and miscellaneous appliance UEC estimates with Fung et al. (2003)

Miscellaneous Appliance	UEC (kWh/year)	
	(Fung et al., 2003)	CREEEM
Colour TV, <26"	84.9	412.4
Colour TV, 26"-36"	216.7	
Colour TV, >36"	199.5	
Black & White TV	18.5	249.4
VCR	48.8	40.0
Computer	82.8	130.0
Laptop Computer	29.7	
Computer Monitor, <=15"	41.4	
Computer Monitor, 17"	110.6	
Computer Monitor, 19"	211.3	
Computer Monitor, 21"	357.3	
Clock - All	8.5	18.8
Microwave	168.7	180.0
Radio	2.9	70.5
Desktop Audio, 1 Disk	23.4	50.0
Desktop Audio, >1 Disk	80.0	
Component Stereo System	78.2	
Miscellaneous Stereo Component	63.3	
Stereo CD Player	25.8	
Stereo Receiver	55.0	
Stereo Tape Player	6.1	
Stereo Tuner	14.3	
Stereo Turntable	4.5	

4.2.1.2.4 Overall Energy Consumption by Appliances

Based on the estimates presented in the previous sections, the UECs of major, minor and miscellaneous appliances in the 1993 Canadian housing stock are 4,524, 2,680 and 1,421 kWh/year/household, respectively. Thus, the total whole house electrical appliance UEC for 1993 is estimated to be 8,625 kWh/year/household.

4.2.2 DHW Usage and Energy Consumption

Since the SHEU database does not contain any information regarding the use of hot water, (e.g. number of showers and/or baths taken, hot water used for meal preparation), an estimate of hot water requirement by each household cannot be directly computed using the formulation given in Chapter 3. Thus, a more general approach is developed and used here for estimating the household DHW requirement based on the information available from the SHEU database on the number of occupants, dishwasher and clothes washer ownership and usage, and the presence of low flow shower heads and aerators in each dwelling.

The daily hot water usage is primarily dependent on the number of occupants in a dwelling and it can be estimated by the following equation (NRCan, 1996):

$$\text{DHW usage (liter/day)} = 85 + 35 * (\text{\# of occupants}) \qquad \text{Eq. 4.6}$$

The DHW consumption estimated using Eq. 4.6 does not take into account the amount of hot water used by the clothes washer and dishwasher. Also, the effect of low-flow shower heads and aerators need to be taken into consideration as these reduce the hot water usage by approximately 40% (Anderson et al., 1993). Taking these two points in consideration, the average total daily hot water demand can be expressed as:

If low-flow shower head/aerators are not used:

$$\text{DHW usage (liter/day)} = 85 + 35 * (\text{\# of occupants}) + L_{cw} + L_{dw} \qquad \text{Eq. 4.7}$$

If low-flow shower head/aerators are used:

$$\text{DHW usage (liter/day)} = 85 + 20 * (\text{\# of occupants}) + L_{cw} + L_{dw} \qquad \text{Eq. 4.8}$$

where, L_{cw} is the average daily hot water usage from clothes washer

L_{dw} is the average daily hot water usage from dishwasher

The amount of hot water required for clothes washer and dishwasher can be estimated from:

$$L_{cw} = (0.86 * UEC_{cw})/(4.18 * (55 - GT)) \qquad \text{Eq. 4.9}$$

$$L_{dw} = (0.75 * UEC_{dw})/(4.18 * (55 - GT)) \qquad \text{Eq. 4.10}$$

where 0.86 is the coefficient of total clothes washer energy usage for water heating (Wenzel et al., 1997)

0.75 is the coefficient of total dishwasher energy usage for water heating (Wenzel et al., 1997)

UEC_{cw} is the average daily clothes washer electricity usage (kJ/day)

UEC_{dw} is the average daily dishwasher electricity usage (kJ/day)

4.18 is the specific heat of water (kJ/kg°C)

55 is the typical hot water temperature set point used in residences (°C)

GT is the average ground temperature (°C) (available from Hot2000 weather data)

By applying Eq. 4.7 and 4.8 to the 8767 low-rise single family dwellings in CREEEM, the average daily hot water demand is estimated to be 248 l/day. In comparison, the reported average daily demand for domestic hot water from long-term metered usage by Perlman and Mills (1985) from a group of 58 single family dwellings in Ontario is 236 l/day, while 256 l/day was reported by Kempton (1988) from a group of seven single family residences in the state of Michigan.

4.2.3 Validation of Energy Consumption Predictions of CREEEM

Since the Hot2000 Batch input files that constitute CREEEM were developed using several sources of data, it is necessary to verify the accuracy of its UEC estimates. Energy billing data for 1993 obtained from fuel suppliers and utility companies are available for a subset of 5048 houses in the SHEU database. However, not all of the billing data appeared to be reliable and complete as explained in detail elsewhere (Farahbakhsh et al., 1997; Farahbakhsh, 1997; Fung et al, 2000; Aydinalp, 2002). An analysis of the data indicated that out of the 5048 billing data files, a total of 3284 belonging to 2811 unique households, could be considered complete. The distribution of the usable whole-year billing records available from the SHEU database is depicted in Figure 4.2. Therefore, Hot2000 runs were made for these 2811 houses using the input files generated as part of CREEEM. The UEC estimates were compared to the actual billing data, and systemic errors in the input files were identified through these comparisons. After several cycles of simulation and input file improvement, an acceptable level of agreement was achieved between the actual billing data and the Hot2000 estimates. It should be noted that this iterative process was manly used in identifying systemic and/or programming errors in data conversion and house description input files generation for use in the Hot2000 building energy simulation.

Since Hot2000 uses long-term average weather data to estimate the annual space heating energy consumption. The energy consumption estimates obtained from Hot2000 simulations represent the energy consumption for a "typical" year. Therefore, the results from Hot2000 cannot be directly used to compare with the actual energy billing records for the period in question. As a result, all space heating energy consumption from Hot2000 simulation results were adjusted with the actual heating degree-days (HDD) calculated from the weather data available from Environment Canada (1999b) for the cities available in Hot2000 using the methodology proposed by McQuiston and Parker (1988) for billing comparison:

$$UEC_{adjusted} = UEC_{H2K} \frac{HDD_{actual} \times CD_{actual}}{HDD_{H2K} \times CD_{H2K}} \qquad \text{Eq. 4.11}$$

Where $UEC_{adjusted}$ = weather adjusted space heating UEC for the actual HDD

UEC_{H2K} = simulated space heating UEC with the long-term HDD

HDD_{actual} = actual HDD calculated from the actual hourly temperatures

HDD_{H2K} = long-term HDD used in Hot2000

CD_{actual} = correction factor for the actual HDD

CD_{H2K} = correction factor for the long-term HDD used in Hot2000

$$CD = \begin{cases} \text{if HDD} < 2800 & 0.85 - 0.000051 \times HDD \times 9/5 \\ \text{if HDD} = 2800 & 0.60 \\ \text{if HDD} > 2800 & 0.52 + 0.000025 \times HDD \times 9/5 \end{cases}$$

The weather adjusted household space heating energy consumption calculated from Eq. 4.11 was added to the energy consumption estimates by other end-uses (such as appliance and DHW heating) of the same fuel type to determine the total simulated annual fuel consumption for each house.

To verify that the relationship between the space heating energy consumption and the heating degree-days (HDD) is linear, a detailed simulation on household space heating energy consumption for a number of cities in North America was conducted using Carrier's HAP hour-by-hour building simulation software. A typical house with three different insulation levels was used in the analysis, and the results showed that space heating energy consumption can be approximated linearly with HDD. The result also demonstrated that lower the insulation (space heating dominated dwelling) the better the linear fit between the space heating energy consumption and the HDD. The detailed analysis is shown in Appendix C.

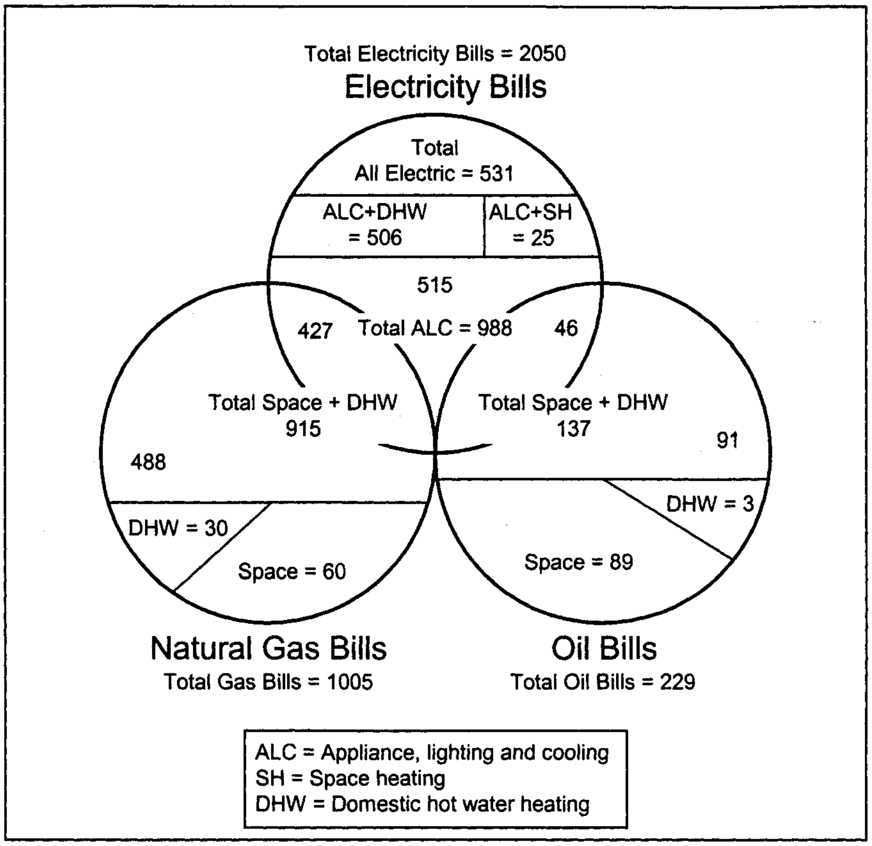

Figure 4.2: Distribution of the usable SHEU billing records

To assess the accuracy of the predictions of CREEEM, a number of statistical measures were used. In addition to the standard prediction error estimate (percent deviation) between the model estimates and billing records, multiple correlation coefficient of determination (R^2) and coefficient of variation (CV) were employed to assess the confidence level of the prediction performance. Percent deviation is simply a measure of percentage difference of the average estimated value to that of the average actual value. The multiple correlation coefficient of determination measures the percentage of variation in the dependent variable accounted for by the independent predictor variables, and the coefficient of variation measures the relative scatter in data with respect to the mean. Percent deviation, multiple correlation coefficient of determination, R^2, and coefficient of variation, CV, can be defined as:

$$\text{Deviation}\,(\%) = 100 * \left(\frac{\text{Estimate UEC - Actual UEC}}{\text{Actual UEC}} \right) \qquad \text{Eq. 4.12}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N} (y_i - t_i)^2}{\sum_{i=1}^{N} t_i^2} \qquad \text{Eq. 4.13}$$

$$CV = \frac{\frac{\sqrt{\sum_{i=1}^{N} (y_i - t_i)^2}}{N}}{\bar{t}} x100 \qquad \text{Eq. 4.14}$$

Where y_i = Estimated UEC

t_i = Actual UEC from billing data

$\bar{t}$ = Average of actual UEC

N = Sample size

4.2.3.1 Validation of Household Appliance Energy Consumption Estimates

Out of the complete 3284 billing data files, there are 988 with complete whole-year electricity billing records from households that use a fossil fuel for space and DHW heating. Thus, the electrical consumption in these households is only due to appliance usage. The appliance energy consumption predictions obtained from CREEEM for these households were compared with the billing data, and the results are presented in Table 4.14 and Figures 4.3 and 4.4.

As can be seen from Table 4.14, CREEEM can accurately estimate the appliance energy consumption. The average estimate of 9,634 kWh/year/house is only 5.7% more than the actual average. The spread of the predictions is narrower than that of the billing records;

(with the maximum consumption of 40,153 kWh/year/house in billing records versus 25,998 kWh/year/house in the predictions), while they both have similar minimums. The high maximum energy consumption in the actual data is likely the result of outliers in the billing records and/or unreported equipment (such as home workshop or office) used in the households. As can be seen from the results presented in Table 4.14 that CREEEM is capable to explain, on average, 81% of the total household appliance UEC with R^2 of 0.81 and CV of 1.77.

Table 4.14: Comparison of estimated household appliance UEC and billing data

Electricity Consumption (kWh/Year)	Appliance Only	
	Actual	Estimate
Sample	988	988
Average	9111	9634
Difference (%)	5.7	
Maximum	40153	25998
Minimum	3030	2991
Standard Deviation	5264	3040
R^2	0.81	
CV	1.77	

Figure 4.3 shows the scatter plot of total annual household appliance UEC estimates versus billing records. As it can be seen from Figure 4.3, there are a few outlier households (scattered points located on the far right side of the figure) with high consumption from billing records and relatively low estimated UECs. On the other hand, CREEEM is able to accurately estimate the high UECs (approximately 20,000 kWh/year) indicating that the present model can be used to estimate the total household appliance

energy consumption, even at extremely high level, if reliable representative information on household appliance characteristics and usage are available.

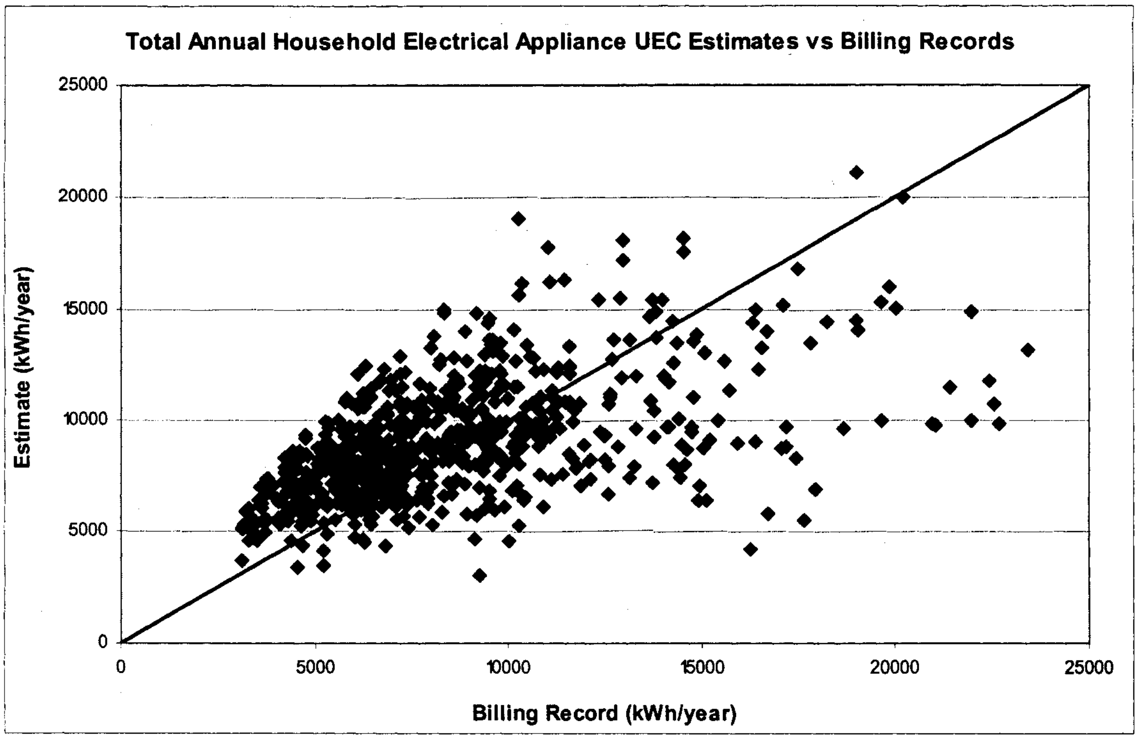

Figure 4.3: Scatter plot of total household appliance UEC estimates versus billing records

The distribution of percent deviation between actual and estimated household appliance UEC is shown in Figure 4.4. As can be seen from Figure 4.4, the prediction error distribution does follow the normal (Gaussian) distribution with a slight evidence of overestimate skewedness, indicting that there is no significant bias in the model.

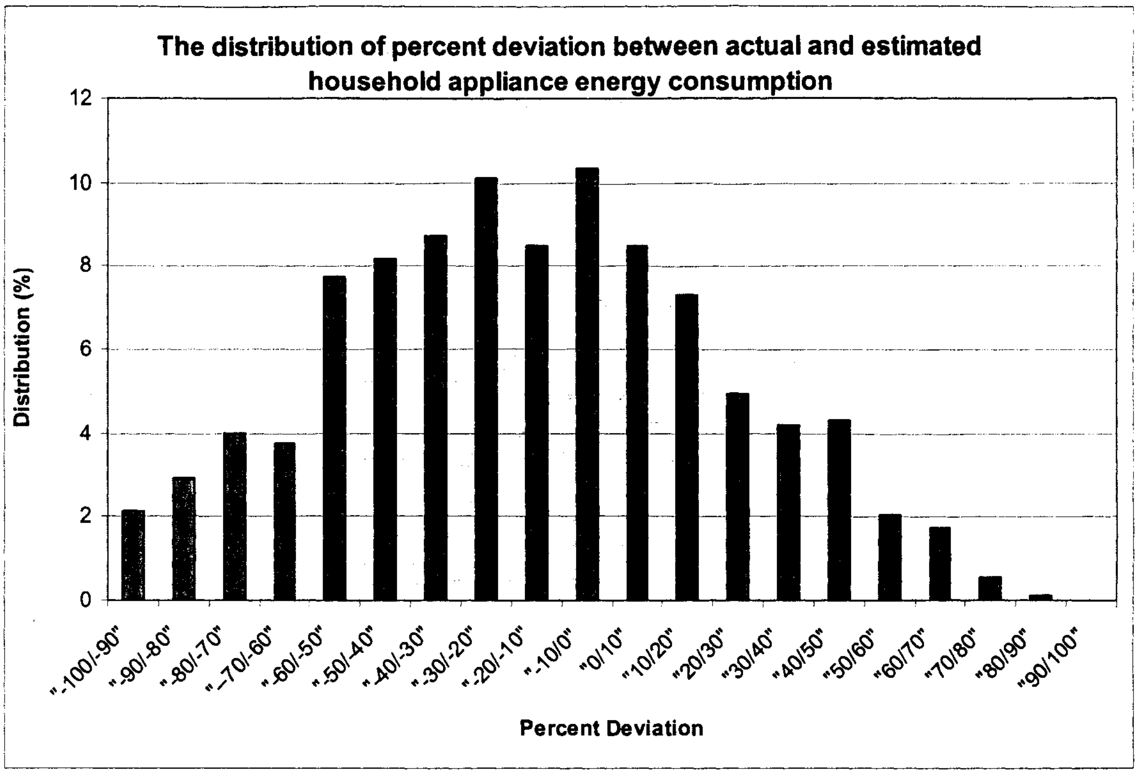

Figure 4.4: Distribution of household appliance energy consumption prediction error

4.2.3.2 Validation of Household Fuel Consumption Estimates

Comparisons of household energy consumption estimates and billing records for space and DHW heating are presented in Table 4.15 to Table 4.18 and Figure 4.5 to Figure 4.10 for electricity, natural gas and oil. As can be seen from these tables, the overall household energy consumption predictions are close to the billing records, with the deviation of 12.3, -4.8 and 2.5% for electricity, natural gas and oil, respectively. Also, the maximum, minimum and standard deviation of the actual and predicted energy consumptions for all three fuels are comparable.

The probable reason for the overestimation of 12.3% of average household electricity consumption is the use of room thermostats in most electrically heated houses. Room thermostats that control electric baseboard heaters provide the flexibility to reduce the settings in unoccupied rooms, resulting in an average indoor temperature for the whole house that is lower than normal. Also due to this flexibility, it is difficult for the occupants to accurately estimate the average indoor temperature.[8] These factors collectively result in an estimated energy consumption that is higher than the actual consumption. The enhanced zoning capability and its effect on energy consumption with the electric baseboard heating system is also reported by Pratt et al. (1993).

As seen in Table 4.16, the average natural gas energy consumption estimate for space heating is 16% lower than the billing records. The reason for this large difference is probably the small sample size (60) of houses that use natural gas for space heating, and another fuel for DHW heating. It is unusual for households to choose natural gas for space heating only, and not for both space and DHW heating, since the unit price of electricity is always higher than that of natural gas. Therefore, one may conclude that the few houses in the sample are not representative of the housing stock and/or there is error in the data. It should be noted that for combined space and DHW heating (sample size 915), the predicted natural gas consumption is only 2.2% less than the actual with R^2 of 0.90, while for natural gas DHW heating the difference is only 0.1% with R^2 of 0.87 in a group of 175 houses. The actual energy consumption data for these 175 houses were derived from the monthly natural gas billing data during the summer period (June to August) when no space heating was required.

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[8] Average indoor thermostat settings reported by the occupant is reported in the SHEU data.

Table 4.15: Comparison of estimated household electricity consumption and billing data

Household Electricity Consumption (GJ/Year)	Appliance Only		Appliance + DHW		All Uses		Any End-use	
	Actual	Estimate	Actual	Estimate	Actual	Estimate	Actual	Estimate
Sample	988	988	506	506	531	531	2050	2050
Average	32.8	34.7	46.2	51.4	92.7	107.1	51.8	58.1
Difference (%)	5.7		11.3		15.5		12.3	
Maximum	145	94	214	96	203	235	214	235
Minimum	11	11	11	21	16	42	11	11
Standard Deviation	19	11	23	12	34	32	35	36
R^2	0.81		0.83		0.84		0.82	
CV	1.77		2.06		1.85		1.13	

Table 4.16: Comparison of estimated household natural gas consumption and billing data

Natural Gas Consumption (GJ/Year)	Space Heat + DHW		Space Heat Only		DHW Only		All	
	Actual	Estimate	Actual	Estimate	Actual	Estimate	Actual	Estimate
Sample	915	915	60	60	175	175	1005	1005
Average	127	125	114	96	32	32	126	120
Difference (%)	-2.2		-15.9		-0.1		-4.8	
Maximum	259	260	174	256	68	52	259	260
Minimum	21	42	34	24	12	17	21	18
Standard Deviation	39	38	34	45	13	7	39	41
R^2	0.90		0.81		0.87		0.88	
CV	1.10		5.95		2.88		1.14	

Table 4.17: Comparison of estimated household oil consumption and billing data

Oil Consumption (GJ/Year)	Space Heat + DHW		Space Heat Only		DHW Only		All	
	Actual	Estimate	Actual	Estimate	Actual	Estimate	Actual	Estimate
Sample	137	137	89	89	N/A	N/A	229	229
Average	120	124	95	99	N/A	N/A	110	113
Difference (%)	3.6		3.7		N/A		2.5	
Maximum	220	250	215	326	N/A	N/A	220	326
Minimum	26	58	18	29	N/A	N/A	18	17
Standard Deviation	40	37	38	46	N/A	N/A	41	43
R^2	0.87		0.73		N/A		0.82	
CV	3.21		5.97		N/A		2.96	

Table 4.18: Comparison of estimated household fuel energy consumption and billing data for combined space and DHW heating

Space + DHW Heating Consumption (GJ/Year)	Gas or Oil	
	Actual	Estimate
Sample	1052	1052
Average	126.4	124.6
Difference (%)	-1.4	
Maximum	259	260
Minimum	22	42
Standard Deviation	39	38
R^2	0.90	
CV	1.05	

Figures 4.5 to 4.10 show that there is general agreement between CREEEM predictions and actual energy consumption records. It should be noted that in Figure 4.5, the high concentration of households at the lower consumption level reflects the household appliance electricity consumption from the non-electric heated households while the higher consumption level reflects the total household consumption for the electric heated households.

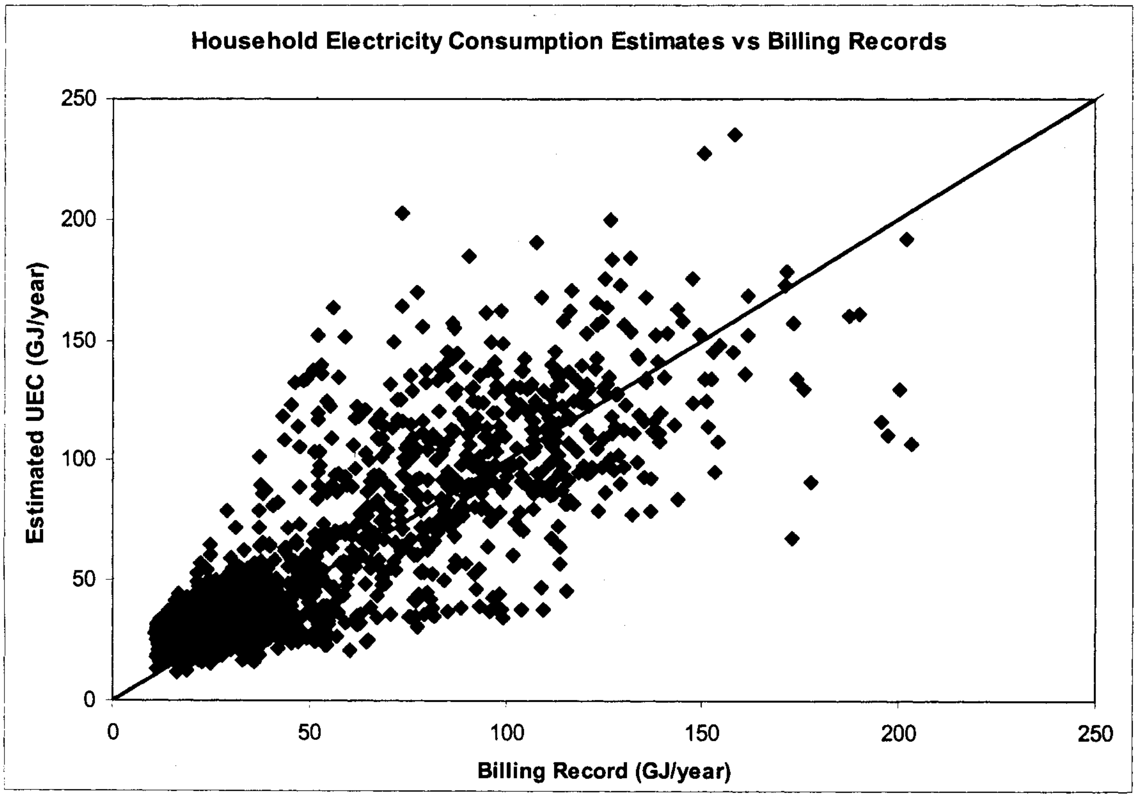

Figure 4.5: Scatter plot of household electricity consumption estimates versus billing records

