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A life cycle assessment model of Canadian residential dwellings and building stocks

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A LIFE CYCLE ASSESSMENT MODEL OF CANADIAN RESIDENTIAL DWELLINGS AND BUILDING STOCKS

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Abstract

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Life Cycle Assessment (LCA) is an internationally recognized and scientifically based methodology to quantify the environmental impact of a product or service, typically from cradle-to-grave. The life cycle performance of housing is influenced by the interdependent nature of material and energy use, and dwelling location and service life. While much research has been conducted building LCA, its incorporation into regulation has been difficult to implement. This research outlines the methodology used to create an LCA database of new Canadian construction for the purpose of building stock modeling and benchmarking national construction practice, two key tools for higher level decision making. A software program has been developed to handle data storage and calculations. Results presented include general performance trends at various sector scales, an analysis comparing LCA to traditional environmental performance measurement, and sensitivity analysis of [1] building material and operating energy fuel choice and [2] energy efficiency measures.

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Finally, I would like to dedicate this work to my parents and Angela Coole for all their love and support the past couple years.

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List of Abbreviations

AB	Alberta
ACH	Air Changes Per Hour
AL	Appliances and Lighting
BC	British Columbia
BOM	Bill of Materials
CCEUD	NRCan Canadian Comprehensive Energy Use Database Tables
CMHC	Canada Mortgage and Housing Corporation
DHW	Domestic Hot Water
GJ	Gigajoules (10^9 J)
GWP	Global Warming Potential (kg CO_2 eq.)
HDD	Heating Degree Day (degree days below 18ºC)
HRV	Heat Recovery Ventilator
kg CFC-11 eq.	Kilograms of Chlorofluorocarbon – 11 Equivalent
kg CO_2 eq.	Kilograms of Carbon Dioxide Equivalent
kg N eq.	Kilograms of Nitrogen Equivalent
kg NO_x eq.	Kilograms of Nitrogen Oxides Equivalent
kg PM2.5 eq.	Kilograms of Particulate Matter (< 2.5 microns) Equivalent
kWh	Kilowatt Hour (3.6×10^6 J)
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LPG	Liquefied Petroleum Gas (liquid propane gas)
MB	Manitoba
MJ	Megajoules (10^6 J)

List of Abbreviations (cont.)

moles H+ eq.	Moles of Hydrogen Ions Equivalent
Mt	Megatonne (10^9 kg)
NB	New Brunswick
NL	Newfoundland
NRCan	Natural Resources Canada
NRPE	Non-renewable Primary Energy Use (J)
NS	Nova Scotia
OBC	Ontario Building Code
ON	Ontario
PCEUD	NRCan Provincial Comprehensive Energy Use Database Tables
PE	Prince Edward Island
PJ	Petajoules (10^{15} J)
QC	Quebec
RAMC	Residential Archetype Materials Calculator
RPE	Renewable Primary Energy Use (J)
RSI	Thermal Resistance (SI unit) (m^2K/W)
SC	Space Cooling
SE	Secondary Energy Use (J)
SH	Space Heating
SHEU	NRCan Survey of Household Energy Use
SK	Saskatchewan
t	Tonne (10^3 kg)
TPE	Total Primary Energy (J)

1.0 INTRODUCTION

Since the oil crises of the 1970's there has been a growing awareness of the residential sector's significant use of natural resources and impact on the environment. Regulation has helped improve the environmental performance of housing through changes to building codes, energy efficiency programs and standards, and government subsidies. These initiatives have thus far focused exclusively on the reduction of secondary energy use (SE). More recently, voluntary green building rating systems such as LEED for Homes [1] have been introduced. These standards take