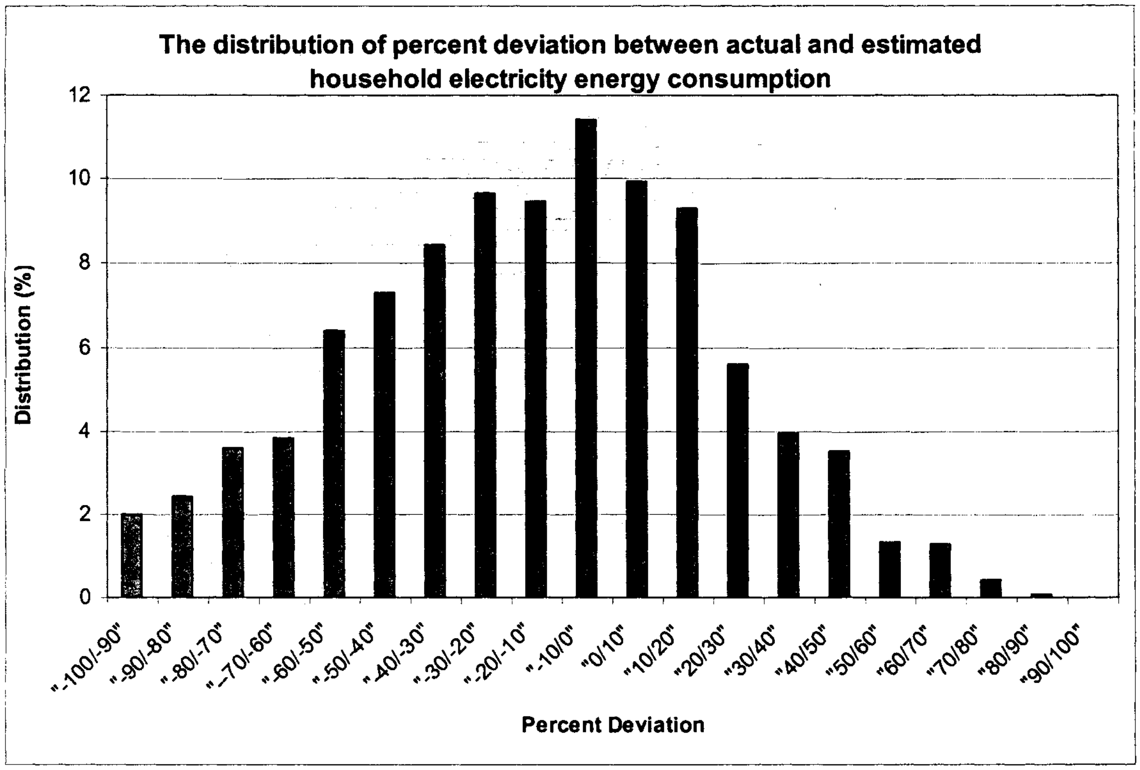

Figure 4.6: Distribution of household electricity consumption prediction error

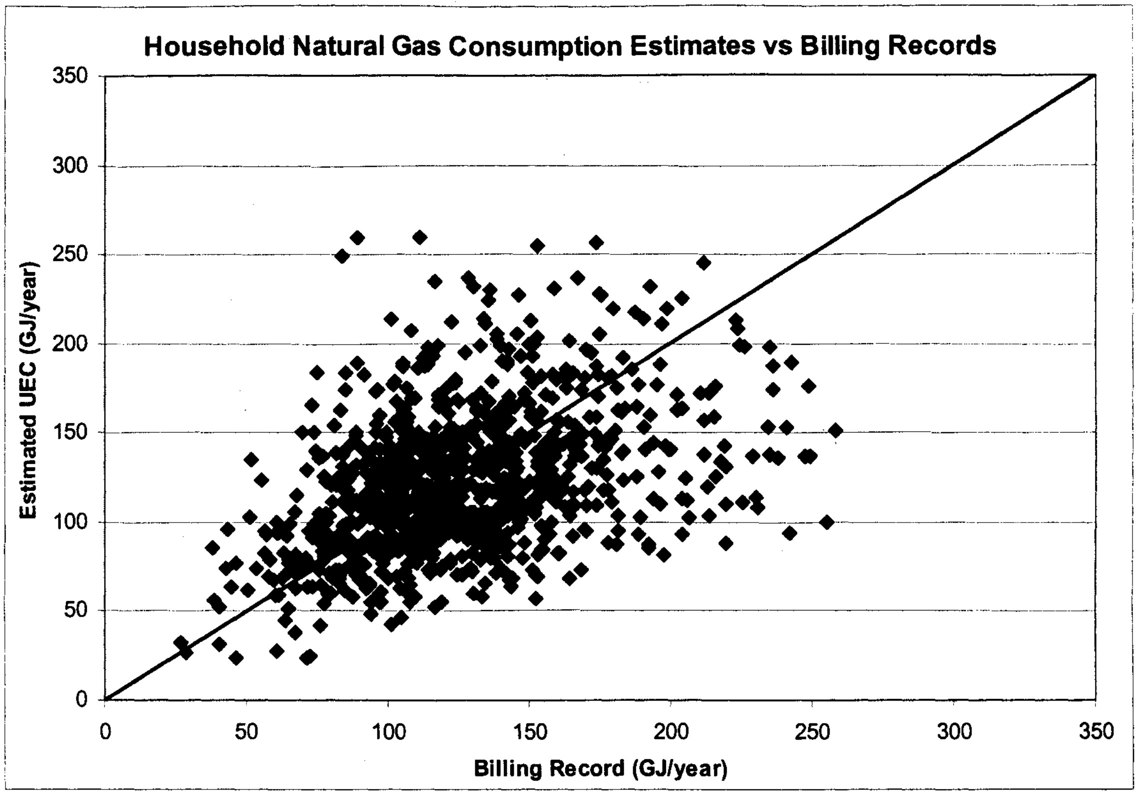

Figure 4.7: Scatter plot of household natural gas consumption estimates versus billing records

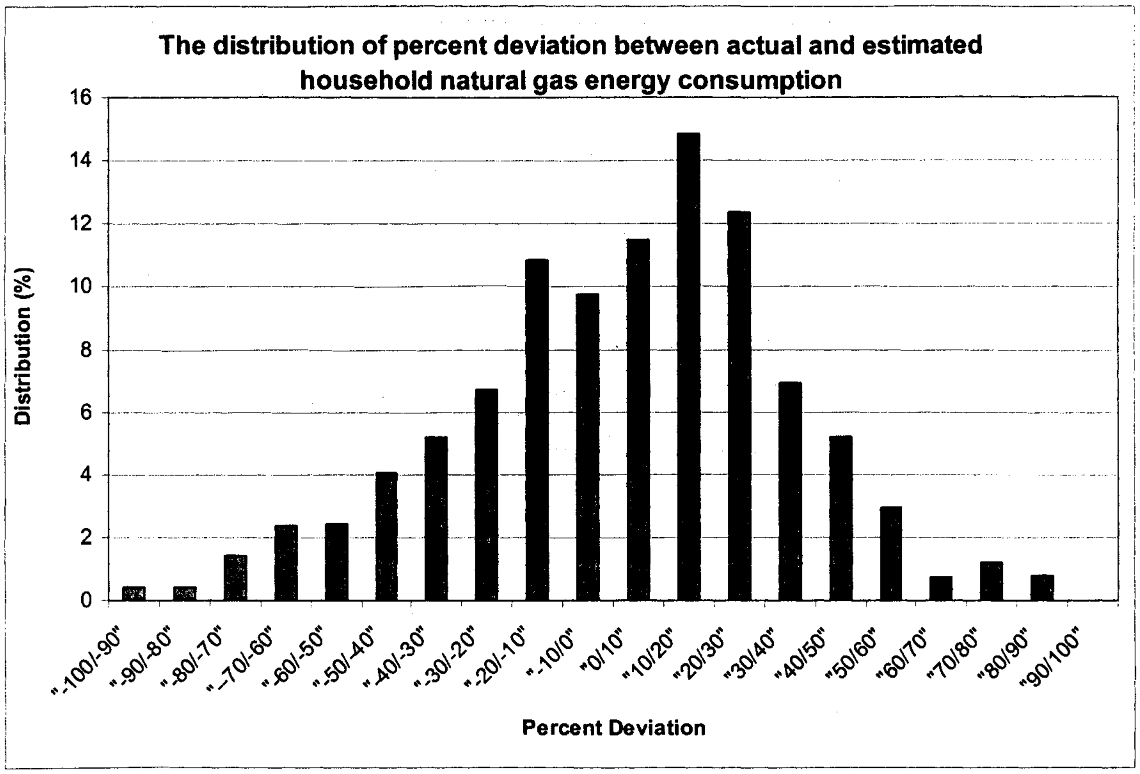

Figure 4.8: Distribution of household natural gas consumption prediction error

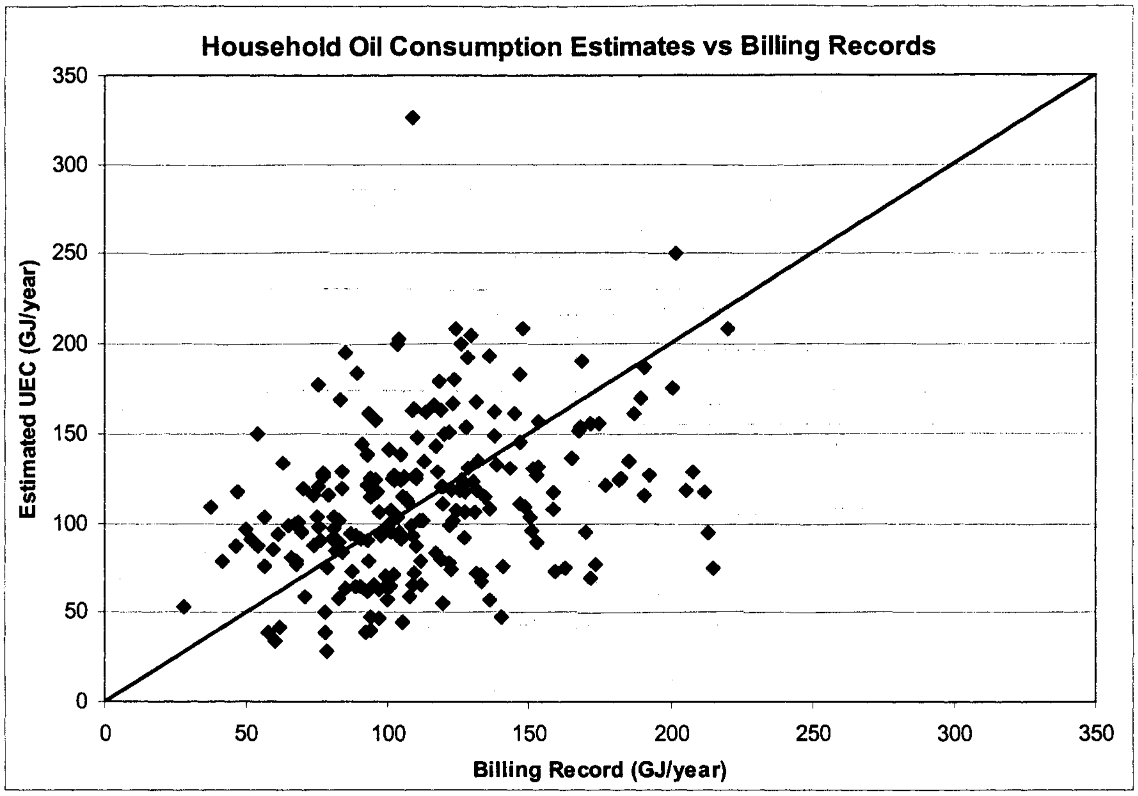

Figure 4.9: Scatter plot of household oil consumption estimates versus billing records

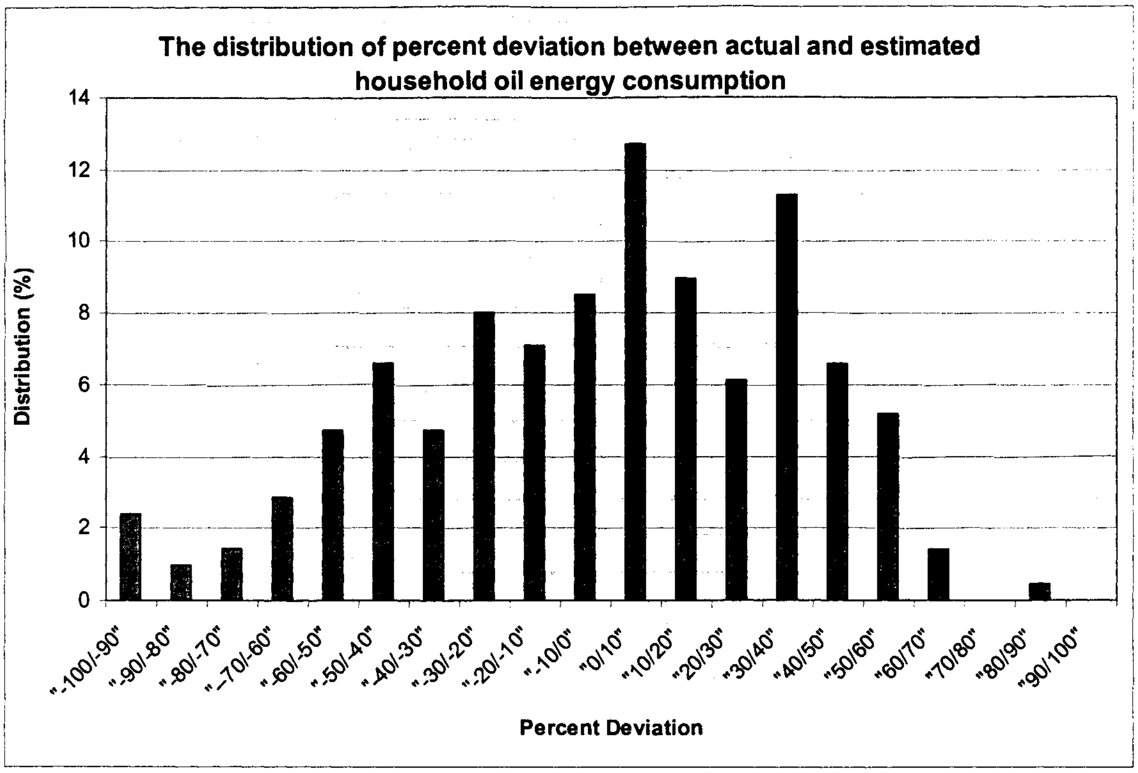

Figure 4.10: Distribution of household oil consumption prediction error

4.2.3.3 Validation of Whole House Energy Consumption Estimates

There is a total of 1004 households with complete annual household energy billing records (531 electric, 427 natural gas and 46 oil heated). The average actual and estimated total energy consumption and the R^2 and CV values are presented in Table 4.19. As can be shown from Table 4.19, the household energy consumption prediction are quite high (R^2 of 0.84 for electric heated household to 0.92 for natural gas heated households), indicating between 84% and 92% of the total household energy consumption can be modeled and explained satisfactorily by CREEEM.

Table 4.19: Summary of whole house energy consumption prediction accuracy

Whole House Fuel Consumption (GJ/Year)	Electric Heated		Natural Gas Heated		Oil Heated		All Fuels	
	Actual	Estimate	Actual	Estimate	Actual	Estimate	Actual	Estimate
Sample	531	531	427	427	46	46	1004	1004
Average	93	107	160	164	143	164	124	134
Diff (%)	15.5		2.5		15.0		8.3	
Maximum	203	235	347	310	231	242	347	310
Minimum	16	42	63	64	67	96	16	42
Standard Deviation	34	32	42	40	38	39	50	46
R^2	0.84		0.92		0.81		0.90	
CV	1.85		1.39		5.16		1.10	

Figure 4.11 shows the scatter plot of total household energy consumption estimates versus billing records. As it can be seen from Figure 4.11 that the predicted total household energy consumption follow the actual consumption closely for most households in spite of some outlier households in the sample. The distribution of total household energy consumption prediction error is shown in Figure 4.12. As can be seen from Figure 4.12 that the prediction error distribution do follow the normal (Gaussian) distribution quite closely with no evidence of bias.

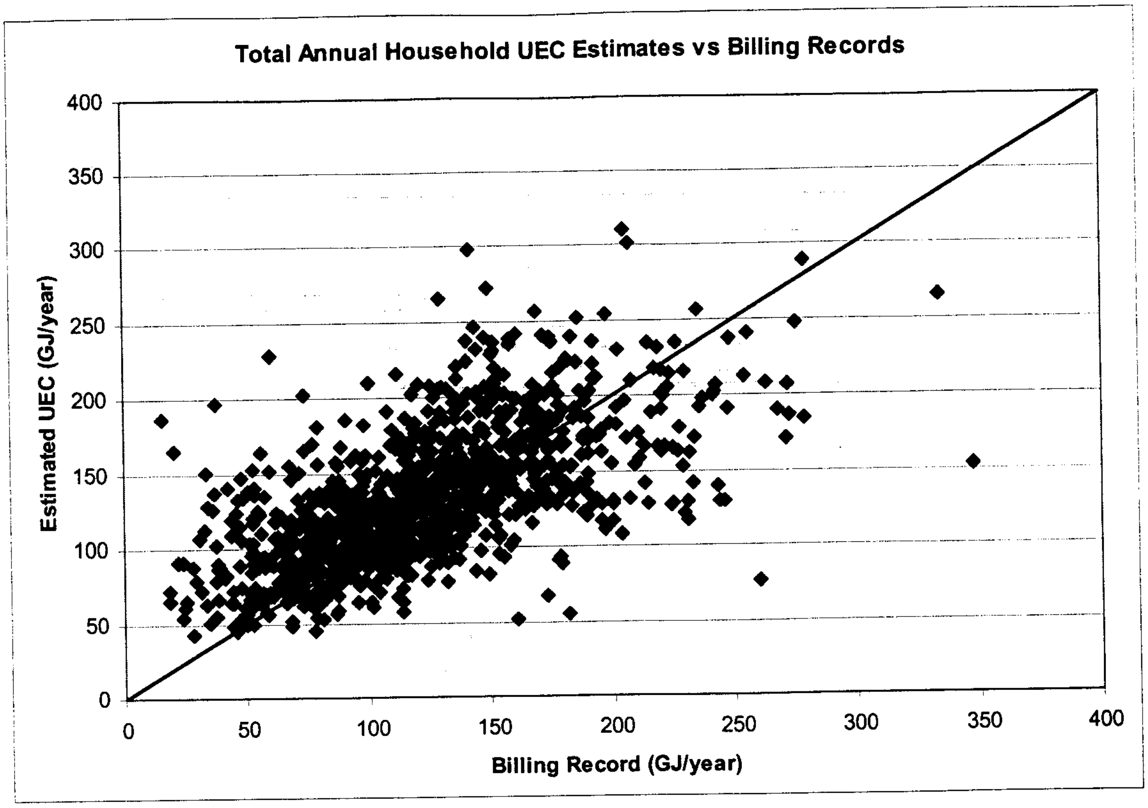

Figure 4.11: Scatter plot of total household energy consumption estimates versus billing records

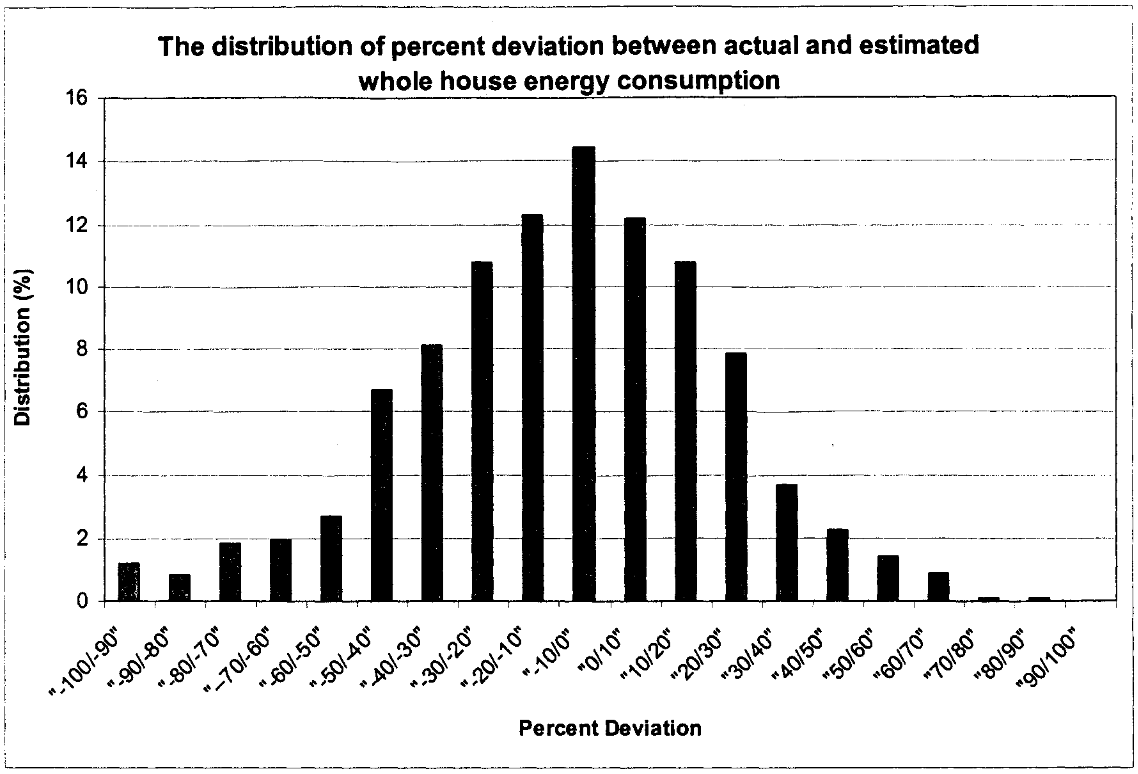

Figure 4.12: Distribution of total household energy consumption prediction error

4.2.4 Estimation of Greenhouse Gas Emissions

One of the objectives of this work is to estimate the GHG emission produced due to the energy consumed in the Canadian housing stock. GHG are emitted from the combustion of fossil fuels in residences, as well as in the generation of electricity in thermal power plants. In the following sections, the methodology used to determine the amount of GHG emissions resulting from the consumption of electricity and fossil fuels in the Canadian housing stock.

4.2.4.1 GHG Intensities For Electricity Production for Each Province and Canada

The amount of GHG emission from electricity generation can be calculated using the "GHG Intensity Factor" (GHGIF) for electricity generation. GHGIF is the amount of GHG emission produced as a result of generating one kWh of electricity.

The fuel mix used in any one province of Canada is substantially different from the fuel mix used in another province. Therefore, the GHGIF for each province must be calculated based on the actual fuel mix of the province and the amount of GHG emission 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. The amount of electricity generated in 1993 from each of these sources and the amount of fuel consumed are given in Table 4.20. The same data for each province are given in Tables D.1 to D.10 in Appendix D.

As a result of the combustion of fossil fuels, three major GHG's are produced: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The amount of emission of CO_2, CH_2 and N_2O varies from one fuel to another, and it is calculated using Emission Factors (EF). Emission Factors are commonly expressed in tons of GHG emission per kilotonne of solid fuel, and in tons of GHG emission per mega liter of fuel for liquid and gaseous fuels. The CO_2, CH_4 and N_2O emission factors for fossil fuels used in electricity production in Canada are given in the last three columns of Table 4.21, and the emission factors for each province are given in Tables D.11 to D.20 in Appendix D.

Table 4.20: Electricity generation in Canada in 1993 and GHG Emission Factors

Canada 1993			GHG Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	CO_2 (2)	CH_4 (2)	N_2O (2)
Canadian bituminous	13,930	5,272 kt	2,209 t/kt	0.015 t/kt	0.05 t/kt
US bituminous	11,928	4,129 kt	2,517 t/kt	0.015 t/kt	0.05 t/kt
Lignite	12,851	9,823 kt	1,451 t/kt	0.015 t/kt	0.05 t/kt
Sub bituminous	41,686	23,689 kt	1,701 t/kt	0.015 t/kt	0.05 t/kt
Light Fuel Oil	362	105 ML	2,828 t/ML	0.006 t/ML	0.013 t/ML
Diesel	335	99 ML	2,734 t/ML	0.26 t/ML	0.4 t/ML
Heavy	9,316	2,245 ML	3,088 t/ML	0.03 t/ML	0.013 t/ML
Natural Gas	11,717	3,344 Mm^3	1,880 t/Mm^3	0.0048 t/Mm^3	0.02 t/Mm^3
Hydro	286,918	N/A	N/A	N/A	N/A
Nuclear	88,620	N/A	N/A	N/A	N/A
Total	477,244	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.

To simplify reporting and facilitate comparative analysis, CH_4 and N_2O emission are converted to and expressed in "tons of CO_2 equivalent" using the Global Warming Potential multiplier (GWP) (Environment Canada, 1999a). 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 (Environment Canada, 1999a). Thus,

1 tonne of CH_4 emission = 21 tonnes of CO_2 emission　　Eq. 4.15

1 tonne of N_2O emission = 310 tonnes of CO_2 emission　　Eq. 4.16

The CO_2 emission, as well as the CO_2 equivalent CH_4 and N_2O emission, and the total CO_2 equivalent GHG emission for 1993 are given in Table 4.21. The same data for each province are given in Tables D.11 to D.20 of Appendix D.

Table 4.21: GHG emission in Canada from electricity production, 1993

Canada 1993 Energy Sources	GHG Emission (kt)			Total GHG emission (kt)
	CO_2	CO_2 Eqv. of CH_4	CO_2 Eqv. of N_2O	(in tonnes of equivalent CO_2)
Canadian bituminous	11,646	2	82	11,729
US bituminous	10,393	1	64	10,458
Lignite	14,253	3	152	14,409
Sub bituminous	40,295	7	367	40,670
Light Fuel Oil	297	0	0	297
Diesel	271	1	12	283
Heavy	6,933	1	9	6,943
Natural Gas	6,281	0	21	6,302
Hydro	N/A	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A	N/A
Total	90,368	16	708	90,808

* Equivalency factors: 1 t of CH4 emissions is equivalent to 21 t of CO2 equivalent CH4 emissions
1 t of N2O emissions is equivalent to 310 t of CO2 equivalent N2O emissions

The GHGIF's are calculated for Canada and for each province by dividing the total electricity production (from Table 4.20 and Tables D.1 to D.10) by the total equivalent CO_2 emission (from Table 4.21 and Tables D.11 to D.20). The results are presented in Table 4.22. It can be seen from Table 4.22 that the variation of GHGIF from one province to another is very large, from a low of 2 g/kWh for Quebec to a high of 920 g/kWh in Alberta. The very low GHGIF for Quebec is due to the predominance of hydro power plants in the province, while the high GHGIF of Alberta is due to the predominance of coal fired electricity generation in Alberta.

Note that Prince Edward Island produces (by low-efficiency oil-based generation) less than 10% of its own electricity, and the rest is imported from New Brunswick. Since the vast majority of the power is imported, the GHGIF for Prince Edward Island shown in Table 4.22 reflects the emission intensity with the New Brunswick source (90%).

Table 4.22: GHGIF for each province and for Canada in 1993

Provinces	GHGIF (g/kWh)
NFLD	33.2
PEI*	413.5
NS	733.6
NB	326.4
QUE	2.0
ON	136.5
MAN	11.3
SAS	796.0
AB	920.6
BC	37.3
Canada	190.5

4.2.4.2 Calculation of GHG Emission due to Residential Energy Consumption

The amount of GHG emission due to energy consumption of each house in CREEEM was calculated based on the amount of each fuel used in the house since the GHG emission for each fuel is different. The fuels used in the Canadian housing stock and their GHG Emission Factors are given in Table 4.23.[9]

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[9] CO_2 emission from combustion of biomass fuels, such as wood, was not included in this analysis since it was accepted that there was no net GHG emission from biomass fuels (IEA, 1999).

Table 4.23: GHG emission factors for non-electric use

Canada 1993 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 for 1990, Report EPS 5/AP/4

Environment Canada, December 1992.

Using the data given in Table 4.23, the GHG emission due to the non-electric energy consumed in any given house was calculated as follows:

$$ECO2 = \sum_{i=1}^{3} (AFC_i)(CO2EF) \qquad \text{Eq. 4.17}$$

$$ECH4 = \sum_{i=1}^{3} (AFC_i)(CH4EF) \qquad \text{Eq. 4.18}$$

$$EN2O = \sum_{i=1}^{3} (AFC_i)(N2OEF) \qquad \text{Eq. 4.19}$$

Where ECO2 = CO_2 emission, tonne/year

ECH4 = CH_4 emission, tonne/year

EN2O = N_2O emission, tonne/year

AFC_i = Annual consumption of fuel type i for the house

CO2EF = CO_2 emission factor, as per Table 4.23

CH4EF = CH_4 emission factor, as per Table 4.23

N2OEF = N_2O emission factor, as per Table 4.23
i = type of fuel
i = 1 for oil
i = 2 for natural gas
i = 3 for propane

The "tonnes of CO_2 equivalent" GHG emission from each house was calculated using the following GWP multipliers:

1 tonne of CH_4 emission = 21 tonnes of CO_2 emission Eq. 4.20

1 tonne of N_2O emission = 310 tonnes of CO_2 emission Eq. 4.21

Thus, the CO_2 equivalent GHG emission due to the fossil fuel consumption of each house was calculated as follows:

$$\text{CO2EEFF} = (\text{ECO2}) + (\text{ECH4})(21) + (\text{EN2O})(310) \qquad \text{Eq. 4.22}$$

The total CO_2 equivalent GHG emission from each house due to all of its energy consumption, including fossil fuels and electricity, was calculated as follows:

$$\text{TCO2EE} = \text{CO2EEFF} + (\text{ELCON})(\text{GHGIF}) \qquad \text{Eq. 4.23}$$

Where CO2EEFF = CO_2 equivalent GHG emission due to fossil fuel consumption from the house, tonnes/ year
TCO2EE = Total CO2 equivalent GHG emission from the house, tonnes/year
ELCON = electricity consumption of the house, kWh/year
GHGIF = as per from Table 4.22

4.2.4.3 Extrapolating the Results of CREEEM to the Canadian Housing Stock

As it was previously pointed out, CREEEM is based on the 8767 houses in the SHEU 1993 database. In its Microdata User's Guide, Statistics Canada (1993a) provided 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 a particular house in SHEU represents in the Canadian housing stock. Thus, the annual energy consumption and the annual GHG emission calculated for each house in CREEEM was multiplied by its weighting factor to estimate the corresponding energy consumption and GHG emission in the entire Canadian housing stock. For the sake of practicality and brevity, only the results pertaining to the Canadian housing stock are presented in this work. Also, unweighted CREEEM results are not useful and/or representative of the Canadian housing stock.

4.3 Results and Discussions

In this section, detailed estimates, using CREEEM, of energy consumption and associated GHG emissions in the Canada residential sector will be presented according to province, fuel types, end-uses, dwelling vintage, and dwelling type. The result presented herein is based on the 1993 Canadian low-rise single family housing stock of 7,103,953 dwellings located in the provinces.

An earlier version of CREEEM was used to conduct a techno-economic analysis of house retrofit activities and associated energy savings and GHG emissions in the residential sector of Canada (Guler et al., 1999, 2000, 2001).

4.3.1 Residential Energy Consumption in Canada

4.3.1.1 Residential Energy Consumption by Province

The overall household end-use energy consumption for each province and Canada is presented in Table 4.24. The second column represents the total number of households in each category in 1993. Columns 3 to 5 present the overall average household energy consumption. The overall average household end-use energy consumption is divided into two parts: electricity and fossil fuel. Electricity represents the amount of electricity consumed at the household level while fossil fuel represents the amount of any other fuel(s), including wood, consumed. The aggregated total household end-use energy consumption is presented in the last three columns. As one would expect due the total number of houses, Ontario, Quebec, and British Columbia were the provinces with the highest residential energy consumption.

The overall residential end-use energy consumption was estimated to be 1000 PJ in 1993 with an average household consumption of 141 GJ. Electricity accounted for approximately 45 percent of this total consumption.

Table 4.24: Overall residential end-use energy consumption by province

		Per house (GJ/house/year)			For the entire housing stock (PJ/year)		
Province	# of Houses	Electricity	Fossil Fuel	Total	Electricity	Fossil Fuel	Total
NFL	169 601	83.75	73.9	157.6	14.2	12.5	26.7
PEI	37 699	38.6	138.1	176.7	1.5	5.2	6.7
NS	256 675	59.6	95.5	155.2	15.3	24.5	39.8
NB	207 428	90.3	65.7	156.0	18.7	13.6	32.4
PQ	1 485 663	95.1	37.5	132.6	141.2	55.8	197.0
ON	2 729 354	55.0	77.7	132.7	150.1	212.2	362.3
MAN	304 401	66.4	99.6	166.0	20.2	30.3	50.5
SAS	300 207	48.4	130.9	179.2	14.5	39.3	53.8
AB	704 141	38.8	139.2	178.0	27.3	98.0	125.4
BC	906 610	51.1	64.7	115.7	46.3	58.6	104.9
CANADA	7 101 779	63.3	77.5	140.7	449.5	550.1	999.6

The provincial distribution of average household energy consumption range from 116 GJ for British Columbia to 179 GJ for Saskatchewan. This wide range in household energy consumption could be mainly attributed to the regional climate (heating degree days - HDD) as well as space and DHW heating fuel mix. The end-use energy consumption for space heating decreases in warmer climates (i.e. lower HDD) and with an increase in the end-use energy efficiency of the heating system. Thus, end-use energy consumption is lower in provinces where electricity is widely used for space heating since the end-use energy consumption efficiency with electric baseboard heating is 100%. This can be best illustrated by comparing the energy consumption between Manitoba and Saskatchewan since both provinces have similar HDDs and total number of houses. The difference in household energy consumption is mainly due to higher usage of electricity in Manitoba than in Saskatchewan.

4.3.1.2 Residential End-use Energy Consumption by Space Heating Fuel Type

The provincial distribution of household energy consumption classified according to space heating fuel type, i.e. electricity, natural gas, oil, wood, and propane is presented in Table 18. Both average annual household and total energy consumption are divided into two distinct parts: fossil fuels and electricity, since all houses use electricity. It should be noted that, not all households use the same fossil fuel for both space and DHW heating. Tables A.5 and A.6 show that a large percentage of households with fossil fuel space heating systems utilize electricity for DHW heating, since electricity share for DHW heating is higher than those of fossil fuels for space heating.

Table 4.25: Overall end-use energy consumption by space heating fuel type

			Per house (GJ/house/year)			For the entire housing stock (PJ/year)		
Province	Fuel Type	# of Houses	Electricity	Fossil Fuel	Total	Electricity	Fossil Fuel	Total
NFL	Propane	1 393	52.1	135.2	187.3	0.1	0.2	0.3
	Wood	32 325	51.0	166.4	217.4	1.6	5.4	7.0
	Electric	73 070	129.0	0.9	130.0	9.4	0.1	9.5
	Oil	62 813	48.6	109.8	158.4	3.1	6.9	10.0
PEI	Propane	466	36.2	164.2	200.4	0.0	0.1	0.1
	Wood	6 364	39.7	185.0	224.7	0.3	1.2	1.4
	Electric	1 112	93.3	18.6	111.8	0.1	0.0	0.1
	Oil	29 757	36.4	132.2	168.5	1.1	3.9	5.0
NS	Propane	5 288	37.9	111.8	149.7	0.2	0.6	0.8
	Wood	40 468	51.2	170.7	221.9	2.1	6.9	9.0
	Electric	61 105	111.0	0.6	111.6	6.8	0.0	6.8
	Oil	149 814	41.7	113.4	155.1	6.3	17.0	23.2
NB	Propane	471	47.0	144.1	191.1	0.0	0.1	0.1
	Wood	37 784	56.3	167.5	223.7	2.1	6.3	8.5
	Electric	114 608	121.2	5.0	126.2	13.9	0.6	14.5
	Oil	54 566	49.5	122.0	171.5	2.7	6.7	9.4
PQ	Propane	2 911	49.5	140.7	190.2	0.1	0.4	0.6
	Wood	166 547	58.2	148.7	206.9	9.7	24.8	34.5
	Electric	978 499	116.4	0.9	117.2	113.9	0.9	114.7
	Oil	300 345	52.8	85.7	138.5	15.9	25.7	41.6
	Natural Gas	37 360	44.2	107.4	151.6	1.7	4.0	5.7
ON	Propane	29 143	53.6	106.5	160.0	1.6	3.1	4.7
	Wood	110 628	50.8	103.7	154.5	5.6	11.5	17.1
	Electric	548 446	96.8	5.6	102.5	53.1	3.1	56.2
	Oil	343 437	52.6	77.3	130.0	18.1	26.6	44.6
	Natural Gas	1 697 700	42.3	98.9	141.2	71.8	168.0	239.7
MAN	Propane	1 657	54.0	121.5	175.5	0.1	0.2	0.3
	Wood	8 844	56.0	147.6	203.7	0.5	1.3	1.8
	Electric	89 413	121.0	2.1	123.1	10.8	0.2	11.0
	Oil	12 696	57.6	103.7	161.3	0.7	1.3	2.0
	Natural Gas	191 791	42.2	142.4	184.5	8.1	27.3	35.4
SAS	Propane	3 174	53.0	116.5	169.5	0.2	0.4	0.5
	Wood	3 871	48.5	135.6	184.2	0.2	0.5	0.7
	Electric	20 567	126.6	7.3	133.9	2.6	0.2	2.8
	Oil	15 954	60.0	111.7	171.7	1.0	1.8	2.7
	Natural Gas	256 641	41.3	142.1	183.4	10.6	36.5	47.1
AB	Propane	13 626	45.7	111.2	156.9	0.6	1.5	2.1
	Wood	7 705	41.3	144.2	185.6	0.3	1.1	1.4
	Electric	8 489	116.0	28.0	144.0	1.0	0.2	1.2
	Oil	6 223	44.5	120.9	165.3	0.3	0.8	1.0
	Natural Gas	668 097	37.6	141.3	178.9	25.1	94.4	119.5
BC	Propane	10 502	38.9	81.8	120.6	0.4	0.9	1.3
	Wood	63 519	54.4	84.7	139.2	3.5	5.4	8.8
	Electric	197 233	81.8	2.9	84.7	16.1	0.6	16.7
	Oil	94 293	47.8	47.0	94.8	4.5	4.4	8.9
	Natural Gas	541 063	40.3	87.6	127.9	21.8	47.4	69.2
CANADA	Propane	68 632	48.2	107.5	155.7	3.3	7.4	10.7
	Wood	478 054	54.1	134.6	188.7	25.9	64.4	90.2
	Electric	2 092 541	108.8	2.8	111.6	227.7	5.8	233.5
	Oil	1 069 899	50.0	88.8	138.9	53.5	95.1	148.6
	Natural Gas	3 392 652	41.0	111.3	152.3	139.1	377.5	516.6

It can be observed from Table 4.25 that energy consumption for electric heated households is usually the lowest as compared to the energy consumption of houses heated with any other fuel. The highest energy consumption usually occurs in wood heated households due to its low efficiency heating system (usually between 45 to 60% at most). It should be noted that energy consumption for propane heated households is usually higher than that of oil or natural gas heated households. This is largely due to 1) the sample bias from the small sample size, and 2) the age (older) of propane heated households. Overall, energy consumption of natural gas heated households is generally higher than that of oil or electric heated households.

4.3.1.3 Residential End-use Energy Consumption by End-uses

Overall distribution of household energy consumption according to different end-uses is presented in Table 4.26. The total household energy consumption is presented in five distinct end-uses: space heating, DHW heating, appliances and lighting, fans and HRV, and air-conditioning. Once again, most end-use energy consumption is divided into "direct" and "indirect" to represent fossil fuels and electricity, respectively. It can be seen from Table 4.26 that the percentage of household energy consumption for different end-uses varies greatly from province to province due to local climate, fuel mix, and equipment type and usage. Overall, approximately 55%, 19% and 26% of total household energy consumption is utilized for space heating, DHW heating, and appliances, respectively. Energy consumption for both furnace fans and HRV, as well as central air-conditioning represents approximately one percent of the total household energy budget.

Table 4.26: Overall end-use energy consumption by end-uses

		Per house (GJ/house/year)									
		Space Heating		DHW Heating		App. & Lighting	HRV	A/C	Total (GJ/year/house)		
Province	# of Houses	Indirect	Direct	Indirect	Direct	Indirect	Indirect	Indirect	Indirect	Direct	Total
NFL	169 601	31.1	69.4	20.2	4.5	30.6	1.8	0.0	83.8	73.9	157.6
PEI	37 699	1.5	109.8	5.0	28.3	30.2	1.9	0.0	38.7	138.1	176.8
NS	256 675	13.2	82.0	13.2	13.5	31.5	1.7	0.0	59.7	95.5	155.2
NB	207 428	35.0	62.1	20.7	3.6	32.7	1.9	0.1	90.3	65.7	156.1
PQ	1 485 663	37.4	34.3	20.5	3.3	34.8	1.7	0.6	95.1	37.5	132.6
ON	2 729 354	8.1	59.6	8.4	18.1	34.8	1.4	2.3	55.0	77.7	132.8
MAN	304 401	18.2	81.3	9.7	18.3	34.9	1.8	1.8	66.5	99.6	166.0
SAS	300 207	4.6	103.6	4.7	27.2	36.2	1.6	1.2	48.4	130.9	179.2
AB	704 141	1.0	108.0	1.1	31.2	35.1	1.6	0.1	38.9	139.2	178.1
BC	906 610	6.0	47.0	9.1	17.6	34.9	0.9	0.2	51.1	64.7	115.8
CANADA	7 101 779	15.0	61.7	11.0	15.8	34.6	1.5	1.2	63.3	77.5	140.8

		For the entire housing stock (PJ/year)									
		Space Heating		DHW Heating		App. & Lighting	HRV	A/C	Total (PJ/year/house)		
Province	# of Houses	Indirect	Direct	Indirect	Direct	Indirect	Indirect	Indirect	Indirect	Direct	Total
NFL	169 601	5.3	11.8	3.4	0.8	5.2	0.3	0.0	14.2	12.5	26.7
PEI	37 699	0.1	4.1	0.2	1.1	1.1	0.1	0.0	1.5	5.2	6.7
NS	256 675	3.4	21.1	3.4	3.5	8.1	0.4	0.0	15.3	24.5	39.8
NB	207 428	7.3	12.9	4.3	0.7	6.8	0.4	0.0	18.7	13.6	32.4
PQ	1 485 663	55.6	50.9	30.5	4.8	51.7	2.6	0.8	141.2	55.8	197.0
ON	2 729 354	22.2	162.7	22.9	49.5	95.0	3.9	6.2	150.2	212.2	362.4
MAN	304 401	5.5	24.7	3.0	5.6	10.6	0.6	0.5	20.2	30.3	50.5
SAS	300 207	1.4	31.1	1.4	8.2	10.9	0.5	0.4	14.5	39.3	53.8
AB	704 141	0.7	76.0	0.8	22.0	24.7	1.1	0.1	27.4	98.0	125.4
BC	906 610	5.5	42.6	8.3	16.0	31.6	0.8	0.2	46.3	58.6	104.9
CANADA	7 101 779	106.8	438.0	78.1	112.1	245.7	10.7	8.2	449.5	550.1	999.6

4.3.1.4 Residential End-use Energy Consumption by Vintage

The provincial distribution of household energy consumption according to house vintage is presented in Table 4.27. Generally speaking, the older the house, the more energy it consumes since older houses usually have lower insulation level. This trend can easily be observed from the table. However, it is interesting to note that the average amount of electricity consumed is inversely related to age: the older the house, the less electricity it consumes. On the other hand, the older the house, the higher the fossil fuel consumption. These trends can be explained by the fact that older houses usually have fewer lights, electrical appliances, lower insulation levels, and less efficient heating equipment than the newer ones. The average household energy consumption for different vintages is found to be ranging from a high of 157GJ/year for dwellings built before 1940 to a low of 134GJ/year for dwellings built after 1978.

Table 4.27: Overall end-use energy consumption by vintage

			Per house (GJ/house/year)			For the entire housing stock (PJ/year)		
Province	Vintage	# of Houses	Electricity	Fossil Fuel	Total	Electricity	Fossil Fuel	Total
NFL	Before 1941	21 856	71.1	102.0	173.1	1.6	2.2	3.8
	1941-1960	26 382	67.3	92.3	159.7	1.8	2.4	4.2
	1961-1977	57 786	78.5	74.8	153.3	4.5	4.3	8.9
	1978 or later	63 578	99.7	55.7	155.4	6.3	3.5	9.9
PEI	Before 1941	10 390	38.3	164.1	202.5	0.4	1.7	2.1
	1941-1960	4 154	35.6	137.1	172.6	0.1	0.6	0.7
	1961-1977	11 178	40.7	123.2	163.9	0.5	1.4	1.8
	1978 or later	11 977	38.0	129.8	167.8	0.5	1.6	2.0
NS	Before 1941	65 432	46.3	130.2	176.5	3.0	8.5	11.5
	1941-1960	39 699	49.5	107.2	156.8	2.0	4.3	6.2
	1961-1977	76 248	56.7	87.7	144.4	4.3	6.7	11.0
	1978 or later	75 296	79.6	67.2	146.7	6.0	5.1	11.0
NB	Before 1941	43 036	74.6	114.4	188.9	3.2	4.9	8.1
	1941-1960	34 222	78.0	76.1	154.2	2.7	2.6	5.3
	1961-1977	70 234	93.2	51.6	144.7	6.5	3.6	10.2
	1978 or later	59 936	105.4	41.4	146.8	6.3	2.5	8.8
PQ	Before 1941	220 897	81.9	82.0	163.9	18.1	18.1	36.2
	1941-1960	275 930	87.2	33.8	121.1	24.1	9.3	33.4
	1961-1977	540 456	92.5	41.5	134.0	50.0	22.4	72.4
	1978 or later	448 380	109.5	13.2	122.6	49.1	5.9	55.0
ON	Before 1941	612 531	49.3	95.9	145.2	30.2	58.7	88.9
	1941-1960	514 939	50.3	83.2	133.5	25.9	42.9	68.7
	1961-1977	715 334	57.5	71.7	129.3	41.1	51.3	92.5
	1978 or later	886 549	59.6	66.9	126.5	52.9	59.3	112.2
MAN	Before 1941	60 529	56.5	119.2	175.7	3.4	7.2	10.6
	1941-1960	72 766	60.0	110.1	170.1	4.4	8.0	12.4
	1961-1977	109 374	67.1	95.6	162.7	7.3	10.5	17.8
	1978 or later	61 732	82.5	75.0	157.6	5.1	4.6	9.7
SAS	Before 1941	53 405	47.1	142.1	189.2	2.5	7.6	10.1
	1941-1960	65 159	42.8	135.2	178.0	2.8	8.8	11.6
	1961-1977	105 557	45.6	129.5	175.1	4.8	13.7	18.5
	1978 or later	76 086	57.8	121.3	179.0	4.4	9.2	13.6
AB	Before 1941	61 400	34.5	137.2	171.7	2.1	8.4	10.5
	1941-1960	125 011	37.0	144.4	181.4	4.6	18.0	22.7
	1961-1977	282 992	38.3	146.0	184.3	10.8	41.3	52.2
	1978 or later	234 737	41.6	128.7	170.3	9.8	30.2	40.0
BC	Before 1941	77 442	39.5	104.4	143.9	3.1	8.1	11.1
	1941-1960	136 942	47.7	66.7	114.5	6.5	9.1	15.7
	1961-1977	388 628	51.2	61.6	112.7	19.9	23.9	43.8
	1978 or later	303 598	55.5	57.5	113.0	16.8	17.5	34.3
CANADA	Before 1941	1 226 917	55.1	102.3	157.4	67.6	125.5	193.1
	1941-1960	1 295 203	57.8	81.9	139.7	74.8	106.1	180.9
	1961-1977	2 357 787	63.6	76.0	139.5	149.8	179.1	329.0
	1978 or later	2 221 870	70.7	62.7	133.5	157.2	139.4	296.5

4.3.1.5 Residential End-use Energy Consumption by Dwelling Type

The overall provincial distribution of household energy consumption by dwelling type is presented in Table 4.28. As expected, energy consumption for single-detached households is higher than that for single-attached dwellings. This is mainly due to the fact that single-detached housings are usually larger and have more exposed surface area for heat loss compared to the single-attached dwellings. On average, overall household energy consumption is found to be 144 GJ and 113 GJ for single-detached and attached dwellings, respectively.

Table 4.28: Overall end-use energy consumption by dwelling type

			Per house (GJ/house/year)			For the entire housing stock (PJ/year)		
Province	Dwelling	# of Houses	Electricity	Fossil Fuel	Total	Electricity	Fossil Fuel	Total
NFL	Single Detached	139 430	84.1	82.5	166.7	11.7	11.5	23.2
	Single Attached	30 171	82.0	34.0	116.0	2.5	1.0	3.5
PEI	Single Detached	33 259	39.0	142.6	181.6	1.3	4.7	6.0
	Single Attached	4 440	35.8	104.9	140.7	0.2	0.5	0.6
NS	Single Detached	238 779	60.3	97.8	158.1	14.4	23.4	37.8
	Single Attached	17 896	50.5	65.0	115.5	0.9	1.2	2.1
NB	Single Detached	190 400	90.9	68.6	159.5	17.3	13.1	30.4
	Single Attached	17 028	84.4	33.3	117.7	1.4	0.6	2.0
PQ	Single Detached	1 309 884	97.1	39.4	136.5	127.2	51.6	178.8
	Single Attached	175 779	79.5	23.9	103.4	14.0	4.2	18.2
ON	Single Detached	2 436 065	55.8	78.9	134.7	136.0	192.3	328.3
	Single Attached	293 289	48.2	67.9	116.1	14.1	19.9	34.1
MAN	Single Detached	282 599	67.2	102.3	169.5	19.0	28.9	47.9
	Single Attached	21 802	57.0	64.1	121.1	1.2	1.4	2.6
SAS	Single Detached	281 995	49.4	132.4	181.8	13.9	37.3	51.3
	Single Attached	18 212	32.8	106.9	139.7	0.6	1.9	2.5
AB	Single Detached	580 424	40.6	147.0	187.7	23.6	85.3	108.9
	Single Attached	123 717	30.5	102.4	132.9	3.8	12.7	16.4
BC	Single Detached	785 617	51.3	68.5	119.9	40.3	53.8	94.2
	Single Attached	120 994	49.5	39.5	88.9	6.0	4.8	10.8
CANADA	Single Detached	6 278 451	64.5	79.9	144.4	404.8	502.0	906.7
	Single Attached	823 328	54.3	58.5	112.7	44.7	48.1	92.8

4.3.2 Residential Greenhouse Gas Emissions

4.3.2.1 Residential Greenhouse Gas Emissions by Province

The overall GHG gas emissions associated with household energy consumption for each province and Canada as a whole are presented in Table 4.29. The second column in the table represents the total number of households in each category in 1993. While columns 3 to 5 present the overall average household GHG gas emissions. The overall average household GHG gas emission is divided into two parts: "indirect" (electricity) and "direct" (fossil fuels). "Indirect" represents the amount of GHG emission associated with electricity consumed while "direct" represents the amount of GHG emissions from any other fuel(s) consumed except wood since wood is considered to be a renewable resource that does not contribute to the net GHG emissions (IEA, 1999). The amount of "indirect" GHG emissions is the projected emissions at the generation source based on provincial electricity generation mix. As a stated assumption, this projected GHG emission from electricity consumption from the household level does not take into the consideration any transmission and distribution losses in the electrical grid. The aggregated total household GHG emissions are presented in the last three columns.

The overall amount of residential GHG emissions associated with residential energy consumption is estimated to be 48.5 Mt in 1993 with an average household emission of 6.8 t. Of this amount, "indirect" (electricity) accounts for approximately 45 percent of the total emissions. The distribution of total aggregate provincial GHG emissions ranged from a high of 11.9 Mt for Ontario to a low of 1.6 Mt for Manitoba. The average provincial household emissions was found to be ranging from a high of 17.4 t/house for Alberta to a low of 1.5 t/house for Quebec. The amount of overall provincial residential GHG emissions generally do not follow the number of households and climate directly, but are mainly influenced by both provincial fuel and electricity generation mix.

Table 4.29: Overall GHG emission by province

		Per house (t/house/year)			For the entire housing stock (Mt/year)		
Province	# of Houses	Indirect	Direct	Total	Indirect	Direct	Total
NFL	169 601	0.77	3.09	3.86	0.13	0.52	0.65
PEI	37 699	4.44	7.96	12.39	0.17	0.30	0.47
NS	256 675	12.15	5.04	17.20	3.12	1.29	4.41
NB	207 428	8.19	2.42	10.61	1.70	0.50	2.20
PQ	1 485 663	0.05	1.48	1.53	0.08	2.19	2.27
ON	2 729 354	2.09	3.96	6.05	5.69	10.82	16.51
MAN	304 401	0.21	4.93	5.14	0.06	1.50	1.57
SAS	300 207	10.69	6.69	17.38	3.21	2.01	5.22
AB	704 141	9.93	7.03	16.96	6.99	4.95	11.94
BC	906 610	0.53	3.10	3.63	0.48	2.81	3.29
CANADA	7 101 779	3.05	3.79	6.83	21.63	26.89	48.53

4.3.2.2 Residential Greenhouse Gas Emission by Space Heating Fuel Type

The provincial distribution of household GHG emissions according to household space heating fuel type, i.e., electricity, natural gas, oil, wood, and propane is presented in Table 4.30. Both average and total household emissions are divided into two distinct parts: "direct" (fossil fuels) and "indirect" (electricity). It should be noted that the amount of GHG emissions from households that utilize wood as space heating fuel is generally lower than the emissions from other households since there is no net GHG emissions from the consumption of wood. The GHG emissions from wood heated households mainly come from the other fossil fuels such as oil, natural gas, and propane and electricity. Table 4.30 shows that household GHG emissions from wood heated households is usually lower than the emissions from households with any other heating fuel. The highest household GHG emissions usually occur in propane heated households. It is also interesting to observe that the amount of GHG emissions for propane heated households is usually higher than those of oil or natural gas heated households. This may due to 1) the sample bias from small sample size, and/or 2) the age (older) and different house physical characteristics for propane heated households. Overall, average GHG emissions for both natural gas and oil heated households are high, but comparable in magnitude. The distribution of average household GHG emissions range from a high of 10.8 t/house for propane heated households to a low of 2.4 t/house for wood heated households.

Table 4.30: Overall GHG emission by space heating fuel type

			Per house (t/house/year)			For the entire housing stock (Mt/year)		
Province	Fuel Type	# of Houses	Indirect	Direct	Total	Indirect	Direct	Total
NFL	Propane	1 393	8.04	0.48	8.52	0.01	0.00	0.01
	Wood	32 325	0.04	0.47	0.51	0.00	0.02	0.02
	Electric	73 070	0.06	1.19	1.25	0.00	0.09	0.09
	Oil	62 813	8.05	0.45	8.50	0.51	0.03	0.53
PEI	Propane	466	9.73	4.16	13.89	0.00	0.00	0.01
	Wood	6 364	1.24	4.56	5.80	0.01	0.03	0.04
	Electric	1 112	1.05	10.71	11.76	0.00	0.01	0.01
	Oil	29 757	9.62	4.18	13.80	0.29	0.12	0.41
NS	Propane	5 288	6.54	7.73	14.27	0.03	0.04	0.08
	Wood	40 468	0.38	10.44	10.82	0.02	0.42	0.44
	Electric	61 105	0.04	22.62	22.66	0.00	1.38	1.38
	Oil	149 814	8.29	8.51	16.79	1.24	1.27	2.52
NB	Propane	471	8.13	4.26	12.39	0.00	0.00	0.01
	Wood	37 784	0.15	5.10	5.25	0.01	0.19	0.20
	Electric	114 608	0.03	10.99	11.02	0.00	1.26	1.26
	Oil	54 566	8.97	4.48	13.46	0.49	0.24	0.73
PQ	Propane	2 911	8.41	0.03	8.44	0.02	0.00	0.02
	Wood	166 547	0.05	0.03	0.09	0.01	0.01	0.01
	Electric	978 499	0.06	0.07	0.13	0.06	0.06	0.12
	Oil	300 345	6.31	0.03	6.34	1.90	0.01	1.90
	Natural Gas	37 360	5.44	0.02	5.46	0.20	0.00	0.20
ON	Propane	29 143	6.30	2.03	8.33	0.18	0.06	0.24
	Wood	110 628	0.23	1.93	2.16	0.03	0.21	0.24
	Electric	548 446	0.28	3.67	3.95	0.15	2.01	2.17
	Oil	343 437	5.65	2.00	7.65	1.94	0.69	2.63
	Natural Gas	1 697 700	5.01	1.60	6.61	8.51	2.72	11.23
MAN	Propane	1 657	6.99	0.17	7.16	0.01	0.00	0.01
	Wood	8 844	0.01	0.18	0.19	0.00	0.00	0.00
	Electric	89 413	0.11	0.38	0.49	0.01	0.03	0.04
	Oil	12 696	7.63	0.18	7.81	0.10	0.00	0.10
	Natural Gas	191 791	7.21	0.13	7.34	1.38	0.03	1.41
SAS	Propane	3 174	6.97	11.72	18.69	0.02	0.04	0.06
	Wood	3 871	0.10	10.73	10.83	0.00	0.04	0.04
	Electric	20 567	0.37	27.98	28.36	0.01	0.58	0.58
	Oil	15 954	8.22	13.27	21.48	0.13	0.21	0.34
	Natural Gas	256 641	7.20	9.13	16.33	1.85	2.34	4.19
AB	Propane	13 626	6.65	11.70	18.35	0.09	0.16	0.25
	Wood	7 705	1.10	10.57	11.67	0.01	0.08	0.09
	Electric	8 489	1.42	29.68	31.09	0.01	0.25	0.26
	Oil	6 223	8.42	11.37	19.79	0.05	0.07	0.12
	Natural Gas	668 097	7.16	9.62	16.79	4.78	6.43	11.21
BC	Propane	10 502	4.89	0.40	5.29	0.05	0.00	0.06
	Wood	63 519	0.18	0.56	0.74	0.01	0.04	0.05
	Electric	197 233	0.12	0.85	0.97	0.02	0.17	0.19
	Oil	94 293	3.43	0.50	3.93	0.32	0.05	0.37
	Natural Gas	541 063	4.43	0.42	4.85	2.40	0.23	2.63
CANADA	Propane	68 632	6.38	4.46	10.84	0.44	0.31	0.74
	Wood	478 054	0.18	2.17	2.35	0.08	1.04	1.12
	Electric	2 092 541	0.13	2.79	2.93	0.28	5.85	6.12
	Oil	1 069 899	6.51	2.52	9.03	6.96	2.70	9.66
	Natural Gas	3 392 652	5.64	3.46	9.10	19.13	11.75	30.87

4.3.2.3 Residential Greenhouse Gas Emission by End-uses

Overall distribution of household GHG emissions based on different end-uses are presented in Table 4.31. The total household GHG emissions are presented in five distinct end-uses: space heating, DHW heating, appliances and lighting, fans and HRV, and air-conditioning. Once again, the GHG emissions are divided into "direct" and "indirect" to represent emissions from fossil fuel and electricity usage, respectively. Table 4.31 indicates that the percentage of household GHG emissions for different end-uses varies greatly from province to province due to local climatic conditions, fuel mix, and equipment type and usage. Overall, approximately 49%, 18% and 33% of total household GHG emissions are attributed to space heating, DHW heating, and appliance usage (all non-heating electricity usage including lighting, appliances, fan, HRV, and air-conditioning, etc.), respectively. GHG emissions associated with energy consumption for both furnace fans and HRV as well as central air-conditioning represent approximately two percent of the total household GHG emission budget.

Table 4.31: Overall GHG emission by end-uses

		Per house (t/house/year)									
		Space Heating		DHWHeating		App. & Lighting	HRV	A/C	Total (t/year/house)		
Province	# of Houses	Direct	Indirect	Direct	Indirect	Indirect	Indirect	Indirect	Direct	Indirect	Total
NFL	169 601	2.78	0.29	0.30	0.19	0.28	0.02	0.00	3.08	0.77	3.86
PEI	37 699	6.05	0.18	1.91	0.57	3.47	0.22	0.00	7.96	4.44	12.40
NS	256 675	4.15	2.68	0.89	2.69	6.43	0.35	0.01	5.04	12.16	17.20
NB	207 428	2.21	3.17	0.21	1.87	2.97	0.17	0.00	2.42	8.19	10.61
PQ	1 485 663	1.26	0.02	0.21	0.01	0.02	0.00	0.00	1.48	0.05	1.53
ON	2 729 354	3.04	0.31	0.92	0.32	1.32	0.05	0.09	3.96	2.09	6.05
MAN	304 401	4.00	0.06	0.93	0.03	0.11	0.01	0.01	4.93	0.21	5.14
SAS	300 207	5.31	1.02	1.38	1.04	8.01	0.35	0.27	6.69	10.69	17.39
AB	704 141	5.44	0.24	1.59	0.27	8.98	0.41	0.04	7.03	9.94	16.96
BC	906 610	2.21	0.06	0.89	0.09	0.36	0.01	0.00	3.10	0.53	3.63
CANADA	7 101 779	2.96	0.40	0.83	0.37	2.13	0.10	0.05	3.79	3.05	6.83

		For the entire housing stock (Mt/year)									
		Space Heating		DHWHeating		App. & Lighting	HRV	A/C	Total (Mt/year/house)		
Province	# of Houses	Direct	Indirect	Direct	Indirect	Indirect	Indirect	Indirect	Direct	Indirect	Total
NFL	169 601	0.47	0.05	0.05	0.03	0.05	0.00	0.00	0.52	0.13	0.65
PEI	37 699	0.23	0.01	0.07	0.02	0.13	0.01	0.00	0.30	0.17	0.47
NS	256 675	1.07	0.69	0.23	0.69	1.65	0.09	0.00	1.29	3.12	4.41
NB	207 428	0.46	0.66	0.04	0.39	0.62	0.04	0.00	0.50	1.70	2.20
PQ	1 485 663	1.87	0.03	0.32	0.02	0.03	0.00	0.00	2.19	0.08	2.27
ON	2 729 354	8.30	0.84	2.52	0.87	3.60	0.15	0.23	10.82	5.69	16.51
MAN	304 401	1.22	0.02	0.28	0.01	0.03	0.00	0.00	1.50	0.06	1.56
SAS	300 207	1.59	0.31	0.42	0.31	2.40	0.11	0.08	2.01	3.21	5.22
AB	704 141	3.83	0.17	1.12	0.19	6.32	0.29	0.03	4.95	7.00	11.94
BC	906 610	2.00	0.06	0.81	0.09	0.33	0.01	0.00	2.81	0.48	3.29
CANADA	7 101 779	21.03	2.83	5.86	2.62	15.16	0.69	0.35	26.89	21.64	48.53

4.3.2.4 Residential Greenhouse Gas Emissions by Dwelling Vintage

The provincial distribution of household GHG emissions according to house vintage is presented in Table 4.32. Generally speaking, the older the house, the higher the emissions since older houses usually consume more energy due to low insulation levels. However, it should be noted that the average amount of GHG emissions from electricity consumption ("indirect" emissions) is inversely related to the dwelling vintage: the older the house, the lower the emission from electricity. On the other hand, the older the house, the higher the GHG emission from fossil fuel consumption (direct emission). These trends can be mainly attributed to the fact that older houses usually have fewer lights and electrical appliances, lower insulation levels, and less efficient heating equipment than the newer ones. The average household GHG emissions for different vintages is found to be ranging from a high of 7.8 t/year for dwellings built before 1940 to a low of 6.3 t/year for dwellings built after 1978.

Table 4.32: Overall GHG emission by vintage

			Per house (t/house/year)			For the entire housing stock (Mt/year)		
Province	Vintage	# of Houses	Indirect	Direct	Total	Indirect	Direct	Total
NFL	Before 1941	21 856	0.66	3.84	4.50	0.01	0.08	0.10
	1941-1960	26 382	0.62	5.11	5.73	0.02	0.13	0.15
	1961-1977	57 786	0.72	3.28	4.00	0.04	0.19	0.23
	1978 or later	63 578	0.92	1.81	2.73	0.06	0.11	0.17
PEI	Before 1941	10 390	4.40	8.44	12.85	0.05	0.09	0.13
	1941-1960	4 154	4.09	8.85	12.93	0.02	0.04	0.05
	1961-1977	11 178	4.68	7.58	12.26	0.05	0.08	0.14
	1978 or later	11 977	4.36	7.57	11.93	0.05	0.09	0.14
NS	Before 1941	65 432	9.43	7.30	16.72	0.62	0.48	1.09
	1941-1960	39 699	10.09	6.45	16.54	0.40	0.26	0.66
	1961-1977	76 248	11.56	5.26	16.82	0.88	0.40	1.28
	1978 or later	75 296	16.21	2.12	18.33	1.22	0.16	1.38
NB	Before 1941	43 036	6.76	4.68	11.44	0.29	0.20	0.49
	1941-1960	34 222	7.08	3.94	11.01	0.24	0.13	0.38
	1961-1977	70 234	8.45	1.99	10.44	0.59	0.14	0.73
	1978 or later	59 936	9.55	0.44	9.99	0.57	0.03	0.60
PQ	Before 1941	220 897	0.05	3.32	3.36	0.01	0.73	0.74
	1941-1960	275 930	0.05	1.87	1.92	0.01	0.52	0.53
	1961-1977	540 456	0.05	1.69	1.75	0.03	0.92	0.94
	1978 or later	448 380	0.06	0.06	0.12	0.03	0.03	0.05
ON	Before 1941	612 531	1.87	5.18	7.05	1.15	3.17	4.32
	1941-1960	514 939	1.91	4.26	6.17	0.98	2.19	3.18
	1961-1977	715 334	2.18	3.56	5.74	1.56	2.55	4.11
	1978 or later	886 549	2.26	3.28	5.54	2.00	2.90	4.91
MAN	Before 1941	60 529	0.18	5.74	5.92	0.01	0.35	0.36
	1941-1960	72 766	0.19	5.55	5.74	0.01	0.40	0.42
	1961-1977	109 374	0.21	4.79	5.00	0.02	0.52	0.55
	1978 or later	61 732	0.26	3.65	3.91	0.02	0.23	0.24
SAS	Before 1941	53 405	10.42	7.32	17.74	0.56	0.39	0.95
	1941-1960	65 159	9.47	6.91	16.38	0.62	0.45	1.07
	1961-1977	105 557	10.08	6.60	16.68	1.06	0.70	1.76
	1978 or later	76 086	12.77	6.19	18.97	0.97	0.47	1.44
AB	Before 1941	61 400	8.81	7.01	15.82	0.54	0.43	0.97
	1941-1960	125 011	9.46	7.16	16.62	1.18	0.90	2.08
	1961-1977	282 992	9.80	7.39	17.19	2.77	2.09	4.86
	1978 or later	234 737	10.64	6.52	17.16	2.50	1.53	4.03
BC	Before 1941	77 442	0.41	5.20	5.61	0.03	0.40	0.43
	1941-1960	136 942	0.49	3.46	3.96	0.07	0.47	0.54
	1961-1977	388 628	0.53	2.95	3.48	0.21	1.15	1.35
	1978 or later	303 598	0.57	2.59	3.16	0.17	0.79	0.96
CANADA	Before 1941	1 226 917	2.66	5.16	7.82	3.26	6.33	9.59
	1941-1960	1 295 203	2.74	4.24	6.99	3.55	5.50	9.05
	1961-1977	2 357 787	3.06	3.71	6.77	7.22	8.74	15.96
	1978 or later	2 221 870	3.42	2.85	6.27	7.60	6.33	13.93

4.3.2.5 Residential Greenhouse Gas Emission by Dwelling Type

The overall provincial distribution of household GHG emissions by dwelling type is presented in Table 4.33. As expected, GHG emissions for single-detached dwellings are higher than that for single-attached dwellings. This is mainly due to the fact that single-detached dwellings usually consume more energy due to their larger size. On average, overall household GHG emissions are found to be 7 t/year and 5.6 t/year for single-detached and attached dwellings, respectively.

Table 4.33: Overall GHG emission by dwelling type

			Per house (t/house/year)			For the entire housing stock (Mt/year)		
Province	Dwelling	# of Houses	Indirect	Direct	Total	Indirect	Direct	Total
NFL	Single Detached	139 430	0.78	3.25	4.03	0.11	0.45	0.56
	Single Attached	30 171	0.76	2.30	3.06	0.02	0.07	0.09
PEI	Single Detached	33 259	4.48	8.04	12.52	0.15	0.27	0.42
	Single Attached	4 440	4.11	7.34	11.45	0.02	0.03	0.05
NS	Single Detached	238 779	12.29	5.08	17.37	2.94	1.21	4.15
	Single Attached	17 896	10.29	4.52	14.81	0.18	0.08	0.27
NB	Single Detached	190 400	8.24	2.43	10.67	1.57	0.46	2.03
	Single Attached	17 028	7.65	2.27	9.92	0.13	0.04	0.17
PQ	Single Detached	1 309 884	0.05	1.46	1.52	0.07	1.91	1.98
	Single Attached	175 779	0.04	1.58	1.63	0.01	0.28	0.29
ON	Single Detached	2 436 065	2.12	4.02	6.14	5.16	9.80	14.96
	Single Attached	293 289	1.83	3.45	5.28	0.54	1.01	1.55
MAN	Single Detached	282 599	0.21	5.06	5.27	0.06	1.43	1.49
	Single Attached	21 802	0.18	3.25	3.43	0.00	0.07	0.07
SAS	Single Detached	281 995	10.91	6.77	17.68	3.08	1.91	4.99
	Single Attached	18 212	7.25	5.48	12.73	0.13	0.10	0.23
AB	Single Detached	580 424	10.39	7.42	17.80	6.03	4.31	10.33
	Single Attached	123 717	7.80	5.19	12.99	0.97	0.64	1.61
BC	Single Detached	785 617	0.53	3.26	3.79	0.42	2.56	2.98
	Single Attached	120 994	0.51	2.04	2.55	0.06	0.25	0.31
CANADA	Single Detached	6 278 451	3.12	3.87	6.99	19.57	24.32	43.89
	Single Attached	823 328	2.51	3.12	5.63	2.06	2.57	4.63

4.3.3 Comparison of CREEEM with other models

Recently, Aydinalp (2002) has completed the development of two different models for the national energy consumption in the Canadian residential sector using mainly the same available data sources used to develop CREEEM. The two distinct data-driven models are based on the Neural Network (NN) and Conditional Demand Analysis (CDA) techniques. CREEEM predictions are compared with those of data driven models of CDA and NN from Aydinalp (2002) to provide a comparative assessment of the three models.

The comparison of the household fuel consumption predictions from CREEEM with those from Aydinalp's (2002) CDA model is shown in Table 4.34. It can be seen from Table 4.34 that CREEEM predicts household electricity consumption better than the CDA model, but the reverse is true for household natural gas consumption. CDA technique has been widely used in the electric utility industry to disaggregate total household billing records into different end-uses using large volumes of sample data. However, it has been shown by Aydinalp (2002) that CDA is actually better for fuels other than electricity. The reasons for the low household electricity consumption prediction from the CDA model are problems of multicolinearity among many explanatory variables and the interrelated nature of space conditioning energy consumption with those of appliances.

The comparison of major end-use energy consumption predictions from CREEEM with those from Aydinalp's (2002) NN and CDA models is shown in Table 4.35. It is shown that CREEEM provides comparable accuracy with the data-driven models of NN and CDA. In addition, the comparison of the aggregated total household energy consumption prediction among the three models show that there is less than 3% (2.8%) difference between the NN and CREEEM predictions while there is a 5% difference between the NN and CDA predictions. This indicates that CREEEM predictions, on average, are in closer agreement with the NN predictions even though both CDA and NN models are both data-driven.

Table 4.34: Comparison of household fuel consumption prediction with ANN and CDA (Aydinalp, 2002)

Comparison of Household Fuel Consumption Prediction (R^2, CV)		Electricity	Natural Gas	Oil
CREEEM	R^2	0.82	0.88	0.82
	CV	1.13	1.14	2.96
CDA (Aydinalp, 2002)	R^2	0.66	0.92	0.82
	CV	N/A	N/A	N/A

Table 4.35: Comparison of major end-use energy consumption prediction with ANN and CDA (Aydinalp, 2002)

Comparison of Household End-use Energy Consumption Prediction (R^2, CV)		Appliance (ALC)	DHW Heating	Space Heating	Space+DHW Heating
CREEEM	R^2	0.81	0.83	0.82	0.90
	CV	1.77	1.93	1.63	1.05
ANN (Aydinalp, 2002)	R^2	0.91	0.87	0.91	N/A
	CV	2.09	3.34	1.87	N/A
CDA (Aydinalp, 2002)	R^2	0.80	0.81	0.89	N/A
	CV	3.34	4.05	2.01	N/A

In terms of the level of detail of parameters considered and the flexibility in evaluating the impact of energy conservation strategies on the residential energy consumption, the EM based CREEEM is significantly more capable than the NN and CDA method based models. Because of the high level of detail and flexibility provided by CREEEM, it can be used to evaluate the impact of a wide range of scenarios for energy conservation (for example, adding insulation to walls, replacing windows or furnaces) on residential energy consumption and greenhouse gas emissions. Consequently, CREEEM requires detailed data on the housing stock, and substantial engineering expertise for its use. However, incorporating socioeconomic factors in CREEEM is difficult.

Compared to the EM based models, the CDA based models are easier to develop and use, and do not require as detailed data. However, since these are regression-based models, the number of dwellings in the database needs to be larger, and the models do not provide much detail and flexibility. As a result, they have limited capability to assess the impact of energy conservation scenarios. It is however possible to include socioeconomic parameters in the model if such data is available in the database.

Based on the research and development work done on NN based models so far (Aydinalp, 2002; Aydinalp et al., 2002a, Aydinalp et al., 2002b), it can be inferred that in terms of their data requirements, flexibility of assessing the impacts of a variety of energy conservation scenarios, and the ease of development and use, NN based models are somewhere in between the EM and CDA based models.

4.3.4 Summary: CREEEM Predictions

A comprehensive and representative bottom-up engineering based model for end-use energy consumption and associated greenhouse gas emissions for the Canadian low-rise single family residential stock was developed. This model is called the Canadian Residential End-use Energy Consumption and Emission Model (CREEEM). The model makes extensive use of current Canadian data sources for providing housing characteristics, and is capable of estimating the amount energy consumption and GHG emissions on regional, provincial, and national levels.

It was found that, on average, overall annual household energy consumption was 141 GJ with a corresponding 6.8 tons of greenhouse gas emissions. The overall total end-use energy consumption and associated greenhouse gas emissions for the entire low-rise housing stock of 7,101,953 households in 1993 were found to be 1000 PJ and 48 Mt, respectively. Of these amounts, contribution from electricity use was approximately 45 percent of the total.

In summary, CREEEM provides:

- the most comprehensive bottom-up engineering based model for Canadian residential end-use energy consumption and associated greenhouse gas emissions,
- a representative model for housing characteristics as well as fuel usage and associated GHG emissions at the regional, provincial, and national levels,
- a modeling framework capable of conducting comparative studies on the impact of potential building code standards, energy efficiency retrofit technologies and fuel switching scenarios on overall energy consumption and GHG emissions, and
- an analytical tool for assessing policy decisions to achieve Canada's overall GHG emission reduction commitment.

Chapter Five

5 Conclusions and Recommendations

5.1 Conclusions

As stated in Section 1.4, the objectives of this work were to develop a comprehensive and representative modeling framework for estimating energy consumption and associated greenhouse gas emissions in the residential sector suitable for a broad range of comparative analyses, and using this framework to develop an end-use energy consumption and greenhouse gas emissions model for the Canadian housing stock for use as a decision making tool for policy development. These said objectives are successfully achieved as follows:

1) A modeling framework was developed to model residential energy consumption and associated greenhouse gas emissions, for cold (heating dominated) climates, at both regional and national levels. The developed modeling framework entails i) detailed data requirements on housing stock, appliance characteristics and usages, heating equipment characteristics, building thermal envelop characteristics, climatic conditions as well as fuel usages and their associated GHG emission factors, and ii) general methodologies for estimating major residential energy end-uses of major, minor and miscellaneous appliances, lighting, cooling, as well as DHW and space heating.

2) To develop the modeling framework, detailed data requirements were analyzed, and existing data sources were identified and reviewed for suitability in energy modeling. It was found that a broad range, albeit relatively incoherent and unorganized, of data exist in Canada that can be used for model development. Inconsistencies and deficiencies in the existing data sources were also identified. In addition, new and emerging data sources

were identified and their potential use for model development was reviewed. As a result, a comprehensive data collection campaign, including the integration of various existing and emerging data collection campaigns, was proposed for Canada and detailed data collection costs were estimated for future data collection and model refinement efforts. It was estimated that the total cost of conducting the proposed comprehensive data collection would be approximately five million dollars, or at $500 per house with a total of 10,000 houses in the sample. This estimated data collection cost is actually only marginally higher that the combined cost of the major residential energy use survey (SHEU) and the home energy auditing campaign (EGH) conducted in Canada.

3) A comprehensive and representative bottom-up engineering based model for estimating end-use energy consumption and associated greenhouse gas emissions for the Canadian low-rise single family residential stock was developed, and its detailed developmental procedure is fully documented in this work. This model is called the Canadian Residential End-use Energy Consumption and Emission Model (CREEEM). The model makes extensive use of the current Canadian data sources to establish housing characteristics as well as energy consumption and GHG emissions estimates at the regional, provincial, and national levels. Since both the energy consumption and the associated GHG emissions of houses are influenced by many factors including provincial fuel mix, climate regions, house envelope characteristics, efficiencies of space and domestic hot water heating equipment, and house type and size, all of these factors have been taken into consideration in the model to estimate the overall energy consumption and the associated GHG emissions from the Canadian housing sector. The engineering method based CREEEM, which is representative of the Canadian low-rise housing stock, is developed using data available from the 1993 Survey of Household Energy Use (SHEU 1993) (Statistics Canada, 1993a), the Modified STAR HOUSING database (STAtistically Representative Housing Stock) (Scanada, 1992; Ugursal and Fung, 1994; Ugursal and Fung, 1996), the 1993/94 "200-House Audit" project (NRCan, 1994), Hot2000 (NRCan, 1995) default values, EnerGuide (NRCan, 1993) and minor contributions from other sources. Overall household energy consumption and its

associated GHG emission are estimated using the Hot2000 Batch v7.14 energy simulation program (NRCan, 1996) and the estimated provincial electricity generation GHG intensity factors.

4) The predictions of CREEEM were validated with 3248 annual energy billing records from 2811 houses. It was found that CREEEM's predictions could be used with confidence. The R^2 ranged from a low of 0.81 for electricity consumption on appliance, lighting and cooling end-uses, to a high of 0.90 for natural gas consumption on combined space and DHW heating end-uses. The lack of equipment and usage information on the minor and miscellaneous appliances from the available data sources was considered to be the major reason for the relatively low (R^2 of 0.81) prediction performance on the household appliance and lighting electricity consumption since such energy consumption is highly dependent on appliance ownership, characteristics and usage patterns.

5) The prediction performance of the engineering based CREEEM was compared with two data-driven residential energy consumption models, Neural Network (NN) and Conditional Demand Analysis (CDA), recently developed by Aydinalp (2002) using the same available data sources used to develop CREEEM. This comparison shows that all three models (CREEEM, CDA and NN), on average, have comparable overall prediction performance, and they are all capable of estimating the overall residential energy consumption with reasonable accuracy. However, both NN and CDA suffer a common difficulty of assessing individual component energy end-use consumption, particularly in situations where an appliance is highly saturated in the sample.

It was found that, on average, overall annual household energy consumption in Canada in 1993 was 141 GJ with a corresponding 6.8 tons of greenhouse gas emissions. The overall total end-use energy consumption and associated greenhouse gas emissions for the entire low-rise housing stock of 7,101,953 households in 1993 were found to be 1000 PJ and 48 Mt, respectively. Of these amounts, contribution from the electricity use was approximately 45 percent of the total.

In summary, CREEEM provides:

- a comprehensive and representative bottom-up engineering based model to estimate the Canadian residential end-use energy consumption and associated greenhouse gas emissions,
- a representative model for housing characteristics as well as fuel usage and associated GHG emissions at the regional, provincial, and national levels,
- a modeling framework to conduct comparative studies on the impact of potential building code standards, energy efficiency retrofit technologies and fuel switching scenarios on overall energy consumption and GHG emissions,
- an analytical tool for assessing policy decisions to achieve Canada's overall GHG emission reduction commitment.

5.2 Recommendations

Although CREEEM is the most comprehensive bottom-up engineering based model for residential end-use energy consumption and greenhouse gas emissions in Canada, it is recommended that the following improvements be made in the future for more accurate predictions. However, most of the proposed recommendations for future work would be highly dependent on the quantity and quality of future data available.

- Weather adjusted analyses should be further considered and incorporated into the model using actual weather data so that weather related energy consumption and associated GHG emissions can be fully assessed. Currently, actual weather data for the approximate location of each dwelling was employed for space heating energy consumption normalization since actual dwelling locations were not given in the SHEU 1993 survey. Local (urban/rural area) micro climates from the same locale might have a significant impact on dwelling energy consumption. PRISM (Fels, 1986) type energy consumption analysis might also be employed for whole house energy billing disaggregation into weather-related and baseload end-uses. The precise disaggregation of the whole house energy consumption is essential for detailed model validation on different end-uses.

- Modeling of whole house appliance (ALC) energy consumption using a combination of engineering-statistical and/or engineering-neural network based methods should be considered since this end-use has the lowest prediction accuracy (R^2 of 0.81) in CREEEM due to the discretionary nature of usage of many different types of appliances. Without detailed information on operating characteristics and usage patterns of these appliances, an engineering based model like CREEEM would have difficulty in estimating such end-uses precisely.
- Since CREEEM only contains residential stock from ten provinces across Canada, incorporation of housing data from the three territories would provide a more complete analysis on overall residential energy consumption and associated GHG emissions in Canada, particularly at the regional level for these territories.
- Analysis of multi-fuel heating systems, particularly for wood supplementary heating systems, should be incorporated into the model since more than 30 percent of total households in SHEU reported use of wood for supplementary space heat. Potential use of ANN, CDA and/or PRISM methods to disaggregate the amount of space heating energy contribution due to the use of wood as supplementary heating fuel should be considered and employed as given conditions for the engineering based model.
- Statistical, CDA or NN methods should be employed to characterize the difficult-to-define variables, such as socio-eco-demographical driven usage behaviors, into CREEEM. Data mining techniques should be fully exploited to discover hidden trends and causal relationships among different physical and socio-eco-demographical variables on energy consumption patterns, then model and integrate such relationships into the engineering method based CREEEM.
- Use of multi-zone capable building energy simulation software should be considered for future CREEEM, particularly for electric baseboard heated

households, since the current model slightly overestimates the amount of electric space heating energy consumption due to the inherent zoning effect of such heating systems. However, detailed room-by-room temperature settings are not available from any of the existing residential energy use databases.

- Geographic Information System (GIS) could be used to further refine the level of detail in modeling regional energy consumption and associated GHG emissions in the residential sector for potential energy system planning and local policy making. GIS could provide more detailed disaggregation of socio-economic, weather, fuel availability and other such variables obtained from data sources such as the census as well as the regional and provincial electricity generations and grid systems. These additional variables could then be incorporated into the CREEEM.
- Future CREEEM should include mid and high-rise multi-family residential building stock since these households comprise approximately one third of the total Canadian residential stock.
- And last but not least, it is clear that it is not possible to improve on the existing models without the availability of quality data from timely and regular updates of residential energy consumption surveys as well as home energy auditing and metering campaigns conducted in a well planned and organized manner.

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Appendix A

Distribution of households in the 1993 SHEU and the Canadian Housing statistics

In order to develop a representative energy consumption and GHG emission model for Canada, it is required that the data used must be representative of Canada in both provincial and national levels. Thus, it is imperative to have a detailed knowledge on the representative characteristics of the housing stock to be able to fully comprehend how energy and emission are consumed and emitted. The following sections present some of these housing stock characteristics in the CREEEM model. These housing characteristics are mainly derived from the statistical analyses conducted on the SHEU (1993) data with the household weighting factors. It should be noted that the total number of households for Canada in the tables presented in the following sections may not add up to the total number of households of 7,101,953 in 1993. This is attributed to the fact that not all households in the SHEU have a complete set of responses to all questions in the survey. It should also be noted that the housing characteristics used in CREEEM can be considered representative of Canada since each household with its weighting factor in the SHEU is designed to represent the houses of its type in Canada.

Distribution of Houses According to Dwelling Type

The dwelling types in Canada are categorized in the SHEU database as follows:

1) Single detached
2) Semi-detached (double)
3) Row or Terrace

4) Duplex
5) Apartment, Flat (less than 5 stories)
6) High-rise apartment (5 stories or more)
7) Mobile home

The distributions of these dwelling types in the SHEU database and in CREEEM are given Table A.1.

Table A.1: Number of houses in different dwelling types

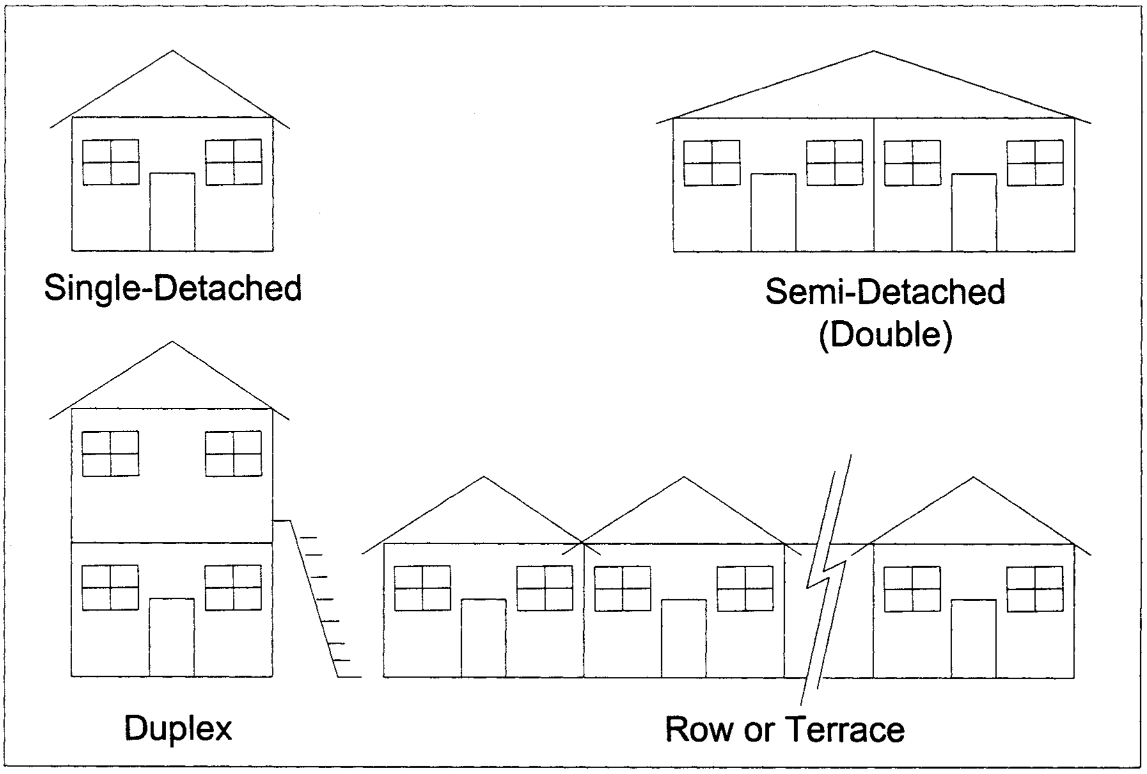
House Type	Sample in SHEU 93		Weighed Sample in SHEU 93	
	Number	**Percent (%)**	**Number**	**Percent (%)**
Singled Detached	7 695	70.1	5 823 176	56.2
Semi-Detached	362	3.3	460 305	4.4
Row or Terrace	375	3.4	489 576	4.7
Duplex	335	3.1	328 896	3.2
Apartment or Flat	1 394	12.7	2 073 859	20.0
High Rise Apartment	366	3.3	936 434	9.0
Mobile Home	455	4.1	246 970	2.4
Total	10 982	100.0	10 359 216	100.0

For this study, only houses (i.e. the first four categories) were considered, excluding apartments, high-rises, and mobile homes.[10] The house types included in the study are depicted in Figure A.1. As can be seen from Table A.2, majority of the houses in Canada (56.2 percent) are single detached. In this study, semi-detached, row or terrace and duplex houses were combined into one category called "single attached" as explained in Appendix B. The distribution of different dwelling types used in CREEEM is shown in Table A.2.

Table A.2: Number of houses in different dwelling types used in CREEEM

House Type	Sample in SHEU 93		Weighed Sample in SHEU 93	
	Number	Percent (%)	Number	Percent (%)
Singled Detached	7 695	87.8	5 823 176	82.0
Semi-Attached	1 072	12.2	1 278 777	18.0
Total	8 767	100.0	7 101 953	100.0

Figure A.1: Different house types given in the SHEU



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[10] There is not sufficient information to conduct a similar analysis to include apartments, high-rises and mobile homes since there is not sufficient information to develop building energy simulation model input files for them.

Distribution of Houses According to Vintage

Originally, there were a total of seven vintage groups used in the SHEU database. The weighted total number and percentage of households in each vintage group for each province are presented in Table A.3. It shows that more than 60 percent of the total low-rise housing stock was built after 1960.

As explained earlier in earlier section, the number of vintage groups used in CREEEM was reduced from seven in the SHEU to four for archetype generation in modeling. The distribution of house vintage groups used in CREEEM is presented in Table A.4.

Table A.3: Original weighted household vintage distribution in the SHEU

	Vintage (No. of Houses)						
Province	**Before 1941**	**1941-1960**	**1961-1977**	**1978-1982**	**1983-1988**	**After 1989**	**Total**
NFL	21 856	26 382	48 837	22 600	23 349	17 630	160 653
PEI	10 390	4 154	10 317	3 959	5 065	2 954	36 839
NS	65 432	39 699	64 141	27 400	31 410	16 486	244 568
NB	43 036	34 222	62 540	23 212	22 904	13 820	199 734
PQ	220 879	275 953	509 139	172 122	157 347	119 018	1 454 457
ONT	612 559	514 911	629 606	307 908	379 009	199 587	2 643 580
MAN	60 529	72 766	91 171	31 498	21 205	9 029	286 198
SAS	53 405	65 159	91 220	40 493	26 510	9 083	285 870
AB	61 400	125 011	241 963	162 643	44 968	27 126	663 112
BC	77 442	136 942	313 952	109 892	103 767	89 939	831 934
Canada	1 226 928	1 295 198	2 062 886	901 726	815 534	504 671	6 806 943

	Vintage (%)						
Province	**Before 1941**	**1941-1960**	**1961-1977**	**1978-1982**	**1983-1988**	**After 1989**	**Total**
NFL	13.6	16.4	30.4	14.1	14.5	11.0	100.0
PEI	28.2	11.3	28.0	10.7	13.7	8.0	100.0
NS	26.8	16.2	26.2	11.2	12.8	6.7	100.0
NB	21.5	17.1	31.3	11.6	11.5	6.9	100.0
PQ	15.2	19.0	35.0	11.8	10.8	8.2	100.0
ONT	23.2	19.5	23.8	11.6	14.3	7.5	100.0
MAN	21.1	25.4	31.9	11.0	7.4	3.2	100.0
SAS	18.7	22.8	31.9	14.2	9.3	3.2	100.0
AB	9.3	18.9	36.5	24.5	6.8	4.1	100.0
BC	9.3	16.5	37.7	13.2	12.5	10.8	100.0
Canada	18.0	19.0	30.3	13.2	12.0	7.4	100.0

Table A.4: Household vintage distribution used in CREEEM

	Vintage (No. of Houses)				
Province	**Before 1941**	**1941-1960**	**1961-1977**	**After 1978**	**Total**
NFL	21 856	26 382	48 837	63 578	160 653
PEI	10 390	4 154	10 317	11 977	36 839
NS	65 432	39 699	64 141	75 296	244 568
NB	43 036	34 222	62 540	59 936	199 734
PQ	220 879	275 953	509 139	448 487	1 454 457
ONT	612 559	514 911	629 606	886 504	2 643 580
MAN	60 529	72 766	91 171	61 732	286 198
SAS	53 405	65 159	91 220	76 086	285 870
AB	61 400	125 011	241 963	234 737	663 112
BC	77 442	136 942	313 952	303 598	831 934
Canada	1 226 928	1 295 198	2 062 886	2 221 931	6 806 943

	Vintage (%)				
Province	**Before 1941**	**1941-1960**	**1961-1977**	**After 1978**	**Total**
NFL	13.6	16.4	30.4	39.6	100.0
PEI	28.2	11.3	28.0	32.5	100.0
NS	26.8	16.2	26.2	30.8	100.0
NB	21.5	17.1	31.3	30.0	100.0
PQ	15.2	19.0	35.0	30.8	100.0
ONT	23.2	19.5	23.8	33.5	100.0
MAN	21.1	25.4	31.9	21.6	100.0
SAS	18.7	22.8	31.9	26.6	100.0
AB	9.3	18.9	36.5	35.4	100.0
BC	9.3	16.5	37.7	36.5	100.0
Canada	18.0	19.0	30.3	32.6	100.0

Distribution of Houses According to Space Heating Fuel Type

In 1993, natural gas was the predominant fuel choice for space heating in Canada, which presented close to half of the total residential space heating fuel market share. Electricity was the next preferred fuel, accounting for close to 30 percent. Oil and wood had 15 and 7 percent share of the total space heating fuel market, respectively. The distribution of space heating fuel share is presented in Table A.5. As can be seen from the table, the space heating fuel mix was very different from province to province. Natural gas was more preferred in Ontario and westward while electricity and oil, to some extent, were the most preferred choices in Quebec and Eastern Canada.

Table A.5: Space heating fuel type distribution used in CREEEM

	Space Heating Fuel Type (No. of Houses)					
Province	**Gas**	**Oil**	**Electricity**	**Wood**	**Propane**	**Total**
NFL	0	57 390	64 711	31 609	1 393	155 103
PEI	0	28 486	863	6 223	474	36 045
NS	0	143 698	54 664	37 086	4 763	240 210
NB	0	52 680	102 431	40 591	471	196 172
PQ	35 384	268 330	891 552	159 227	2 911	1 357 404
ONT	1 628 202	335 674	527 416	106 398	26 921	2 624 611
MAN	185 920	12 696	87 127	8 658	1 657	296 059
SAS	246 025	15 954	18 243	3 409	3 174	286 805
AB	643 044	6 223	8 489	7 705	13 626	679 088
BC	531 534	81 649	168 269	61 984	10 502	853 938
Canada	3 272 077	1 002 780	1 923 766	462 889	63 925	6 725 436

	Space Heating Fuel Type (%)					
Province	**Gas**	**Oil**	**Electricity**	**Wood**	**Propane**	**Total**
NFL	0.0	37.0	41.7	20.4	0.9	100.0
PEI	0.0	79.0	2.4	17.3	1.3	100.0
NS	0.0	59.8	22.8	15.4	2.0	100.0
NB	0.0	26.9	52.2	20.7	0.2	100.0
PQ	2.6	19.8	65.7	11.7	0.2	100.0
ONT	62.0	12.8	20.1	4.1	1.0	100.0
MAN	62.8	4.3	29.4	2.9	0.6	100.0
SAS	85.8	5.6	6.4	1.2	1.1	100.0
AB	94.7	0.9	1.3	1.1	2.0	100.0
BC	62.2	9.6	19.7	7.3	1.2	100.0
Canada	48.7	14.9	28.6	6.9	1.0	100.0

Distribution of Houses According to Domestic Hot Water Heating Fuel Type

Overall, in 1993, electricity was the predominant fuel choice for residential DHW heating, found in more than 50 percent of the total households. The next preferred fuel was natural gas, representing more than 45 percent. The overall distribution of DHW heating fuel for all provinces and Canada is presented in Table A.6. Once again, a clear trend could be observed from Table A.6 that electricity was the most preferred in Central and Eastern Canada (except in Prince Edward Island) while natural gas was the dominant DHW heating fuel choice in the Prairies and West Coast.

Table A.6: DHW heating fuel type distribution used in CREEEM

	DHW Heating Fuel Type (No. of Houses)					
Province	**Electricity**	**Oil**	**Gas**	**Propane**	**Other**	**Total**
NFL	141 563	17 608	0	1 316	1 098	161 584
PEI	7 931	25 612	0	1 953	1 087	36 584
NS	151 108	81 670	0	10 513	4 344	247 634
NB	183 678	16 181	0	2 183	2 081	204 123
PQ	1 336 949	85 923	37 770	8 018	0	1 468 659
ONT	1 078 353	34 159	1 526 376	22 000	6 674	2 667 563
MAN	133 105	205	164 312	938	108	298 668
SAS	62 325	1 005	228 167	1 639	0	293 137
AB	32 527	4 545	641 104	10 524	0	688 700
BC	365 493	21 961	467 442	9 138	3 934	867 968
Canada	3 493 032	288 869	3 065 446	67 947	19 325	6 934 620

	DHW Heating Fuel Type (%)					
Province	**Electricity**	**Oil**	**Gas**	**Propane**	**Other**	**Total**
NFL	87.6	10.9	0.0	0.8	0.7	100.0
PEI	21.7	70.0	0.0	5.3	3.0	100.0
NS	61.0	33.0	0.0	4.2	1.8	100.0
NB	90.0	7.9	0.0	1.1	1.0	100.0
PQ	91.0	5.9	2.6	0.5	0.0	100.0
ONT	40.4	1.3	57.2	0.8	0.3	100.0
MAN	44.6	0.1	55.0	0.3	0.0	100.0
SAS	21.3	0.3	77.8	0.6	0.0	100.0
AB	4.7	0.7	93.1	1.5	0.0	100.0
BC	42.1	2.5	53.9	1.1	0.5	100.0
Canada	50.4	4.2	44.2	1.0	0.3	100.0

Appendix B

Generation of archetypes and Hot2000 input files

ARCHETYPE GENERATION

B.1.1 Source of Data for Archetype Development

The data that were used in the development of house archetypes come from the Modified STAR-HOUSING database (Scanada, 1992; Ugursal and Fung, 1994; Ugursal et. al., 1996), the 1993/94 "200-House Audit" project (NRCan, 1994), Hot2000 (NRCan, 1995) default values and minor contributions from other sources. This combined new database contains a total of 895 houses as follows:

- Total of 698 house files from the modified STAR database. The house files included are:
    60 files from Alberta
    122 files from British Colombia
    174 files from Ontario
    146 files from Quebec
    59 files from Manitoba
    58 files from Saskatchewan
    17 files from New Brunswick, and
    62 files from Newfoundland
- Total of 197 house files from the 1993/1994 "200-House Audit" project. The Hot2000 Batch Version 7.14 (NRCan, 1996) was used to extract the required data from the HDF files into a comma separated variable (CSV) format.

B.1.2 Initial Archetype Categories

Initially, the intention was to use the following categorization as the basis for developing archetypes:

Region: There are ten provinces in the SHEU database (Stats. Can., 1993a), which are grouped into four regions for archetype development, as follows:

1. Atlantic (Newfoundland, Prince Edward Island, Nova Scotia, New Brunswick)
2. Center (Quebec, Ontario)
3. Prairies (Manitoba, Saskatchewan, Alberta)
4. West (British Colombia)

House Type: There are seven types of dwellings in the SHEU database, among which only four represent houses in Canada. These four are:

1. Single Detached
2. Double (Semi Detached)
3. Row or Terrace
4. Duplex

The other three are:

5. Apartment, Flat (Less than 5 storeys)
6. High-Rise Apartment (5 storeys or more)
7. Mobile Home

Of these four house types, three are included in the STAR database (Single-detached, Double, and Row) and the fourth category is "Other".

1. Single Detached
2. Double (Semi Detached)
3. Row or Terrace
4. Other

Thus, these four categories were to be used in the archetype development.

Number of Storeys: There are seven categories in the SHEU database for number of storeys:

1. One Storey
2. One and Half Storeys
3. Two Storeys
4. Two and Half Storeys
5. Three Storeys
6. Split Level
7. Bi-Level (Split Entry)

STAR database contains the following categories:

1. One Storey

2. One and Half Storeys
3. Two Storeys
4. Two and Half Storeys
5. Three Storeys

Thus, these five categories were to be used in the archetype development.

Vintage: Vintage is the time period in which the houses in the database were built. This category is divided into six groups in the SHEU database.

1. Before 1941
2. 1941 - 1960
3. 1961 - 1977
4. 1978 - 1982
5. 1983 – 1988
6. 1989 or Later

Based on these categories, there would be 480 archetypes as shown below:

(4 regions) x (4 house types) x (5 numbers of storeys in STAR) x (6 vintages) = 480 archetypes

B.1.3 Development of Archetype Categories

A statistical analysis performed on the STAR+200 house database indicated that the numbers of houses in the "Double" and "Row or Terrace" category were very small as compared to the single detached houses. The number of houses with more than two storeys were also very small. Thus, the "Row or Terrace" category was combined with the "Double", and more than two storeys were combined with the two storeys category and called "Two+" category. The number of archetypes was now 144, with the distribution of houses amongst the categories shown in Table B.1.

Table B.1: Distribution of houses amongst 144 archetypes for STAR+200 houses

	Atlantic						Central					
	Single-Detached			Double and the rest			Single-Detached			Double and the rest		
Vintage	One	1 1/2	Two+	One	1 1/2	Two+	One	1 1/2	Two+	One	1 1/2	Two+
Before 1941	10	8	6	0	0	0	45	1	0	8	0	0
1941-1960	28	4	8	2	0	0	114	2	1	2	4	0
1961-1977	43	1	1	11	0	0	123	0	0	16	0	0
1978-1982	6	1	0	0	0	0	4	0	0	0	0	0
1983-1988	0	0	1	0	0	0	0	0	0	0	0	0
1989 or later	0	0	0	0	0	0	0	0	0	0	0	0
Total	87	14	16	13	0	0	286	3	1	26	4	0

	Prairies						West					
	Single-Detached			Double and the rest			Single-Detached			Double and the rest		
Vintage	One	1 1/2	Two+	One	1 1/2	Two+	One	1 1/2	Two+	One	1 1/2	Two+
Before 1941	30	3	2	0	0	0	32	7	7	0	0	1
1941-1960	59	1	8	1	0	0	51	0	3	1	0	1
1961-1977	97	0	4	9	0	0	53	3	17	3	0	1
1978-1982	12	0	1	0	0	0	13	0	6	0	0	2
1983-1988	0	0	4	0	0	0	3	0	3	0	0	1
1989 or later	0	0	1	0	0	0	1	1	1	0	0	0
Total	198	4	20	10	0	0	153	11	37	4	0	6

"Double and the rest" includes double, row or terrace and "other" category, as explained in the previous page.
"Two+" includes two or more storeys houses.

It can be seen from Table B.1 that there are very few houses in the vintage category of 1983-1988 and 1989 or later. Therefore, these two categories are combined and called the "1978 or later" category. Similarly, the number of houses in the one and half and two storeys categories are very small for "double and the rest" houses. Thus, all of the houses in the "double and the rest" category are also combined into one category and named "All". Consequently, the number of archetypes was now reduced to 64 as shown in the Table B.2.

Table B.2: Distribution of houses amongst 64 archetypes for STAR+200 houses

	Atlantic				Central			
	Single-Detached			Double and the rest	Single-Detached			Double and the rest
Vintage	One	1 1/2	Two+	All	One	1 1/2	Two+	All
Before 1941	10	8	6	0	45	1	0	8
1941-1960	28	4	8	2	114	2	1	6
1961-1977	43	1	1	11	123	0	0	16
1978 or later	6	1	1	0	4	0	0	0
Total	87	14	16	13	286	3	1	30

	Prairies				West			
	Single-Detached			Double and the rest	Single-Detached			Double and the rest
Vintage	One	1 1/2	Two+	All	One	1 1/2	Two+	All
Before 1941	30	3	2	0	32	7	7	1
1941-1960	59	1	8	1	51	0	3	2
1961-1977	97	0	4	9	53	3	17	4
1978 or later	12	0	6	0	17	1	10	3
Total	198	4	20	10	153	11	37	10

This categorization was also carried out for the SHEU database and the results are presented in Table B.3.

Table B.3: Distribution of houses amongst 64 archetypes for the SHEU database

	Atlantic				Central			
	Single-Detached			Double and the rest	Single-Detached			Double and the rest
Vintage	One	1 1/2	Two+	All	One	1 1/2	Two+	All
Before 1941	104	334	314	56	46	80	167	36
1941-1960	241	143	114	31	141	43	61	23
1961-1977	686	58	135	49	218	14	96	60
1978 or later	570	96	281	82	150	29	195	66
Total	1601	631	846	218	555	166	519	185

	Prairies				West			
	Single-Detached			Double and the rest	Single-Detached			Double and the rest
Vintage	One	1 1/2	Two+	All	One	1 1/2	Two+	All
Before 1941	216	150	132	7	16	5	12	2
1941-1960	447	89	70	23	61	6	13	3
1961-1977	692	23	129	63	120	7	40	19
1978 or later	409	28	179	91	60	9	64	27
Total	1764	290	510	184	257	27	129	51

A total of 834 houses were not included in the statistical analysis, due to the missing values pertaining information on the house type, number of storeys, or vintage of the house.

With 64 archetypes, it can be seen that the number of houses in the one and half and two storeys categories of the single detached houses are very small. Therefore, it was decided to further reduce the archetype categorization by combining house types into "Single detached" and "Single Attached". The "Single Attached" houses are the same as the "Double and the rest" category. The name changed to reflect more closely the house types in this category. This is shown in Table B.4.

Table B.4: Distribution of houses amongst 32 archetypes for the STAR+200 houses and the SHEU database

	STAR+200 Houses							
	Atlantic		**Central**		**Prairies**		**West**	
Vintage	**Single Detached**	**Single Attached**	**Single Detached**	**Single Attached**	**Single Detached**	**Single Attached**	**Single Detached**	**Single Attached**
Before 1941	24	0	46	8	35	0	46	1
1941-1960	40	2	117	6	68	1	54	2
1961-1977	45	11	123	16	101	9	73	4
1978 or later	8	0	4	0	18	0	28	3
Total	117	13	290	30	222	10	201	10

	SHEU Database							
	Atlantic		**Central**		**Prairies**		**West**	
Vintage	**Single Detached**	**Single Attached**	**Single Detached**	**Single Attached**	**Single Detached**	**Single Attached**	**Single Detached**	**Single Attached**
Before 1941	754	56	293	36	498	7	33	2
1941-1960	498	31	245	23	606	23	80	3
1961-1977	879	49	328	60	844	63	167	19
1978 or later	947	82	374	66	616	91	133	27
Total	3078	218	1240	185	2564	184	413	51

In its final form, the archetype categorization has 16 categories as shown in Table B.5.

Table B.5: Distribution of houses amongst 16 archetypes for the STAR+200 houses and the SHEU database

	STAR+200 houses			
Vintage	**Atlantic**	**Central**	**Prairies**	**West**
Before 1941	24	54	35	47
1941-1960	42	123	69	56
1961-1977	56	139	110	77
1978 or later	8	4	18	31
Total	130	320	232	211

	SHEU database			
Vintage	**Atlantic**	**Central**	**Prairies**	**West**
Before 1941	810	329	505	35
1941-1960	529	268	629	83
1961-1977	928	388	907	186
1978 or later	1029	440	707	160
Total	3296	1425	2748	464

B.1.4 Archetype Attributes

The insulation values used in the archetypes are given in Table B.6.

Table B.6: Insulation values used in the archetypes

Vintage	Regions	ArchNo	CeilR	MWR	DoorR	EFR	CSWR	SlabPR	SlabCR	AGWR	FBUR	FBLR	FBFP	FBFC	SHBR	SHFP	SHFC	MFR	ACH
1	West	1	2.52	1.36	0.44	1.19	0.45	0.20	0.20	0.93	0.50	0.50	0.22	0.22	0.48	0.22	0.22	0.22	8.00
2	West	2	3.20	1.71	0.44	2.57	0.46	0.20	0.20	1.13	0.70	0.70	0.27	0.26	0.69	0.27	0.27	0.27	7.00
3	West	3	3.38	1.99	0.50	2.70	0.76	0.30	0.30	1.38	0.80	0.80	0.27	0.27	0.82	0.30	0.30	0.30	6.25
4	West	4	4.43	2.31	0.64	3.19	1.04	0.30	0.30	1.52	0.90	0.90	0.35	0.35	0.83	0.35	0.35	0.35	5.00
1	Prairies	5	3.40	1.89	0.59	2.18	0.30	0.20	0.20	0.82	0.65	0.65	0.27	0.26	0.57	0.27	0.27	0.27	5.57
2	Prairies	6	3.70	2.11	0.60	2.51	0.85	0.20	0.20	0.93	0.70	0.70	0.30	0.30	0.75	0.30	0.30	0.30	3.81
3	Prairies	7	4.00	2.20	0.60	2.70	0.90	0.30	0.30	1.10	0.83	0.81	0.30	0.30	0.90	0.30	0.30	0.30	2.79
4	Prairies	8	4.49	2.39	0.72	3..46	1.00	0.30	0.30	1.54	1.27	1.27	0.35	0.35	1.00	0.35	0.35	0.35	2.73
1	Central	9	3.38	1.70	0.50	1.75	0.43	0.20	0.20	0.77	0.60	0.60	0.27	0.27	0.44	0.27	0.27	0.27	5.30
2	Central	10	3.70	1.83	0.50	2.54	0.50	0.20	0.20	0.87	0.70	0.70	0.29	0.29	0.79	0.29	0.29	0.29	4.02
3	Central	11	4.00	2.21	0.50	3.05	0.80	0.30	0.30	1.21	0.96	0.96	0.33	0.33	0.95	0.33	0.33	0.33	3.34
4	Central	12	4.11	2.50	0.50	3.40	1.00	0.30	0.30	1.40	1.10	1.10	0.35	0.35	1.10	0.35	0.35	0.35	2.61
1	Atlantic	13	2.50	1.78	0.40	1.55	0.28	0.20	0.20	0.83	0.56	0.54	0.25	0.25	0.50	0.25	0.25	0.25	6.57
2	Atlantic	14	3.54	2.09	0.50	1.82	0.39	0.20	0.20	0.93	0.83	0.83	0.29	0.29	0.70	0.29	0.29	0.29	5.85
3	Atlantic	15	3.80	2.16	0.54	2.40	0.60	0.30	0.30	1.25	1.02	1.00	0.33	0.33	0.90	0.33	0.33	0.33	3.53
4	Atlantic	16	4.00	2.30	0.55	2.72	1.00	0.30	0.30	1.40	1.10	1.10	0.35	0.35	1.02	0.35	0.35	0.35	2.70

Where:

Vintage 1:	Before 1941
Vintage 2:	1941 - 1960
Vintage 3:	1961 - 1977
Vintage 4:	1978 or later
Atlantic:	Newfoundland, Prince Edward Island, New Brunswick, and Nova Scotia
Center:	Quebec, Ontario
Prairies:	Manitoba, Saskatchewan, Alberta
West:	British Colombia
CeilR:	RSI-value for ceiling, entered in columns 61-70 of the card for ceiling
MWR:	Main wall RSI-value, entered in columns 45-54 of the card for main walls
DoorR:	Door RSI-value, entered in columns 30-39 of the card for doors
EFR:	Exposed floor RSI-value, entered in columns 35-44 of the card for exposed floor
CSWR:	Crawl space wall RSI-value, entered in columns45-54 of the card for crawl space wall area
SlabPR:	Slab perimeter RSI-value, entered in columns35-44 of the card for slab-on-grade perimeter area

SlabCR: Slab center RSI-value, entered in columns 35-44 of the card for slab-on-grad center area

AGWR: Above grade basement wall RSI-value, entered in columns 45-54 of the are for basement walls above grade

FBUR: Upper basement wall RSI-value, entered in columns 45-54 of the card for full basement

FBLR: Lower basement wall RSI-value, entered in columns 45-54 of the card for full basement

FBFP: Floor perimeter RSI-value, entered in columns 35-44 of the card for full basement

FBFC: Floor center RSI-value, entered in columns 35-44 of the card for full basement

SHBR: Basement wall RSI-value, entered in columns 45-54 of the card for shallow basement

SHFP: Floor perimeter RSI-value, entered in columns 35-44 of the card for shallow basement

SHFC: Floor center RSI-value, entered in columns 35-44 of the card for shallow basement

MFR: Main floor RSI-value, entered in columns 35-44 of the card for the floor above shallow or full basement

ACH: Air change rate per hour, entered in columns 22-27 of Card D1.2

B.2 Development of Batch Hot2000 7.14 Input Files

Hot2000 Batch (NRCan, 1996) program requires an input file for each house in the SHEU database to perform the simulation in order to estimate the annual fuel consumption. Every input file name must have *.V71 suffix at the end. The files are named according to their sequence number in the SHEU database. Thus, the input file for the house number 101 is called 101.V71.

Each Batch input file consists of different sections and different cards, which present specific information on the house; its envelope characteristics, appliances, location information, heating and cooling system, domestic hot water system, and so on. The following cards are required for the input files. The input data requirements are for the Hot2000 Batch program, version 7.14. The manual of this program can be referred to for more information. The source of information for each card entry is also described, along with each entry.

Card A - Case Control Card

Col 1-3: Database command (Not operational, left blank)
Col 4-13: Input house data name (Builder code), left blank
Col 14-17: Weather file city number, will be done by Statistics Can.
Col 18-20: Region number, Field 3 in the SHEU database (Province)
Col 21-23: Change option (not operational), set to zero
Col 24-29: Output selector (0-5 and -1), set to zero (Full report)
Col 30:Report units selector, set to M (Metric)
Col 31-50: Weather file city name, set to the city name according to columns 14-17
Col 51-60: Output house data name, set to sequence number from the SHEU database
Col 61-65: File format version, set to 612

Cards B - Identification, General Description

Card B.1

Col 1-30: Client name, left blank
Col 31-60: Street address, left blank
Col 61:Indicator, set to z

Card B.2

Col 1-20: Client city, left blank
Col 21-40: Client region, left blank
Col 41-50: Client postal code, left blank
Col 51-62: Client phone number, left blank

Card B.3

Col 1-30: Mailing address, left blank
Col 31-50: Mailing city, left blank
Col 51-70: Mailing region, left blank
Col 71-80: Mailing postal code, left blank

Card B.4

Col 1-2: House type. Source: Field 6 in the SHEU

Col 3-4: Number of storeys. Source: Field 181 in the SHEU

Col 5-6: Wall construction, set to 1 (Platform frame, with single stud walls). This column is used only for documentation purposes. Source: statistics on 200 audit houses

Col 7-8: Thermal mass type. Source: Field 182 in the SHEU.

If **Brick**	2-Medium, Wood frame
If **Stone/Concrete**	3- Heavy, Masonry
Else	1- Light, Wood frame

Col 9-10: Foundation soil condition, set to 1 (Normal conductivity: dry sand, loam, clay, low water table). Source: statistics on STAR+200 houses

Col 11-12: Year built (Vintage), set to 1 (User defined)

Col 13-17: Year built (User defined), set to the average value in Field 348 in the SHEU

Col 18-19: Solid fuel burning equipment #1. Source: Fields 138, 140, 149, 151 in the SHEU

Col 20-21: Solid fuel burning equipment #2, set to 1 (Not applicable)

Col 22-23: Data entry by (Name), left blank

Col 24-25: Date of entry (Year), left blank

Col 26-27: Date of entry (Month), left blank

Col 28-29: Date of entry (Day), left blank

Card C - Option Selector Cards

Card C.1

Col 1: Same as column 7-8 in Card B.4.

Col 2: Same as column 9-10 in Card B.4.

Col 3: Input units, set to M (Metric)

Col 4-7: Basement component insulation specs for each basement type. Col 4 - Crawl space, Col 5 - Slab on grade, Col 6 - Shallow basement, Col 7 - Full basement: Fields 191 and 193 in the SHEU

Col 8-11	Configuration code for each basement type. Source: Field 6 in the SHEU. If **Semi-detached (Double)** Code 2= Attached on one side If **Row or Terrace** Code 3= Attached on 2 or more sides Else Code 1 = Not attached
Col 12-13	The wall color (1-11). Source: Field 182 in the SHEU. If **Brick** Medium Brown (0.84) Else Default (0.40)
Col 14	Temperature rise type (1, 2, 3) is set to 2, program's default
Col 15	Basement heated? (1=Yes, 2=NO). Source: Field 201 in the SHEU
Col 16	Basement cooled? (1=Yes, 2=NO). Assume no cooling
Col 17	Separate thermostat in basement? (1=Yes, 2=NO). Source: Field 138 in the SHEU. If **Electric Baseboard or Electric Radiant Heating** 1=Yes Else 2= No
Col 18	If slab on grade specified, is edge insulated? (Y/N). Source: statistics on STAR+200 houses. There is no specific pattern between the age of the house and the type of edge insulation for the slab-on-grade basement types. The results of the statistics are given in Table B.7.

Table B.7: Results of statistics on slab-on-grade edge insulation

Data Source	**No. of Houses**	**No. of Slab-on-grade**	**Edge Insulated**	
			Y	**N**
STAR	698	29	29	0
200 House	197	67	2	65

All the houses in STAR with slab-on-grade basement type have edge insulation, but only 3% of the 200 houses with slab-on-edge have edge insulation. Assuming insulated slab-on-grade.

Col 19	If crawl space specified, is it **H**eated or **U**nheated? Source: Fields 191 and 201 in the SHEU
Col 20	If crawl space specified, is it **C**losed, **V**entilated, or **O**pen? Source: statistics on STAR+200 houses. Set to **C**losed.
Col 21	If crawl space specified, is it insulated on **F**loor or **G**rade? Source: Fields 191 and 201 in the SHEU. If the crawl space is fully or partially heated, then insulation is placed on grade (Hot2000 interactive manual, page 6-33). Else choose on floor insulation.
Col 22-24	Number of user defined window code data sets. Set to 0
Col 25-29	Main floor temperature. The weighted average value for Fields 178, 179, and 180 in the SHEU.
Col 30-34	Basement temperature. 3°C less than main floor temperature. Source: statistics on STAR+200 houses. For the STAR+200 houses the average T(main) - T(Basement) is about 3°C.
Col 35-39	Crawl space temperature. Source: statistics on STAR+200 houses. All the STAR houses have this temperature set to zero and only 9 houses in 200 houses have a value for this entry. There is no specific pattern or relationship between this value and the main temperature, and the $T_{main} - T_{Crawl\ Space}$ values range from 0 to 17. Out of 9 houses 5 of them have $T_{main} - T_{Crawl\ Space}$ equal to 5 or 6. Thus, we may use this value for the heated crawl space, since there is no other option at this moment. If craw space is heated set the temperature 5°C less than the main temperature, otherwise set it to the ground temperature. Ground temperature is provided by the Batch out for each house.
Col 40-55	Directions for which window data will be input. Assume "S", "E", "N", and "W".

Col 56-57 No. of rooms for kitchen, living room and dining room. Number of rooms is used to determine the mechanical ventilation rate in compliance with the F-326 minimum ventilation requirements. There is no value entered for the STAR house (All are zero). Only houses in NS and Alberta have values for these columns. The average values for these columns, using only houses in Nova Scotia and Alberta are given in Table B.8.

Table B.8: Results of statistics on the number of rooms

No. of Rooms					
Room Type	**Kitchen**	**Bedroom**	**Bathroom**	**Other**	**Other Basement**
3	1	3	2	1	2

These values could be used for the number of rooms. Kitchen includes kitchen, living room and dining room.

Considering an average house, the following values were used based on the statistics results given in the above table. One of three bedrooms is counted as master bedroom, requiring 10 L/s (21 CFM) of ventilation, and the other two require 5 l/s. Other basement areas was set to 3, indicating that basement hasn't been included in any other rooms entries with 10 l/s of ventilation rates, according to the Hot2000 Batch manual. The values given in Table B.9 were used in Card C.1 for the number of rooms for each entry.

Table B.9: Number of rooms used to calculate the required ventilation rates

No. of Rooms					
Room Type	**Kitchen**	**Bedroom**	**Bathroom**	**Other**	**Other Basement**
3	1	3	2	1	3

Col 58-59 No. of utility rooms, set to 1.

Col 60-61	No. of bedrooms, set to 3.
Col 62-63	No. of bathrooms, set to 2.
Col 64-65	No. of other habitable rooms in house, set to 1.
Col 66-67	Other basement areas (Code 1, 2, 3), set to 3.

Card C.2

Col 1-3	Attic/Roof inputs (1=default, 2=user specified). Source: Field 207 in the SHEU.
Col 4-6	Window air tightness type (1-5); **1:** CSA-A1 (2.79 m^3/hr/m), **2:** CSA-A2 (1.65), **3:** CSA-A3 (0.55), **4:** CSA-Fixed (0.25), **5:** User specified. Source: Fields 243 and 244 in the SHEU. Fields 243 and 244 ask if there is air leak around windows and if all the windows leak. If 243 = Yes and 244 = Yes 1) CSA-A1 (2.79 m^3/hr/m) If 243 = Yes and 244 = No 2) CSA-A2 (1.65 m^3/hr/m) If 243 = No 3) CSA-A3 (0.55 m^3/hr/m) Else Average, CSA-A2 (1.65 m^3/hr/m)
Col 7-9	Number of user defined wall, ceiling and floor codes. Set to 0
Col 10-12	Number of user defined lintel codes. Set to 0
Col 13-18	Wall absorptivity, if wall color is user defined. Same as column 12-13 in Card C.1.
Col 19-24	Effective mass fraction, is specified when there are more than one thermal mass type. Set to Hot2000 default value of 1.
Col 25-30	Windows air leakage rate, user specified. According to the window air tightness type specified in column 4-6, the values are input here.
Col 31-36	Design heating set point. Set to 21° C
Col 37-42	Design cooling set point. Set to 25° C
Col 43-50	Volume of crawl space. The floor area of the house is first determined, using either Field 192 or 189, taking into account the

number of floors determined from Field 181. The first source is Field 192, which specifies the square footage of the basement. If the area is not given in Field 192, then Field 189 is used to determine the square footage of the basement. In the latter case, it is being assumed that the square footage of the house and basement are the same. This area (in m^2) is then multiplied by 0.6 to calculate the volume of crawl space. 0.6 m is the assumed wall height for crawl space.

Col 51-58	Volume of shallow basement. The house floor area in m^2 is multiplied by 1.8.
Col 59-66	Volume of full basement. The house floor area in m^2 is multiplied by 2.5.
Col 67-74	Area of opening to basement. Set to 0 (Statistics).

Ceiling

Col 1-2	Set to "Ce". Assuming that there is one ceiling type.
Col 3-5	Construction type (1=N/A, 2=Attic/Gable, 3= Attic/Hip, 4=Cathedral, 5=Flat, 6=Scissor) Field 207 in the SHEU and statistics on 200 houses. If responses in the SHEU are 1, 2 and 3, then 2=Attic/Gable is selected. If 4 is selected, then 4=Cathedral is used. In other cases 1=N/A is selected. The reason for choosing "Attic/Gable" and "Cathedral" among the 5 ceiling types that are mentioned above is the result of the statistics performed on 200 houses. These results are presented below. As it can be seen, among 5 ceiling types only "Attic/Gable" and "Cathedral" are input.

Table B.10: Results of statistics on ceiling types done on houses in the "200-House Audit" project

Construction Type	N/A	Attic/Gable	Attic/Hip	Cathedral	No Info	Total
No. of Houses	82	66	0	44	5	197
% Houses	41.6	33.5	0.0	22.3	2.5	100.0

Col 6-8	Roof slope (1=User Defined, 2= Flat roof, 3=2/ 12, 4= 3/ 12, 5=4/ 12, ..., 8=7/ 12) 1=User defined is selected. The slope will be entered later, in columns 41-50.
Col 11-20	Structural codes. All set to 0, i.e. 000000000.
Col 21-30	Length Assuming square shape house, the side length of the square is calculated (Area$^{0.5}$). For the Attic/Gable ceiling, the ceiling length is twice the side length, where for other types it is the side length (see page 6-16 of the interactive manual). The "Area" is calculated as explained in Col 43-50 of Card C.2.
Col 31-40	Area For Attic/Gable this are is the square footage of the house, but for cathedral type ceilings the area is larger, since the ceiling and roof are parallel. Assuming a roof slope of 0.25, the area will be 1.04 times the area in the case of Attic/Gable.
Col 41-50	User specified slope. Set to 0.25 (Statistics on 200 houses).
Col 51-60	Heel height. Set to 0 (Statistics on 200 houses).
Col 61-70	RSI-value. Source: Statistics on STAR+200. The results are the average value for each archetype.

Attic/Roof

This card is input, if column 1-3 in Card C.2 is set to 2.

Col 1-2	Gable sheathing material (1-9, A-C). Set to 1. This means that the RSI-value should be specified by the user.
Col 3-4	Gable exterior (1-7). Set to 1.
Col 5-6	Roof sheathing (1-9). Set to 1.

Col 7-8 Roofing material (1-9). Set to 1.

Col 9-10 Roof color (1-9, A- B). Set to 1.

Col 11-18 Gable ends, total area. Assuming square shape house with roof slope of 0.25, the area will be calculated from this equation, where B is the side of the square: Area = 0.125 B^2. For cathedral ceiling this area is 0.

Col 19-25 Gable sheathing RSI-value.

For the case of cathedral ceilings or finished attics, the RSI-value is set to the main wall RSI-value determined for each archetype. For the case of unheated attic/gable ceiling, RSI-value is set to 0.355, which is the average value for 200 houses. Results of statistics performed on 200 houses are given in Table B.11.

Table B.11: Results of statistics on attic input requirements

	Gable Sheating RSI	**Gable Exterior RSI**	**Roof Area**	**Roof Sheating RSI**	**Roof Material RSI**	**Roof Absorptivity**	**Attic Volume**	**Attic ACH**
Max.	1.280	0.335	227.2	0.600	0.335	0.860	2915.0	0.500
Min.	0.160	0.000	5.4	0.110	0.000	0.400	1.0	0.100
Average	0.355	0.009	103.1	0.332	0.010	0.857	82.8	0.498

There is no value given for houses in STAR database. The sheathing materials and their respective RSI-values (Source: Hot2000 interactive manual (NRCan, 1995)) are given in Table B.12.

Table B.12: Sheathing materials given in Hot2000 Program and their RSI-values

Sheathing Material	Gable End RSI Value
User Defined	-
Waferboard/OSB (9.5 mm)	0.10
Waferboard/OSB (11.1 mm)	0.12
Waferboard/OSB (15.9 mm)	0.17
Plywood/Part. Bd. (9.5 mm)	0.08
Plywood/Part. Bd. (12.7 mm)	0.11
Plywood/Part. Bd. (15.5 mm)	0.13
Plywood/Part. Bd. (18.5 mm)	0.16
Fibreboard (9.5 mm)	0.16
Fibreboard (11.1 mm)	0.18
Gypsum Sheating (9.5 mm)	0.06
Gypsum Sheating (12.7 mm)	0.08

Roof material	RSI Value
User Defined	-
Asphalt Shingles	0.08
Metal Roofing	0.11
Buildup Membrane	0.06
Asphalt Roll Roofing	0.03
Wood Shingles	0.17
Crushed Stone (Not Dried)	0.15
Slate	0.01
Clay Tile	0.20

Exterior Material	RSI Value
User Defined	-
Wood (lapped)	0.18
Hollow Metal/Vinyl Cladding	0.11
Insul. Metal/Vinyl Cladding	0.32
Brick	0.32
Mortar	0.01
Stucco	0.01

Col 26-32	Gable exterior RSI-value. Set to 0 (Statistics on 200 houses). The gable exterior material and their respective RSI-values (Source: Hot2000 interactive manual) are given in the table below. The exterior RSI-value is included in the sheathing material RSI-value.
Col 33-40	Roof total area. Roof total area is equal to the ceiling area for cathedral and flat ceilings. For gable ceiling the area is calculated using the ceiling area and slope.
Col 41-47	Roof sheathing RSI-value. Set to 0.332, which is the average value for 200 houses. Roof sheathing material and their RSI-values can also be seen in the above table.
Col 48-54	Roof material RSI-value. Set to 0. This value has been entered as zero for most 200 houses. The roof material RSI-value is included in the sheathing material RSI-value.

Col 55-61	Roof material, absorptivity. Set to 0.86. Roof material absorptivity is selected from the roof color. The average value for 200 houses is 0.86, which is between medium brown=0.84 and dark gray = 0.91.
Col 62-69	Attic cavity volume. Attic cavity volume is defaulted to 1 for cathedral ceiling. For gable type ceilings this value is calculated from this equation: Attic volume = Gable area x Length.
Col 70-77	Attic ventilation rate (ACH). Set to 0.50 ACH, which is adopted by almost all 200 houses.

Wall Components

Col 1-2	Component code. Set to "Mw", if it is the last row in the wall section.
Col 5-14	Structural code. Set to 0.
Col 16-18	Lintel type. Set to "N/A".
Col 19-20	Wall direction. Set to 1 (N/A), since there is no information available. This means that all walls are input as one wall section.
Col 21-22	Number of corners. Set to 1.
Col 23-24	Number of intersections. Set to 1.
Col 25-34	Wall height. Wall height is set to 2.5 m (8.3 ft), which is a good estimation of average wall and also is recommended by Hot2000 interactive manual. Attic space is used as part of the heated living space in Hot2000, and the half storey is assigned to the attic space. Therefore the half storey wall height is not considered, since it will be taken into account with the attic and roof cavity section.
Col 35-44	Wall perimeter. Wall perimeter can be estimated from the ceiling length, assuming a square shape house (Wall perimeter = length).
Col 45-54	Wall RSI-value. RSI-values are set according to the average value for each archetype (Statistics on STAR+200 houses).

Door Components

The total numbers of doors in the SHEU are added together, and then divided between two directions, South and North. All the doors are assigned to the main walls, except patio doors, which are dealt differently. According to the Hot2000 interactive manual pg. 6-25, the glazed patio door should be entered as window components. This enables Hot2000 to include solar gain from the patio door in the analysis of the house. Thus, the patio doors are assumed to be glazed and are treated according to the above note. In the main wall section, the first row entered is assigned "M1", which is also the wall facing South, as it is specified in the CARD C.1 section. Thus, the second wall "M2" is facing West, the third "M3" facing North, and forth one "M4" is facing East. Thus, to assign the doors to South and North walls, we should select M1 and M3 for the second entry in each row for the door section.

Col 1-2	Component code. Set to "Do", if it is the last row in the door section.
Col 4-6	Location code. Set to M1 and M3, which are main walls facing South and North, respectively.
Col 7-9	Door type (1-8). Set to 8 (User specified). The Hot2000 door type options and their respective RSI-values are given in the Table B.13.

Table B.13: Door materials and their RSI-values given in the Hot2000 Program

Door Type		RSI Value
1	Wood (Hollow Core)	0.37
2	Solid Wood	0.39
3	Steel (Fiberglass Core)	0.29
4	Steel (Polystyrene Core)	0.98
5	Steel (Polyurethane Core)	1.14
6	Fiberglass (Polystyrene Core)	0.85
7	Fiberglass (Polyurethane Core)	0.98
8	User Defined	-

Col 10-19	Door height. The door nominal size according to ASHRAE is 1.12 m by 2.03 m. These values will be used for the height and width of the door, since there is no information available is the SHEU. Set to 2.03 m.
Col 20-29	Door width. Set to 1.12 m. 1.12 is then multiplied by the number of doors in "S" or "N" directions to determine the total width, since there is only one row entry for South and one for North doors.
Col 30-39	Door RSI-value. RSI-values are set according to the average value for each archetype (Statistics on STAR+200 houses).

Exposed or Overhanging Floors

There is no information in the SHEU on exposed floor, therefore, exposed floor was assigned to 28% of the houses in the SHEU, randomly. Selection of 28% concentration is due to the concentration in STAR+200 houses. There are total of 248 of 895 houses in STAR+200 houses have exposed floor.

28% of 8767 houses in the SHEU were selected randomly, and numbers "1" and "0" were assigned to the selected and unselected houses, respectively. Thus, another column of "1 and 0" was added to the input file, to ease the process of random selection.

Col 1-2	Component code. Set to “Ef”, if it is the last row in the door section.
Col 5-14	Structural code. Set to 0.
Col 15-24	Length. The exposed floor area and R values are given in the Batch output files for STAR+200 houses, but the lengths are not available. The values for the exposed floor lengths were extracted for each house in 200 new houses database (if it was available), and it was determined that the floor lengths were the square root of the area. Since this is the only source of information at this point, the same relation was assumed for the determination of the floor length for the houses in the SHEU database, using the average area.
Col 25-34	Area. Source: Statistics on Star+200 houses. Area values are set to the average value of 18.1 m^2, for 28% of houses in the SHEU, selected randomly.
Col 35-44	RSI-value. Source: Statistics on Star+200 houses. RSI-values are set to the average value of 2.58, for 28% of houses in the SHEU database, selected randomly.

Basement Components

Data for the basement component is only required for those components specified in Card C.1, columns 4-7. Each card describes one component of one type of basement, using one of the format from the previous components (Main Walls or Floors). The following four sections describes each basement component.

Full Basement

Full basement requires the following components to be specified:

Basement Walls above Grade

Col 1-2	Component code. Set to “Bw”, if it is the last row in the wall section.

Col 5-14	Structural code. Set to 0.
Col 16-18	Lintel type. Set to “N/A”.
Col 19-20	Wall direction. Set to 1 (N/A), since there is no information available.
Col 21-22	Number of corners. Set to 1.
Col 23-24	Number of intersections. Set to 1.
Col 25-34	Wall height. Wall height is set to 0.6 m, which is the average value for 200 houses.
Col 35-44	Wall perimeter. Wall perimeter = 4 x length of the house.
Col 45-54	Wall RSI-value. RSI-values are set according to the average value for each archetype.

Upper Basement Walls

Col 1-2	Component code. Set to “Fu”, if it is the last row in the wall section.
Col 5-14	Structural code. Set to 0.
Col 16-18	Lintel type. Set to “N/A”.
Col 19-20	Wall direction. Set to 1 (N/A), since there is no information available.
Col 21-22	Number of corners. Set to 1.
Col 23-24	Number of intersections. Set to 1.
Col 25-34	Wall height. Wall height is set to 0.6m, which is the average value for 200 houses.
Col 35-44	Wall perimeter. Wall perimeter = 4 x length of the house.
Col 45-54	Wall RSI-value. RSI-values are set according to the average value for each archetype.

Lower Basement Walls

Col 1-2	Component code. Set to “Fl”, if it is the last row in the wall section.
Col 5-14	Structural code. Set to 0.

Col 16-18	Lintel type. Set to "N/A".
Col 19-20	Wall direction. Set to 1 (N/A), since there is no information available.
Col 21-22	Number of corners. Set to 1.
Col 23-24	Number of intersections. Set to 1.
Col 25-34	Wall height. Wall height is set to 1.3 m, which is the average value for 200 houses.
Col 35-44	Wall perimeter. Wall perimeter = 4 x length of the house.
Col 45-54	Wall RSI-value. RSI-values are set according to the average value for each archetype.

Floor Perimeter Area

Col 1-2	Component code. Set to "Fp", if it is the last row in this section.
Col 5-14	Structural code. Set to 0.
Col 15-24	Length. Set to be equal to the house perimeter.
Col 25-34	Area. Area. Equations from Hot2000 interactive user manual, page 6-39. Floor perimeter area is {(length x 4) - 4} For single detached {(length x 3) -2} For semi-detached Length x 2 For Row or Terrace
Col 35-44	RSI-value. RSI-values are set according to the average value for each archetype (Statistics on STAR+200 houses).

Floor Center Area

Col 1-2	Component code. Set to "Fc", if it is the last row in this section.
Col 5-14	Structural code. Set to 0.
Col 15-24	Length. Set to be equal to (house perimeter - 2).
Col 25-34	Area. Floor perimeter area is the square of the floor center length.
Col 35-44	RSI-value. RSI-values are set according to the average value for each archetype (Statistics on STAR+200 houses).

Floor above Shallow or Full Basement

Col 1-2	Component code. Set to "Mf", if it is the last row in this section.
Col 5-14	Structural code. Set to 0.
Col 15-24	Length. Set to be equal to the house perimeter.
Col 25-34	Area. Floor perimeter area is the square of the floor perimeter length.
Col 35-44	RSI-value. RSI-values are set according to the average value for each archetype (Statistics on STAR+200 houses).

Shallow Basement

A shallow basement is defined as any basement with an average below grade component of less than 1.2 (4 ft). A raised foundation is also considered a shallow basement for Hot2000 (Hot 2000 interactive manual).

The shallow basement cards' inputs are similar to the ones for the full basement, and the formats are the same as for the full basement. It includes basement walls above grade "Bw", basement walls below grade "Bb", floor perimeter area "Bp", floor center area "Bc", and above shallow or full basement floors "Mf". Shallow basement requires the following components to be specified:

Basement Walls above Grade

Col 1-2	Component code. Set to "Bw", if it is the last row in the wall section.
Col 5-14	Structural code. Set to 0.
Col 16-18	Lintel type. Set to "N/A".
Col 19-20	Wall direction. Set to 1 (N/A), since there is no information available.
Col 21-22	Number of corners. Set to 1.
Col 23-24	Number of intersections. Set to 1.
Col 25-34	Wall height. Wall height is set to 0.6 m, which is the average value for 200 houses.
Col 35-44	Wall perimeter. Wall perimeter = 4 x length of the house.

Col 45-54	Wall RSI-value. RSI-values are set according to the average value for each archetype.

Basement Walls below Grade

Col 1-2	Component code. Set to "Bb", if it is the last row in the wall section.
Col 5-14	Structural code. Set to 0.
Col 16-18	Lintel type. Set to "N/A".
Col 19-20	Wall direction. Set to 1 (N/A), since there is no information available.
Col 21-22	Number of corners. Set to 1.
Col 23-24	Number of intersections. Set to 1.
Col 25-34	Wall height. Wall height is set to 1.2 m, which is the average value for 200 houses.
Col 35-44	Wall perimeter. Wall perimeter = 4 x length of the house.
Col 45-54	Wall RSI-value. RSI-values are set according to the average value for each archetype.

Floor Perimeter Area

Col 1-2	Component code. Set to "Bp", if it is the last row in this section.
Col 5-14	Structural code. Set to 0.
Col 15-24	Length. Set to be equal to the house perimeter.
Col 25-34	Area. Area. Equations from Hot2000 interactive user manual, page 6-39.

Floor perimeter area is

{(length x 4) - 4}	For single detached
{(length x 3) -2}	For semi-detached
Length x 2	For Row or Terrace

Col 35-44	RSI-value. Set to 0.22 (Statistics on 200 houses).

Floor Center Area

Col 1-2	Component code. Set to "Bc", if it is the last row in this section.
Col 5-14	Structural code. Set to 0.
Col 15-24	Length. Set to be equal to (house perimeter - 2).

Col 25-34	Area. Floor perimeter area is the square of the floor center length.
Col 35-44	RSI-value. Set to 0.20 (Statistics on 200 houses).

Floor above Shallow or Full Basement

Col 1-2	Component code. Set to “Mf”, if it is the last row in this section.
Col 5-14	Structural code. Set to 0.
Col 15-24	Length. Set to be equal to the house perimeter.
Col 25-34	Area. Floor perimeter area is the square of the floor perimeter length.
Col 35-44	RSI-value. RSI-values are set according to the average value for each archetype (Statistics on STAR+200 houses).

Crawl Space

Crawl space has three cards, which each describes one component of crawl space. These are walls, perimeter floor, and center floor. The wall height for the crawl space is assumed to be 0.6 m, which is the maximum height that a crawl space wall can have. This is according to the Hot2000 interactive manual, pg. 6-31.

Wall RSI-value is estimated according to the statistics done on STAR+200. This value is estimated as 0.2 for the wall area as well as for the perimeter and the center floor. There are not that many houses with the crawl space among the STAR+200 files, and the 0.2 estimation is based on the few houses with crawl space.

Crawl Space Wall Area

Col 1-2	Component code. Set to “Cw”, if it is the last row in the wall section.
Col 5-14	Structural code. Set to 0.
Col 16-18	Lintel type. Set to “N/A”.
Col 19-20	Wall direction. Set to 1 (N/A), since there is no information available.
Col 21-22	Number of corners. Set to 1.

Col 23-24 Number of intersections. Set to 1.

Col 25-34 Wall height. Wall height is set to 0.6 m, Hot 2000 menu.

Col 35-44 Wall perimeter. Wall perimeter = 4 x length of the house.

Col 45-54 Wall RSI-value. Set to 0.20 (Statistics on STAR+200 houses).

Floor Perimeter Area

Col 1-2 Component code. Set to "Cp", if it is the last row in this section.

Col 5-14 Structural code. Set to 0.

Col 15-24 Length. Set to be equal to the house perimeter.

Col 25-34 Area. Equations from Hot2000 interactive user manual, page 6-39.

Floor perimeter area is

{(length x 4) - 4}	For single detached
{(length x 3) -2}	For semi-detached
Length x 2	For Row or Terrace

Col 35-44 RSI-value. Set to 0.20 (Statistics on STAR+200 houses).

Floor Center Area

Col 1-2 Component code. Set to "Bc", if it is the last row in this section.

Col 5-14 Structural code. Set to 0.

Col 15-24 Length. Set to be equal to (house perimeter - 2).

Col 25-34 Area. Floor perimeter area is the square of the floor center length.

Col 35-44 RSI-value. Set to 0.20 (Statistics on STAR+200 houses).

Slab on Grade

Floor Perimeter Area

Col 1-2 Component code. Set to "Cp", if it is the last row in this section.

Col 5-14 Structural code. Set to 0.

Col 15-24 Length. Set to be equal to the house perimeter.

Col 25-34 Area. Equations from Hot2000 interactive user manual, page 6-39.

Floor perimeter area is

{(length x 4) - 4}	For single detached
{(length x 3) -2}	For semi-detached
Length x 2	For Row or Terrace

Col 35-44 RSI-value. Set to 0.20 (Statistics on STAR+200 houses).

Floor Center Area

Col 1-2	Component code. Set to "Bc", if it is the last row in this section.
Col 5-14	Structural code. Set to 0.
Col 15-24	Length. Set to be equal to (house perimeter - 2).
Col 25-34	Area. Floor perimeter area is the square of the floor center length.
Col 35-44	RSI-value. Set to 0.20 (Statistics on STAR+200 houses).

Window Components

A card is required for each window. If the directions for which window data will be input are specified on card "C.1", then only cards for those windows will be used. In our case these directions will be "S", "E", "N", and "W".

There is no information available in the SHEU database regarding the window and overhang dimensions. These values in STAR houses are all zero and the given window area gives the total area of windows in each direction (Not for each window). This is the same for 200-houses. The dimension of individual window should be extracted directly from input files (*.v71). This required a separate program, which was created. The statistics on these houses reveals the following average dimension values given in Table B.14 for the windows and overhangs in each direction, for 200 houses. Window dimensions are specified by "Height" and "Width" (including the glazing and frame). The number indicates the number of windows in each specific category.

Table B.14: Results of statistics on the window dimensions

Window Height Statistics from 200-House Data

	South			East			North			West		
	M. Wall	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**
No. of Houses	521	105	40	531	129	36	487	102	39	541	110	34
Max.	2.12	3.85	1.72	2.80	2.06	1.72	2.24	2.08	2.06	2.50	2.12	1.68
Min.	0.25	0.38	0.22	0.25	0.29	0.25	0.25	0.29	0.20	0.22	0.27	0.24
Average	1.19	0.78	0.74	1.16	0.76	0.86	1.17	0.77	0.78	1.16	0.78	0.77

Window Width Statistics from 200-House Data

	South			East			North			West		
	M. Wall	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**
No. of Houses	521	105	40	531	129	36	487	102	39	541	110	34
Max.	2.82	3.85	1.72	2.80	2.06	1.72	3.27	2.08	2.06	3.18	2.12	1.68
Min.	0.25	0.38	0.22	0.25	0.29	0.25	0.24	0.29	0.20	0.22	0.27	0.24
Average	1.21	0.82	0.74	1.17	0.79	0.86	1.18	0.79	0.78	1.17	0.81	0.77

Window Overhang Height Statistics from 200-House Data

	South			East			North			West		
	M. Wall	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**
No. of Houses	521	105	40	531	129	36	487	102	39	541	110	34
Max.	2.40	0.76	0.91	2.80	0.90	1.83	1.80	0.90	0.97	1.30	2.80	0.90
Min.	0.03	0.01	0.02	0.05	0.05	0.10	0.07	0.05	0.13	0.01	0.05	0.05
Average	0.51	0.38	0.49	0.54	0.41	0.61	0.53	0.44	0.58	0.51	0.46	0.48

Window Overhang Width Statistics from 200-House Data

	South			East			North			West		
	M. Wall	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**	**M. Wall**	**Bsmt.**	**Door**
No. of Houses	521	105	40	531	129	36	487	102	39	541	110	34
Max.	0.95	0.76	0.91	0.95	0.90	0.95	0.95	0.90	0.97	0.96	0.83	0.90
Min.	0.03	0.05	0.02	0.03	0.05	0.10	0.07	0.05	0.13	0.01	0.05	0.05
Average	0.53	0.42	0.48	0.53	0.41	0.53	0.55	0.44	0.59	0.51	0.39	0.54

The houses in the STAR database do not give the dimension and RSI-value for individual window. Table B.15 presents the results of statistics on STAR houses, for the total number of windows in each direction.

Table B.15: Results of statistics on the window areas and RSI-values performed on the house in the Modified STAR database

Window Area and RSI Value Statistics from STAR								
	Area (m^2)				RSI Value			
	South	East	North	West	South	East	North	West
Max.	9.96	9.60	9.51	9.73	0.59	0.57	0.59	0.57
Min.	0.02	0.05	0.03	0.01	0.21	0.20	0.20	0.20
Average	2.15	2.16	1.94	2.20	0.35	0.34	0.35	0.35

The number of houses and windows in each glazing category are given in Table B.16 for the SHEU. Some houses have more than one type window. That is why that the total number (1085 + 7690 + 1294) exceeds the total number of houses in the SHEU.

Table B.16: Number of windows in each glazing category in the SHEU database

	Single without Storm Window	Double & Single with Storm Window	Triple Glaze
No. of Houses	1085	7690	1294
No. of Windows	5415	76374	7716

The number of windows in each glazing category for different locations are given in Table B.17 for 200 houses.

Table B.17: Number of windows in each glazing category for each location in houses in the SHEU database

	Number of Windows		
Location	**Single**	**Double**	**Triple**
Main Wall	667	1848	65
Basement	159	378	11
Door	92	87	6
Total	918	2313	82

	Percentage of Windows		
Location	**Single**	**Double**	**Triple**
Main Wall	25.9	71.6	2.5
Basement	29.0	69.0	2.0
Door	49.7	47.0	3.2
Total	27.7	69.8	2.5

The total number of windows was divided between the main walls and basement walls. Only the houses with full and shallow basement were given windows for their basements. The total number of windows was first determined for each glazing type (single, double, and triple) according to the Fields 231 - 241 in the SHEU. Single glazing are all the single pane windows without storm windows. The ones with storm windows were considered double-glazing. If a patio door is specified for a house, it is considered as single glazed window. Since the height of a door (1.12 x 2.03) is almost twice the assumed window height (1 x 1), the patio door is entered as two windows for the South direction. Then, each location received a portion of these windows of each glazing type, according to the percentage given above. The number of windows located in doors was assigned to main walls, to avoid a long program. The number of windows was determined for each direction by dividing the total number of windows in each glazing category and location into four directions. The priority was given to south, east, north and west direction, respectively. It means that if there is 6 double glaze windows for the main walls, 2 are assigned to south, 2 to east, 1 to north and 1 to west. These procedures were repeated for all houses in the SHEU and the resulting values for each direction, window location (Main wall and basement), and glazing type were added to the house input file for the BASIC program.

Curtain shading factor is a number between 0 to 1. The default value by Hot2000 is 1. This number is used to reduce the amount solar radiation as a result of using curtain or other obstructions. Since the average of the shading factors is very close to the individual values for each direction, the average value will be used for each direction as given in Table B.18.

Table B.18: Average curtain shading factor used for each direction

	South	**East**	**North**	**West**
Average	0.78	0.78	0.78	0.77

Col 1-2	Component code. Set to “Wn”, if it is the last row in the window section.
Col 4-6	Window location code. Set to M1, M2, M3 and M4, which are main walls facing South, East, North and West, respectively.
Col 8-13	Window type code. The window type code is designated by 6 digits. These digits specify “Number of Glazing”, type of “Coating/Tints”, “Spacing/Fill Type”, “Spacer Type”, “Window Type”, and “Frame Material”. The first 5 digits are assumed to be “20000”, which means double glaze, clear coating, 13 mm air fill, metal spacer type, and picture size window. The double glaze window is selected since the majority of windows in the SHEU are double glaze. The other 4 digits are selected based on the statistics on STAR+200 houses. The frame material is selected according to the Field 243 in the SHEU.
Col 14-16	Number of identical windows. The total number of windows are divided by 4 and these 4 values assigned to each direction.
Col 17-26	Window height. Set to the value given above for each direction. The window dimensions given in Table B.19 were used, based on the statistics done on 200-houses database and engineering judgment.

Table B.19: Window dimensions used for the houses in the SHEU database

	Dimension (m)			
Location	**Window Height**	**Window Width**	**Overhang Height**	**Overhang Width**
Main Wall	1.00	1.00	0.52	0.53
Basement	0.55	0.80	0.42	0.42

Col 27-36	Window width. Set to the value given above for each direction in the table.

Col 37-46	Overhang width. Set to the value given above for each direction in the table.
Col 47-56	Height above window. Set to the value given above for each direction in the table.
Col 57-66	Shutter RSI or RSI-value. Set to 0 (Statistics on STAR+200 houses).
Col 67-76	Curtain shading factor. Set to the value given above for each direction. There are 465 houses without any entries for the number of windows (i.e., They seem to have no window). For these cases total number of 10 double glazed windows were assigned to each house; 3 for south, 3 east, 2 north, and 2 west. 10 is the average number of double glazing windows extracted from the SHEU.

Cards "D" - Ventilation / Plant Description

Card D1.1

Col 1	Air tightness type. The options are: A= Loose (10.35 ACH @50 pa) B= Average (4.55 ACH @50 pa) C= Present (3.57 ACH @50 pa) D= Energy Tight (1.50 ACH @50 pa) x = Blower door test values For our case, we use the last option (blower door test), and the values from the statistics done on each archetype, using the STAR+200 houses.

Table B.20: Air infiltration rate used in CREEEM

Vintage Group	Region Group	Archetype No.	ACH@50
1	West	1	8.00
2	West	2	7.00
3	West	3	6.25
4	West	4	5.00
1	Prairies	5	5.57
2	Prairies	6	3.81
3	Prairies	7	2.79
4	Prairies	8	2.73
1	Center	9	5.30
2	Center	10	4.02
3	Center	11	3.34
4	Center	12	2.61
1	Atlantic	13	6.57
2	Atlantic	14	5.85
3	Atlantic	15	3.53
4	Atlantic	16	2.70

Col 2	Fuel costs input? (Y/N). Set to “N”.
Col 3	Furnace fuel (E, G, O, P, W). Furnace fuel types are obtained from the Fields 138 and 140 in the SHEU. Only one type of space heating equipment can be selected. In the case of more than one fuel used, the primary fuel is being selected.
Col 4	Exhaust flow or F326 data given (Meet F326) (Y/N). Set to “N”.
Col 5	Not used, left blank.
Col 6	Include a heat pump for space heating? (Y/N). The information on heat pump are available in the SHEU in Fields 132 - 137, and 145-148. There are only 155 houses in the SHEU with a heat pump. Field 132 specifies the existence of a heat pump.

Col 7 Include an air conditioner? (Y/N). Fields 296 - 300 describe central air conditioner (1067 houses) and Fields 301 - 312 are used to specify the information on window units (996 houses). Fields 296 and 301 specifies the existence of a central and window air conditioner.

Central air conditioning systems are considered here, and window units are entered under the exterior electricity usage. This is because window air conditioners don't contribute to the interior heat load.

Five houses in the SHEU responded "Yes" to both central and window air conditioner questions (Fields 296 and 301, respectively). There were no value given for the central A/C system capacities. Thus, window A/C were considered for these 5 houses, since the window A/C capacity were given in Field 303. The responses to Field 296 were set to 2 (No central A/C for these five houses).

Col 8 Space heating equipment type, which depends on choice of fuel type specified in column 3. The furnace system type menu is given on page 66 of Batch manual. Fields 138, 140 and 142 in the SHEU are used, as well as the statistics done on STAR+200 houses. Houses with a heat pump were set to "2" (Forced air furnace for electric systems).

The results of statistics performed on STAR and 200 houses are presented in Table B.21.

Table B.21: Results of statistics on space heating system types performed on the houses in the Modified STAR database and "200-House Audit" project

Statistics On 200-Houses							
# of Houses	**System type according to Hot2000 User Manual**						
Fuel Type	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
E	42	6	3	0	0	0	51
G	92	5	3	4	0	0	104
O	5	7	3	21	0	0	36
P	0	0	0	2	0	0	2
W	0	2	2	0	0	0	4
Total	139	20	11	27	0	0	197

Statistics On STAR							
# of Houses	**System type according to Hot2000 User Manual**						
Fuel Type	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
E	157	1	0	0	0	0	158
G	4	28	262	11	0	0	305
O	20	42	146	21	0	0	229
P	3	0	0	0	1	0	4
W	1	0	1	0	0	0	2
Total	185	71	409	32	1	0	698

Field 142 was only used for oil and natural gas. Propane and wood stove efficiencies were set to 80% and 50%, respectively.

The space heating systems and their efficiencies given by Hot2000 interactive manual are presented in Table B.22.

Col 9 Ventilation system type

Fields 250 and 251 were used to determine the ventilation type of the house to be:

No force Ventilation (Supply and exhaust flow rates are zero.)

Heat Recovery Ventilator (HRV)

Fans without Heat Recovery

Based on the option chosen for this column, appropriate flow rates have to be entered in columns 20-26 and 27-33 of this card.

If Field 250 = 1 AND Field 251 = 1 Then Heat Recovery Ventilator (HRV)

If Field 250 = 1 AND Field 251 = 2 Then Fans without Heat Recovery

If Field 250 = 2 AND Field 251 = 2 Then No forced ventilation

All other responses in the SHEU were designated as "No forced ventilation".

Table B.22: Space heating system types and their steady state efficiencies given in the Hot2000 program

Space Heating System Type	**Efficiency (%)**
Electric:	
1- Baseboard/Hydronic/Plenum (Duct)	100
2- Forced Air Furnace	100
3- Radiant Floor Panels	100
4- Radiant Ceiling Panels	100
Natural Gas:	
1- Furnace/Boiler with Continuous Pilot	78
2- Furnace/Boiler with Spark Ignition	78
3- Furnace/Boiler with Spark Ignition (Vent Damper)	78
4- Induced Draft Fan Furnace/Boiler	80
5- Condensing Furnace/Boiler	94
6- Gas-fired Furnace/Heat Pump System	-
Oil:	
1- Furnace/Boiler	71
2- Furnace/Boiler with Flue Vent Damper	71
3- Furnace/Boiler with Flame Retention Head	83
4- Mid-efficiency Furnace/Boiler (No Dilution Air)	85
5- Condensing Furnace/Boiler (No Chimney)	93
6- Direct Vent, Non Condensing	87
Propane:	
1- Furnace/Boiler with Continuous Pilot	80
2- Furnace/Boiler with Spark Ignition	80
3- Furnace/Boiler with Spark Ignition (Vent Damper)	80
4- Induced Draft Fan Furnace/Boiler	82
5- Condensing Furnace/Boiler	91
6- Gas-fired Furnace/Heat Pump System	-
Wood:	
1- Advanced Airtight Wood Stove	74
2- Advanced Airtight Wood Stove and Catalytic Converter	78
3- Wood Furnace	50

Col 10 Primary DHW system fuel type

Field 317 in the SHEU. 505 houses in the SHEU don't have clear information on fuel for DHW heating, responding as follows to the question "What fuel is used to heat the running water?"

5- Other
6- Don't know
8- Fuel not stated, hot running water indicated
9- Fuel and hot water not stated

For these cases the results of statistics given in Table B.23 have been used.

Table B.23: Results of statistics on DHW fuel types for each region

	DHW Fuel Type			
Location	**Gas**	**Electricity**	**Oil**	**Solar**
Atlantic	0	95	32	0
Central	87	199	34	0
Prairies	181	42	9	0
West	93	110	7	1

Col 11 Secondary DHW system. Set to 7 (Not applicable).

Col 12-19 House volume.

The following approach is used to determine the volume of the house:

The area of the house is calculated either from Field 189, by dividing the average value for each area range (550, 750, 1250, 1750, 2250, 2650 sq. ft) by the number of floors, or from F192, which is the area (in square foot) of the basement.

The area is multiplied by the number of floors and wall height of 2.3m to calculate the volume of living space. The value of area was converted to m^2.

The volume of basement or crawl space, when it is heated is added to this living volume.

If house has a cathedral ceiling, the volume of the cathedral portion of the ceiling is also added to the other portions.

Col 20-26 Central ventilation system, supply rate.

For houses with no forced ventilation system, supply and exhaust rate set to zero. (as explained in Col 9).

For houses with heat recovery ventilator and fans (without heat recovery), the following equation was employed:

Supply = Exhaust = [(Number of kitchen/living/dining + utility room + bathroom + other habitable room) * 5] + [(number of bedroom * 5) + 5] + 10

The number 10 at the end of the equation indicates 10 l/s ventilation for the basement, as was explained in Card C.1.

The value 5 added to the ventilation rate for bedroom indicates that one bedroom is considered as master bedroom, which requires 10 l/s instead of 5 l/s.

Col 27-33 Central ventilation system, exhaust rate. The same as in the previous column.

Col 34-40 Interior loads, lighting (kWh/day).

Interior loads (lighting) is calculated using the following equation:

kWh/day = No. of the light bulbs x Average wattage of each type of bulb x Average number of hours of usage per day

The values of kWh/day for each type of light bulbs (incandescent, fluorescent, and halogen) are added to determine the total kWh/day for the lighting. The values given in Table B.24 were extracted from the Lighting Energy Use in Canada Report (Fung et al., 1995 and 1998).

Table B-24: Average power use and number of hours for each lighting type

Type of Fixture	Average Usage (Hour/day)	Average Wattage (watt)
Incandescent	2.1	67
Fluorescent	3.8	41
Halogen	3.8	41

Col 41-47 Interior loads, appliances (kWh/day).

Interior load (appliances) is calculated using the regression approach. This approach was utilized for the Appliances Unit Energy Consumption project (Fung et al., 1996). Equation(s) were developed for each major appliance, based on the regression performed on the subset of the SHEU (with appliance Make and Model number) having the Energuide (NRCan, 1993) values for the appliances. These equations were applied to each house in the SHEU to find the daily energy consumption for each appliance (kWh/Month). These values were then divided by 30 to determine the kWh/day. Then the kWh/day for appliances were added up to determine the interior loads of appliances.

The daily energy consumption of cooking appliances was taken from the Energy Efficiency Technology Impact, Interim Report No.1. The average values were used for this purpose.

Col 48-54 Interior loads, others

This value should include the other interior loads, which are not specified in the two previous entries (lighting and appliances). This could include TV, CD player, Computer, electric blanket, etc. The default value for this entry in Hot2000 is 3.0 kWh/day.

The daily energy consumption for other appliances mentioned above were taken from the Energy Efficiency Technology Impact, Interim Report No.1. The average values were used for this purpose. These appliances and the average UEC's used are presented in Table B.25.

An average baseload has been also added to the total interior daily load to account for the appliances, which are not given in the SHEU database. This average value takes into account the saturation of the appliance in the national scale. These appliances and the average yearly and daily baseload are given in Table B.26.

Table B.25: The UEC values and saturation rates for minor appliances given in the SHEU database (Ugursal and Fung, 1994)

	Field in	UEC	UEC	Number of houses	Number of houses	Saturation %	Saturation %
Appliances	SHEU	kWh/Yr	kWh/day	in SHEU	in Canada	in Canada	in SHEU
Range (Oven+cooktop)*	F52	1147.7	3.14	9979.0	9311207.0	89.9	90.9
Oven*	F52	401.0	1.10	710.0	816787.0	7.9	6.5
Cooktop*	F52	553.0	1.52	710.0	816787.0	7.9	6.5
Microwave	F63	180.0	0.49	8658.0	8135851.0	78.5	78.8
Color TV	F116	412.4	1.13	7522.0	7095431.6	68.5	68.5
Black & White TV	F117	249.4	0.68	1857.0	1751690.6	16.9	16.9
VCR	F118	40.0	0.11	6862.0	6472859.9	62.5	62.5
CD Player	F119			2563.0	2417653.7	23.3	23.3
Stereo	F120	50.0	0.14	5555.0	5239979.1	50.6	50.6
Computer	F121	130.0	0.36	1808.0	1705469.3	16.5	16.5
Electric Blanket	F122	142.6	0.39	897.0	846131.6	8.2	8.2
Water Bed Heater	F123	1250.0	3.42	1436.0	1354565.3	13.1	13.1
Portable Humidifier	F124	140.5	0.38	1474.0	1390410.3	13.4	13.4
Portable Dehumidifier	F125	382.2	1.05	1447.0	1364941.4	13.2	13.2
Car Block Heater	F126	250.0	0.68	3523.0	3323212.7	32.1	32.1
Interior Car Warmer	F127			602.0	567860.9	5.5	5.5
Water Cooler	F128			185.0	174508.8	1.7	1.7
Aquarium	F129	548.0	1.50	450.0	424480.8	4.1	4.1
Bathroom Exhaust Fan*	F130	15.0	0.04	4063.0	3832589.6	37.0	37.0
Kitchen Exhaust Fan	F61			6262.0	6892254.0	66.5	57.0
Central Electronic Air Filter	F145	216.0	0.59	590.0	874891.0	8.4	5.4
Central Humidifier	F146			1219.0	1599783.0	15.4	11.1
Central Dehumidifier	F147			165.0	222877.0	2.2	1.5
Elec. Portable Heater	F165-F167	173.0	0.47	938.0	883245.0	8.5	8.5
Central Vacuum*	F253	42.2	0.12	1362.0	1346002.0	13.0	12.4
Sump Pump	F254	40.0	0.11	1481.0	1022481.0	9.9	13.5
Pool (pump)*	F256	1269.0	3.48	318.0	701902.0	6.8	2.9
Electric Pool Heater	F257-F258			17.0	43861.0	0.4	0.2
Hot Tub	F261-F263	2300.0	6.30	606.0	711387.0	6.9	5.5
Sauna	F264			55.0	76145.0	0.7	0.5
Ceiling Fan	F313-F314	110.0	0.30	4376.0	4040677.0	39.0	39.8
Portable Fan	F315-F316	135.5	0.37	4710.0	4149887.0	40.1	42.9

All The UEC values are extracted from The Table 14 of "Energy Impacts - Appliances: Interim Report No. 1" (EIAR), otherwise specified.

Bold Italic Taken from Table 7 of EIAR

Col 55-61 Average exterior use (include vented clothes dryer) (kWh/day). Assuming 95% of the total clothes dryer electricity use as external load; 5% as indoor load.

Average exterior use includes the total electrical load consumed by exterior lighting, automobile block heaters, garage electrical use, and other electrical requirements outside the home.

For the window air conditioner the daily energy consumption was calculated knowing the EER (BTU/Wh) based on their ages (F309), usage hours (F312), and capacity (F303). The equation used for calculating the daily energy consumption of A/C is as follows:

$$\text{kWh/Day} = (W_{cap} * \text{usage}) / (\text{EER} * 1000 * 365)$$

Outdoor lighting energy consumption was calculated from the number of light bulbs given in Fields 332, 335, 346, and 347. The car block heater, and bathroom and kitchen exhaust energy consumption were extracted from the Energy Efficiency Technology Impact, Interim Report No.1 (Ugursal and Fung, 1994).

Table B.26: The UEC and saturation rates for the minor appliances not given in the SHEU database (Ugursal and Fung, 1994)

Miscellaneous Appliances

Appliances	Saturation (%)	UEC kWh/year	UEC X Sat. (kWh/year)	UEC (kWh/Day)
Clock	95.66	18.8	17.98	0.05
Electric Mower				
Garbage Disposal	34.54	26.7	9.22	0.03
Grow-lights & Acc.	4.00	800.0	32.00	0.09
Attic Fan	41.55	290.0	120.50	0.33
Fry Pan (skillet)	56.45	182.4	102.96	0.28
Iron	59.50	121.4	72.23	0.20
Coffee Maker	60.13	97.1	58.39	0.16
Toaster	90.75	40.0	36.30	0.10
Hair Dryer	77.68	19.2	14.91	0.04
Blender	70.87	12.2	8.65	0.02
Sewing Machine	67.85	11.0	7.46	0.02
Mixer	76.63	10.7	8.20	0.02
Shaver	49.09	1.2	0.59	0.00
Instant Hot Water	1.00	160.0	1.60	0.00
Crackpot	32.09	139.0	44.61	0.12
Window Fan	10.00	120.0	12.00	0.03
Heat Tape	4.00	100.0	4.00	0.01
Broiler	17.93	96.3	17.27	0.05
Toaster Oven	21.61	93.0	20.10	0.06
Plate Warmer	15.36	92.2	14.16	0.04
Circulating Fan	9.00	91.5	8.24	0.02
Griddle	10.27	46.0	4.72	0.01
Trash Compactor	2.63	40.0	1.05	0.00
Waffle Iron	33.09	21.6	7.15	0.02
Heat Lamp	7.20	15.0	1.08	0.00
Floor Polisher	6.00	15.0	0.90	0.00
Wok/Fondue Set	5.54	9.0	0.50	0.00
Heating Pad	5.74	8.4	0.48	0.00
Knife/Slicer	38.99	6.2	2.42	0.01
Tooth Brush	8.54	5.3	0.45	0.00

Miscellaneous Appliances

Appliances	Saturation (%)	UEC (kWh/year)	UEC X Sat. (kWh/year)	UEC (kWh/Day)
Can Opener	34.00	3.9	1.33	0.00363
Massager	1.33	1.2	0.02	
Ice Cream Maker	9.87	0.7	0.07	0.00019
Juicer	5.34	0.6	0.03	0.00009
Ice Crush	6.95	0.5	0.03	0.00010
Opener/Sharpener	33.09	0.2	0.07	0.00018
Sharpener	4.78	0.2	0.01	0.00003
Hot Comb	45.69			
Tape Deck	38.24			
Curler	37.57			
Popcorn Popper	32.74			
Slide/Movie Projector	28.71			
Flood Lights	28.20			
Food Grinder	26.39			
Curling Iron	21.45			
Water Pic	7.85			
Amp'r (Guitar/Organ)	7.65			
Roaster		156.7		
Deep Fryer		83.0		
Kettle		75.0		
Rotisserie		73.0		
Sandwich Grill		28.7		
Cooker/Fryer		23.0		
Baby Food Warmer		22.0		
Egg Cooker		13.7		

Total Baseload kWh/Yr 631.67
Total Baseload kWh/day 1.73

Col 62-67 Hot water load.

Hot water load is the amount of hot water used at the tap (i.e., for domestic consumption only) and does not include space heating hot water. Hot2000 assumes that this value is constant throughout the year. The Hot2000 default value is calculated based on the number of occupancy using the following equations:

Liter/Day = 85 + 35 * (# of occupants) + L_{cw} + L_{dw} if no low-flow/aerator is used

Liter/Day = 85 + 20 * (# of occupants) + L_{cw} + L_{dw} if low-flow/aerator is used

where L_{cw} is the daily hot water usage from clothes washer

L_{dw} is the daily hot water usage from dishwasher

$L_{cw} = (0.86 * Q_{cw})/(4.18 * (55 - GT))$

$L_{dw} = (0.75 * Q_{dw})/(4.18 * (55 - GT))$

where 0.86 is the coefficient of total clothes washer energy usage for water heating (Wenzel et al., 1997)
0.75 is the coefficient of total dishwasher energy usage for water heating (Wenzel et al., 1997)
Q_{cw} is daily clothes washer electricity usage
Q_{dw} is daily dishwasher electricity usage
4.18 is specific heat for water
55 is the assumed hot water temperature set point
GT is the ground temperature (known from Hot2000 weather station data)

Col 68-69	Hot water load, 1= default, 2=User specified. Set to 2.
Col 70-75	Hot water temperature. Set to 55°C.

Card D1.2

Col 1	No. of occupants, adults. Field 11 in the SHEU.
Col 2	No. of occupants, children. Fields 13 and 14 in the SHEU.
Col 3	No. of occupants, infants. Field 12 in the SHEU.
Col 4-9	Percent of time at home, adults.

The percentages of time at home for the occupants are not available in the SHEU. This values are set to the average values taken from the statistics done on 200 houses. The results of the statistics are presented in Table B.27.

Table B.27: Results of statistics performed on houses in "200-House Audit" Project for the percentages of time at home for adults and children

Percent of Time at Home		
	Adult	**Children**
Max.	100	100
Min.	1	0
Average	66	30

The percentage of time at home for infants is set to 66, which is the same as adults.

Col 10-15	Percent of time at home, children. As explained above.
Col 16-21	Percent of time at home, infants. As explained above.
Col 22-27	Air change rate at 50Pa (ACH) The air change rate @ 50Pa is set to the average values for each archetype regions. These average values are obtained by the statistics performed on STAR+200 files (shown in Table B.20).
Col 28-34	Equivalent leakage area (cm^2 or in^2) The equivalent leakage area is calculated by the program based on the given ACH rate.
Col 35-40	Fraction of internal gain released in basement. The fractional internal gain released in the basement represents the fraction of net internal electrical load released in basement. The Hot2000 default value of 0.15 is adopted for the houses in CREEEM, with shallow or full basement.
Col 41-46	Vented combustion appliances depressurization limit (Pa). Vented combustion appliances depressurization limit is the depressurization limit for the combustion appliances with the tolerance for house depressurization (i.e., the lowest

depressurization point). All combustion appliances have the potential to create back-draft into the house. This could be health and safety hazards if the house is excessively depressurized by the exhaust of these appliances. Combustion appliances include fuel-fired furnaces, hot water heaters/tanks, fireplaces, stoves, gas-fired dryers, and other appliances that vent combustion products to the outside. Naturally aspirated appliances such as conventional fuel-fired furnaces, hot water tanks, and most fireplaces and stoves have a minimum depressurization limit of about 5Pa.

Col 47-56 Furnace/Boiler rated output heating capacity (kW or Btu/hr).

The rated output heating capacity is specified by the manufacturer's literature or the face plate on the unit. This value is given in kW or Btu/hr. Hot2000 calculates the energy consumption of the space heating equipment based on the heating load, the system capacity, the steady-state efficiency, and part-load factors. The calculation includes estimates of the monthly and seasonal efficiencies of the furnace.

There is no specific information in the SHEU on the capacity of the heating system. The statistics performed on 200 houses is the only source of information at this moment. According to the results, this capacity could be estimated from the "Design Heat Loss" obtained from the simulation results of Batch program. Knowing the design heat loss and the heating system capacity from 200-houses simulation results, a coefficient was calculated for each house based on the following equation:

Ht. Sys. Cap (kW) = Coeff. * Design Heat Loss / 1000

The results of the statistics are presented in Table B.28.

Table B.28: Results of statistics on the coefficient used to calculate heating system capacity

	Coefficient
Max.	7.3
Min.	1.2
Avaerge	1.8

The average value of 1.8 is chosen to estimate the heating system capacity. The design heat loss is determined by the program during the first simulation, having an assumed constant value of 30 kW for the required value in Card D1.2.

Col 57-62 Furnace/Boiler steady state efficiency (%).

The furnace/boiler efficiencies are given in the SHEU for oil- and gas-fired system. These values are expressed in the following ranges:

Standard	(50 – 65%)
Medium	(75 – 80%)
High	(90% or Higher)

As it can be seen from the above ranges, a specific number cannot be selected. Thus, median values were chosen for each specified range. The other problem with these values is the fact that values between 65-75% and 80-90% are not included in the responses. Using these averages, Hot2000 default values and engineering judgment, the following efficiencies were used for each fuel type:

Electricity	100%
Propane	80%
Wood	50%

Table B.29: Furnace/boiler efficiency according to the SHEU responses

Efficiency (%)	**SHEU Response**		
Fuel Type	**1**	**2**	**3**
Natural Gas	57	77	93
Oil	57	77	94

Col 63-64 Furnace fan mode, 0 = N/A, 1= Auto, 2=Continuous.

Auto is selected if the fan operates only when the furnace is on.

Continuos mode is selected, if fan runs 24 hours a day, 365 days a year.

Not applicable is selected if the heating system doesn't include a fan.

The only source of information is the 200-house database.

According to this source, most houses use "Auto" mode for their furnace fan.

Col 65-71 Furnace fan power (Watts).

No information available in the SHEU. Setting this value to zero (0), makes Hot2000 to estimate the fan power based on the space heating system capacity. If this is the case, only for the houses with a space heating system including a fan without a heat pump.

Furnace fan power is set to zero.

Col 72-78 Pilot light energy consumption (MJ/day or Btu/hr)

The Hot2000 default pilot light energy consumption for natural gas and propane heating systems is 23.5 MJ/day if the heating system is not high efficiency one. This value is also adopted for this study, since there is no information available in the SHEU. The default value of 23.5 MJ/day is used.

Card D1.3 - AIM-2 Inputs

There is no information available in the SHEU on this section, thus, the only source of data is the 200-House database. The older houses do not have these information, therefore, 200 houses were used for the statistics. Since there are no houses of central region among 200 houses, the values for the Central region (Ontario, Quebec) are not included in the statistics, and are assumed the same as Prairies.

Terrain description at Weather station is selected from the menu given in the Hot2000 Batch manual page 38. There are 8 selections in this menu.

The values given in Table B.30 are used for the entries required for this section:

Table B.30: Results of statistics on terrain characteristics for different regions

Region	Terrain at Weather St	Terrain at Bldg. Site	Shield Wall	Shield Flue	Height of Anemometer	Height of Eaves	Leak. Fraction Ceiling	Leak. Fraction Wall	Leak. Fraction Floor
Atlantic	4	7	2	2	10	N/A	0.2	0.5	0.2
Central	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Praries	4	8	3	2	10	N/A	0.3	0.6	0.2
West	2	7	2	2	10	N/A	0.4	0.2	0.4

For West (BC) there are 53 of "2" and 24 of "7" for the terrain @ weather station

Col 1 Terrain description @ weather station. Set to the values in Table C.23.

Col 2 Terrain description @ building site. Set to the values in Table C.23.

Col 3 Local shielding for walls. Set to the values in the Table B.30.

The local shielding specifies how well the walls and the flue are shielded from the wind. The followings are the types of shielding specified by Hot2000:

1- No Local Shielding
2- Light Local Shielding
3- Heavy

	4- Very Heavy 5- Complete (By Large Building)
Col 4	Local shielding for flue. Set to the values in Table B.30.
Col 5	Leakage fraction, 1=Use defaults, 2=User specified User specified is selected.
Col 6	Solid fuel burning equipment #1. Same as column 18-19 in Card B.4.
Col 7	Solid fuel burning equipment #2. Same as column 20-21 in Card B.4.
Col 8-15	Height of anemometer (m). The anemometer height is the height at which the wind speed is measured. The default value of 10 m is chosen.
Col 16-23	Height of building eaves (m). The eaves height can be calculated using the following equation. This is the same equation that Hot2000 uses to default the value for the height. Height of building eaves = 2.5 x (# of storeys) + 0.5
Col 24-31	Leakage fraction for ceiling. The leakage fractions should add-up to 1.0. The program default values for ceiling, walls, and floors are 0.25, 0.5, 0.25, respectively. Set to the values in the above table.
Col 32-39	Leakage fraction for walls. Set to the values in the above table.
Col 40-47	Leakage fraction for floors. Set to the values in the above table.
Col 48-55	Effective flue diameter for furnace (mm). The value for each fuel type is averaged for the 200-house database. The following values are used for each fuel type: Gas and Propane 152 mm Oil 160 mm Wood 200 mm
Col 56-63	Effective flue diameter for fireplace (Solid equip. 1) (mm) For the houses having fireplace, the flue diameter is set to 200 mm.

Col 64-71	Effective flue diameter for fireplace (Solid equip. 1) (mm). Set to 0.
Col 72-73	Energy efficient lighting used, 1=Yes, 2= No. Set to 2= No.
Col 74	Kitchen energy efficient credits, 1=Yes, 2= No. Set to 2= No.
Col 75	Main hallway energy efficient credits, 1=Yes, 2= No. Set to 2= No.
Col 76	Living room energy efficient credits, 1=Yes, 2= No. Set to 2= No.
Col 77	Family room energy efficient credits, 1=Yes, 2= No. Set to 2= No.
Col 78	Dining room, bedroom, entrance, bathroom or other finished room energy efficient credits, 1=Yes, 2= No. Set to 2= No.
Col 79	Utility or laundry room, or other unfinished room energy efficient credits, 1=Yes, 2= No. Set to 2= No.

Card D2.1 - Space Heating System

Col 1-30	Name of manufacturer. Set to "~~".
Col 31-60	Model number. Set to "~~".
Col 61-62	Space heat capacity set by, 1= user, 2= Program. Set to 2.
Col 63-64	Radiant panels / In floor hydronic heating, 2= Yes, 1= No. Set to 1.

Card D3- DHW System Description

Col 1-30	Name of manufacturer. Set to "~~".
Col 31-60	Model number. Set to "~~".
Col 61-68	Tank capacity (liters). Field 323 in the SHEU. The values given in Table B.31 were used for each response.

Table B.31: DHW tank capacities used according to the responses in the SHEU database

Response	No. of Houses	Percentage
1- Small (140 L or less)	1 252	17
2- Medium (180 L)	5 064	68
3- Large (230 L)	664	9
4- Very large (270 L)	475	6
5- Don't know	155	
6- Not stated	712	
Without DHW system	445	

The value of 180 is chosen for the "Don't know" and "Not Stated" responses, since it represents medium size tank, which accounts for the maximum number of houses.

Col 69-70 System type, defined by menus which vary with fuel type.

Based on the column 10 of Card D1.1 and the statistics done on STAR+200 houses, the system types given in Table B.32 were selected.

No tank systems are used for the houses, which responded "No" to Field 319 in the SHEU questionnaire. The question asks if they use hot water tank (separate from furnace).

Table B.32: DHW system types used for each fuel type

Fuel Type	**Electric**	**Oil**	**Gas**	**Propane**	**Wood**
System Type	2	2	3	3	2
No Tank Sys.	4	3	6	6	2

The system types and corresponding default energy factors defined by Hot2000 interactive manual are given in Table B.33.

Table B.33: DHW systems type and their corresponding energy factors given by theHot2000 program

Natural Gas/Propane		
Equipment Type		**EF**
1	Not Appliable	-
2	Conventional Tank	0.554
3	Conventional Tank (Pilot)	0.554
4	Tankless Coil	0.480
5	Instantaneous	0.830
6	Instantaneous (Pilot)	0.800
7	Induced Draft Fan	0.571
8	Induced Draft Fan (Pilot)	0.571
9	Direct Vent (Sealed)	0.575
10	Direct Vent (Sealed, Pilot)	0.575
11	Condensing	0.860

Electricity		
Equipment Type		**EF**
1	Not Appliable	-
2	Conventional Tank	0.824
3	Conserver Tank	0.868
4	Instantaneous	0.936
5	Tankless Heatpump	1.900
6	Heatpump	1.900

Wood		
Equipment Type		**EF**
1	Not Appliable	-
2	Fireplace	0.300
3	Wood Stove Water Coil	0.300

Oil		
Equipment Type		**EF**
1	Not Appliable	-
2	Conventional Tank	0.530
3	Tankless Coil	0.400

These energy factors were used in Col 91-97.

Col 71-72 Tank capacity category.

The following menu is given by Hot2000 Batch manual, describing these categories:

1. 113.6 Liter
2. 151.4 Liter
3. 189.3 Liter
4. 246.1 Liter
5. 302.8 Liter
6. Not Applicable

Values from this menu corresponding to the responses in the SHEU given in Columns 61-68 are used.

Col 73-74 Tank location.

According to the basement type specified in Col 4-7 of Card C, the location of tank was determined. For the houses having crawl space, slab on grade, shallow basement and full basement, the tank located in main floor, main floor, basement, and basement, respectively.

Col 75-76	Energy factor, 1=Use defaults, 2=User specified. Set to 1.
Col 77-83	Pilot energy (MJ/day). Set to 17.7 for propane and natural gas fuels. According to 200 houses, the pilot energy of 17.7 MJ/day is given for only natural gas DHW systems. The rests are set to 0.
Col 84-90	Flue diameter (mm or in). Set to 100, 150, and 0 for natural gas and propane, oil, and electricity fuels (200 houses). These houses were investigated individually, since the Batch output does not provide the information on the flue diameter for the DHW systems.
Col 91-97	Energy factor (decimal). This entry gives the actual value of the energy factor for the DHW system. Hot2000 default values are used.
Col 98-104	Tank blanket insulation.

If the response to Field 324 is yes	0.5
Else	0.0

Card D4 and D5 – Ventilation System

These two cards are read, if forced ventilation system (HRV or fans without heat recovery) is specified in column 9 of Card D1.1.

Card D4

Col 1-30	Name of Manufacturer Set to "Ventilation Manufacturer"
Col 31-60	Model Number Set to "Ventilation Model Number"

Card D5.1

Card D5.1 gives specific information on the forced ventilation system such as test point temperatures, efficiencies, etc. For fans without heat recovery system, only the third Field is used, which is on fan and pre-heater power at high temperature. The rest of the card 5.1 can be left blanks or equal to zero. For heat recovery ventilators both cards, D5.1 and D5.2, are read.

Col 1-7	High temperature test point (°C) The high- and low-test temperatures for the fan power are used to determine the energy costs, unit energy consumption, and the performance of the unit at different temperatures. Set to zero (Statistics on 200-house database and Hot2000 Default).
Col 8-14	Low temperature test point (°C) Set to –25 (Statistics on 200-house database and Hot2000 Default).
Col 15-21	Fan + pre-heater power at high temperature (watts) A pre-heater is a heating coil, which is placed in the fresh air intake of the unit. It warms the sir before entering the unit to prevent very cold air from freezing the core of certain types of heat recovery ventilators. Set to 125 watts (Statistics on 200-house database).
Col 22-28	Fan + pre-heater power at low temperature (watts) The rest of this card is set to zero for fans without HRV systems. Set to 125 watts.
Col 29-35	Heat recovery efficiency at high temperature (%) Set to 55% (Statistics on 200-house database and Hot2000 default).
Col 36-42	Heat recovery efficiency at low temperature (%) Set to 45% (Statistics on 200-house database and Hot2000 default).
Col 43-49	Pre-heater capacity (watts) This Field specifies the sum of capacities of the multi-stage pre-heaters and is used to determine the amount of available preheat energy at very cold temperature. Set to zero (Statistics on 200-house database).
Col 50-56	Low temperature ventilation reduction (%)

This value gives the reduction in ventilation rate due to frost build up inside the unit in cold temperatures.

Set to zero (Statistics on 200-house database).

Col 57-63 Total cooling efficiency during A/C operation (%)

This Field is required for cooling calculation. If a house is specified having a conventional cooling system with ventilator cooling (Column 61 in Card G), a value has to be given in this Field. Set to zero, since air conditioning systems are entered as conventional A/C without ventilator cooling.

Card D5.2

This cord should be specified only for houses with heat recovery ventilator systems. Columns 1-25 give information on cold air supply ducts, while columns 27-52 specify data on cold air exhaust ducts.

Cold air supply ducts

Col 1 Location

Duct Location Menu

1. Basement
2. Crawl Space
3. Attic
4. Main Floor

Col 2 Duct type

Duct type menu

1. Flexible
2. Sheet Metal with liner
3. Ext. Insulted Sheet Metal

Flexible duct was chosen.

Col 3 Duct Sealing

Duct Sealing Menu

1. Very Tight
2. Sealed
3. Unsealed

Sealed option was selected.

Col 4-11 Duct length (m)

	Set to 25 m.
Col 12-18	Duct diameter (mm)
	Set to 152.4 mm.
Col 19-25	Duct insulation (RSI or R)
	Set to 0.58 m^2C/W.

<u>Cold air exhaust ducts</u>

	Same as cold air supply ducts
Col 28	Location
Col 29	Duct type
Col 30	Duct Sealing
Col 31-38	Duct length (m)
Col 39-45	Duct diameter (mm)
Col 46-52	Duct insulation (RSI or R)

Card D6 and D7 - Heat Pumps

These cards for heat pumps are read, if column 6 of Card D1.1 is set to "Y". Total 153 houses in the SHEU have heat pump, among which only 26 houses specify the capacity for their heat pump as given in Table B.34.

Table B.34: Results of statistics done on houses in the SHEU database for heat pumps

	Heat Pump Source				
	Air	**Ground**	**Don't Know**	**Not Stated**	**Total**
No. of Houses	81	16	13	43	153
% of Houses	53	10	8	28	100

In order to determine energy consumption of the heat pump, Hot2000 requires information on the source and capacity of the systems. Hot2000 assumes that all heat pumps are used for space heating.

The capacity of the heat pumps in the SHEU varies from 14500 to 60000 Btu/hr, with an average of about 32500 Btu/hr. Since there is no other options at this point, the average capacity is assigned to the rest of the houses with no capacity specified.

The heat pump source is also unknown for about 37% of the houses with heat pump. The source was assigned to these houses randomly, according to the percentage of the houses in the SHEU with known sources, (16.5% ground source and 83.5% air source heat pumps in the SHEU; 16 and 81 out of 97 houses with known sources).

The furnace type specified in column 3 of Card D1.1 serves as the auxiliary heat source for the heat pump.

Card D6s

Col 1-30	Heat pump manufacturer. Set to "Heat pump manufacturer".
Col 31-60	Model number. Set to "Heat pump model number".

Card D7

Col 1	Heat pump source, 0=Air, 1=Water, 2=Ground. Source: Field 133 in the SHEU. Field 132 in the SHEU only specifies air and ground source heat pumps.
Col 2	Temperature cut-off type, 1=Balance Point, 2=Restricted, 3=Unrestricted The temperature cut-off controls the time that heat pump or back up system operates. **Balance point**: The heat pump is shut off when it is not able to meet the full space heating load. **Restricted**: The heat pump is shut off below a user-specified temperature. If restricted is selected, user has to specified the cut-off temperature in column 21-28. **Unrestricted:** When the heat pump is operated without restriction.

	There is no information available on this entry. There are 4 houses among the houses in the 200-House database with heat pump. Among these, only one has the unrestricted cut-off temperature. The other three have balanced selected. Unrestricted cut-off temperature is assumed
Col 3	Fan mode, 0=N/A, 1=Auto, 2=Continuous. All heat pumps systems include at least an indoor fan. If a heat pump is selected, but no fan, Hot2000 makes two estimates of fan power; one from the fan power for the heating equipment (Col 63-64 of Card D1.2) and one from the heat pump (this column). The highest value of these two estimates is selected. Set to 1. This is the same option selected for space heating systems.
Col 4	Use calculated source temperate (For weather location), 1=Yes, 2=No. This is for ground or water source heat pumps only. If no is selected, then Card D7.2 has to be used to define the monthly temperatures. Set to 1.
Col 5-12	Heat pump capacity (kW or Btu/hr). Source: Field 135 in the SHEU. The heat pump capacity given in the SHEU is in Btu/hr and must be multiplied by 0.000293 to convert it to kW.
Col 13-20	Heat pump COP. COP (Coefficient Of Performance) is a measure of heat pump efficiency system and varies from 1.0 to 7.5. A COP of 3.5 means that 3.5 kW of heat energy is produced by the heat pump for each 1.0 kW of electricity used to run the unit. No information is available in the SHEU. Using Hot2000 defaults, COP's are set to 2.0 and 3.0 for air and ground source heat pumps, respectively.

Col 21-28	Heat pump cut-off temperature (If restricted). Set to 0.
Col 29-36	Heat pump fan power (Watts). Set to zero, so Hot2000 estimate the value (See Col 3).
Col 37-44	Gas mode rated capacity (kW). If the fuel type specified for the heating equipment is natural gas or propane with a "Gas-fired furnace/heat pump system" selected as the system type, the information on the system are given for gas mode parameters. Set to 0.
Col 45-52	Gas mode COP. Set to 0.
Col 53-60	Gas mode electric capacity (kW). Set to 0.
Col 61-68	Heat pump crankcase heater power (watts). A crankcase heater is a small electric coil inside the compressor unit, which makes sure that oil stays warm when unit is not operating. Set to 60 and 0 for air and ground or water source heat pumps, respectively, since no information is available. These are Hot2000 defaults.
Col 69-76	Average depth for ground or water source heat pump (m). Set to 25 m (All 4 houses of 200 houses having heat pump, have this value equal to 25 m.)

Card G - Air Conditioner Data

Card G1

This section includes only central air conditioners. Window air conditioners were considered in appliance section.

There are total of 1047 houses among the SHEU houses having central air conditioning systems, but only 97 of them included a value for the cooling capacity of the A/C system (almost 10%). Therefore, the A/C capacity was set to 0 to make the program to estimate it to meet the average design conditions for the rest of the houses.

Col 1-30	Air conditioner manufacturer. Set to “~~”.
Col 31-60	Model Number. Set to “~~”.
Col 61	A/C system type, which is selected from the following menu: Conventional A/C 2- Conventional A/C, with vent. Cooling 3- A/C with economizer 4- Not installed System type 1 (Conventional A/C) is selected, since there is no specific information is given in the SHEU. ** System type 2 includes a high capacity attic exhaust fan that operates whenever outside temperature is lower than the inside temperature. This is sometimes referred as “free” cooling, although the electrical energy required by the fan is not free. ** System type 3 includes an economizer, a device that controls a set of dampers that introduces outside air into the cooling air and exhaust the return air stream.
Col 62	Economizer control mode (1=dry bulb, 2=enthalpy, 3=not selected). Option 3 should be chosen, unless column 61 is set to 3 (A/C with economizer). Set to 3 (not selected).
Col 63	Indoor fan operating mode (1=auto, 2=continuous). Set to 1.
Col 64	A/C is integrated with heating system (1=Yes, 2=No). If this Field set to “Yes”, Hot2000 assumes that furnace and air conditioner uses the same fan. This has effect on the total energy consumption, if fan mode is set to continuous. Set to 1. No information is given in the SHEU. Most 200 houses have A/C integrated with heating system.

Col 65-67	Starting month for A/C operation (1-12). Set to 5. No information is given in the SHEU. All 200 houses have this value set to 5.
Col 68-70	Ending month for A/C operation (1-12). Set to 10. No information is given in the SHEU. All 200 houses have this value set to 10.
Col 71-73	Month to be used for design conditions (1-12). Hot2000 uses the weather data for this month in its calculation. Set to 7. No information is given in the SHEU. All 200 houses have this value set to 7.
Col 74-76	Use calculated design values (1=Yes, 2=No, 3=Always). "**Yes**" is used to size an air conditioning system for a house. Hot2000 calculates the rated capacity, indoor fan flow rate, and fan power required for an air conditioning system for the house. If the above values (rated capacity, indoor fan flow rate, and fan power required for an air conditioning system for the house) are set to zero, the values will be calculated by program, even if "**No**" is selected here. "**Always**" option is the default and if is selected, every time a calculation is performed, the program redesigns the air conditioner and matches it to the house. It is strongly recommended by the Hot2000 manual that the user select "**Always**" so that Hot2000 can match the air conditioner to the load. Set to 3.
Card G2	
Col 1-6	House cooling temperature set point. Set to 22°C.
Col 7-14	Air conditioner capacity (Watts). Set to the Fields 298 in the SHEU, for central units. The value has to be multiplied by 0.293 to convert it from BTU/hr to Watts. Zero is selected for the houses with no value given in the SHEU for this Field, in order to have Hot2000 estimate the capacity to meet the average design conditions.

Col 15-20 Air conditioner COP. The COP of the A/C can be obtained from the EER value, by multiplying the EER by 0.293 (ASHRAE F37.1):

$$COP = EER\left[\frac{Btu}{Wh}\right] x \left[\frac{1000Wh}{1kWh}\right]\left[\frac{kWh}{3412Btu}\right] = EERx0.293\left[\frac{kWh}{kWh}\right]$$

EER is estimated from Field 299 depending on the age of the A/C. The relationship between the age of A/C, EER, and the corresponding COP is shown in Table B.35.

Table B.35: The EER and COP values of air conditioners according to responses in the SHEU database

Response	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Age	1	2	3	4	5	6.5	9	13	18	25	7.5
EER	8.80	8.80	8.73	8.48	8.23	7.93	7.50	7.00	6.35	5.98	7.70
COP	2.58	2.58	2.56	2.48	2.41	2.32	2.20	2.05	1.86	1.75	2.26

The respond 11 in the SHEU (11- Not Stated) is assumed to correspond to the average EER (7.7).

Col 21-26 Air conditioner sensible heat ratio. Set to the default value of 0.76.

Col 27-34 A/C indoor fan flow rate (l/s). Set to zero (0), in order to have the program estimate the value.

Col 35-42 Crankcase heater power (Watts). Set to the default value of 60 W.

Col 43-50 Attic ventilator cooling flow rate (l/s). Set to zero to get the default value by the program. Hot2000 assumes a default value of 10 ACH or 2000 l/s, whichever is less.

Col 51-58 Indoor fan power (Watts). Set to zero (0), in order to have the program estimate the value.

Col 59-63 Fraction of windows that are opened (When $T_{out} < T_{in}$). Set to zero.

Appendix C

Impact of heating degree days on household space heating energy consumption

In this work, the number of heating degree-days (HDD) is used to adjust the "typical" annual energy consumption (estimated using Hot2000 and typical weather data) to obtain energy consumption estimates for the actual billing period as follows:

$$UEC_{SH,i} = (HDD_i / HDD_{typical}) \times UEC_{SH,typical} \qquad \text{Eq. C.1}$$

Where $UEC_{SH,i}$ = Annual energy consumption for space heating in year i

HDD_i = Heating degree days in year i

$HDD_{typical}$ = Heating degree days in typical year

$UEC_{SH,typical}$ = Annual energy consumption for space heating in typical year

This approach assumes that the annual energy consumption for space heating is proportional to the HDD, and ignores the effect of solar and interior heat gains as well as differences in infiltration due to other weather related variables.

To test the validity of this assumption, a series of simulations were conducted on a simple two-level (80 m^2/level), slab-on-grade, single detached house with electric baseboard heating, using the HAP hour-by-hour building energy simulation program (Version 4.03 of Carrier's HAP (Carrier, 1999)). Three different sizes of window were used 1) patio door 60" wide and 80" tall, 2) large windows 48" wide and 36" tall, and 3) small windows 24" wide and 36" tall. 24 kWh/day (8760 kWh/year) of electricity consumption was assumed for appliance and lighting uses. The house is of typical Canadian wood-frame construction, with wood sheathing and siding outside and drywall inside. Three levels of insulation were considered and simulations were run for the house in a wide range of climates as shown in Table C.1. These three different envelope insulation levels represent low-, medium-, and high-insulated houses (MacGregor et al., 1993). Thermal and construction characteristics of the houses are presented in Tables C.2 and C.3.

Table C.1: Household energy consumption prediction and heating degree days

City	HDD (base 18°C) (°C-day)	Annual Space Heating Energy Consumption (GJ/year)		
		Low Insulation	Medium Insulation	High Insulattion
Halifax	4089	200	54	23
Montreal	4557	227	67	32
Toronto	3793	200	56	25
Calgary	5391	236	67	31
Winnipeg	5933	277	85	42
Vancouver	3064	148	36	13
Anchorage	6036	306	93	46
Seattle	2858	144	34	12
Chicago	3688	161	45	20
New York	2706	133	34	14
Atlanta	1645	80	18	6
London	2320	148	35	13
Stockholm	4125	229	66	31
Oslo	4663	283	85	42
Amsterdam	2771	157	38	32
Paris	2378	138	33	12
Brussels	2695	137	32	11
Berlin	2996	163	42	17
Milan	1840	149	40	17
Tokyo	1567	77	16	5
Melbourne	1785	59	9	2
Sydney	741	34	4	1
Seoul	2631	138	37	15
Wellington	1643	69	10	2
Shanghai	1597	79	17	5

The simulation results are given in Table C.1 and plotted in Figure C.1. As expected, the estimated annual space heating energy consumption is shown to be linearly proportional to the heating degree-days, and the linear fit is shown to be strongest for the least insulated scenario (highest demand for space heating). It is seen that the annual energy consumption and the HDD are indeed proportional for the houses with the three levels of insulation (R^2 of 0.85, 0.91, 0.91 for high, medium and low insulation houses, respectively). Thus, annual dwelling space heating energy consumption can be assumed to be linearly proportional to the heating degree-days, and Eq. C.1 can be used with confidence to normalize annual space heating energy consumption for weather.

Table C.2: Envelope details of the test house

	North	South	East	West
Gross exposed wall area (m^2)	21.95	21.95	27.43	27.43
Window area (m^2)	4.20 / 2.20	1.39 / 2.50	0.56 / 0.56	0.56 / 0.56
Door area (m^2)	N/A	1.86 / N/A	N/A	N/A

Table C.3: House construction details for three insulation levels

	High	Medium	Low
Wall R value (m^2.°C/W)	3.30	1.90	0.00
Roof R value (m^2.°C/W)	6.70	3.90	0.00
Slab-on-grade R value (m^2.°C/W)	0.88	0.00	0.00
Window R value (m^2.°C/W)	0.50	0.35	0.19
Door R value (m^2.°C/W)	0.88	0.88	0.88
Infiltration rate (ACH)	0.33	0.50	1.00

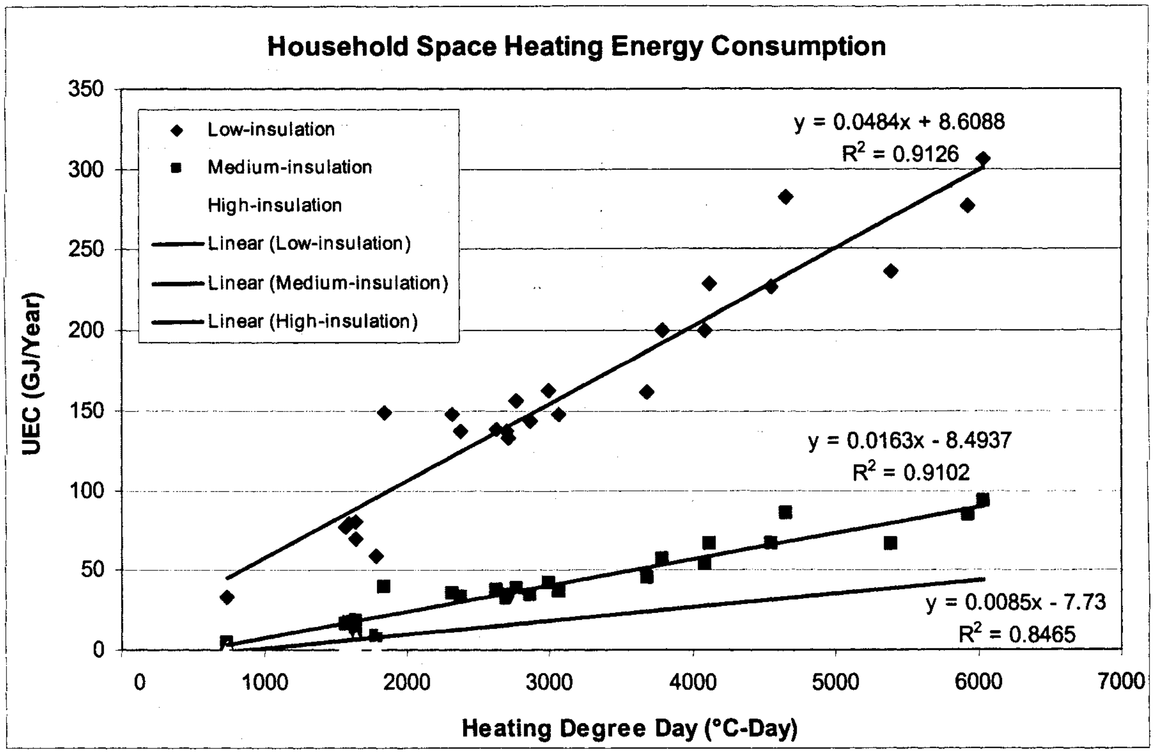

Figure C.1: Linear plot of household space heating energy consumption versus heating degree-day

Appendix D

Provincial electricity generation and greenhouse gas emission factors

Table D.1: Electricity Generation in Newfoundland in 1993 and GHG Emission Factors

Newfoundland 1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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 D.2: Electricity Generation in Prince Edward Island in 1993 and GHG Emission Factors

Prince Edward Island 1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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 D.3: Electricity Generation in Nova Scotia in 1993 and GHG Emission Factors

Nova Scotia 1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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 D.4: Electricity Generation in New Brunswick in 1993 and GHG Emission Factors

New Brunswick1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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	1.878 t/ML	0.0000048 t/ML	0.00002 t/ML
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 D.5: Electricity Generation in Quebec in 1993 and GHG Emission Factors

Quebec1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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	1.878 t/ML	0.0000048 t/ML	0.00002 t/ML
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 D.6: Electricity Generation in Ontario in 1993 and GHG Emission Factors

Ontario 1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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	1,131,405 ML	1.878 t/ML	0.0000048 t/ML	0.00002 t/ML
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 D.7: Electricity Generation in Manitoba in 1993 and GHG Emission Factors

Manitoba1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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	451 ML	1.878 t/ML	0.0000048 t/ML	0.00002 t/ML
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 D.8: Electricity Generation in Saskatchewan in 1993 and GHG Emission Factors

Saskatchewan1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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	155,405 ML	1.878 t/ML	0.0000048 t/ML	0.00002 t/ML
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 D.9: Electricity Generation in Alberta in 1993 and GHG Emission Factors

Alberta1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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	1,176,756 ML	1.878 t/ML	0.0000048 t/ML	0.00002 t/ML
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 D.10: Electricity Generation in British Columbia in 1993 and GHG Emission Factors

British Columbia 1993			Emission Factor		
Energy Source	Electricity Generated (GWh) (1)	Fuel Input (1)	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	880,428 ML	1.878 t/ML	0.0000048 t/ML	0.00002 t/ML
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 D.11: GHG Emission in Newfoundland from Electricity Production, 1993

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 D.12: GHG Emission in Prince Edward Island from Electricity Production, 1993

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 D.13: GHG Emission in Nova Scotia from Electricity Production, 1993

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 D.14: GHG Emission in New Brunswick from Electricity Production, 1993

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 D.15: GHG Emission in Quebec from Electricity Production, 1993

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 D.16: GHG Emission in Ontario from Electricity Production, 1993

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 D.17: GHG Emission in Manitoba from Electricity Production, 1993

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 D.18: GHG Emission in Saskatchewan from Electricity Production, 1993

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 D.19: GHG Emission in Alberta from Electricity Production, 1993

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 D.20: GHG Emission in British Columbia from Electricity Production, 1993

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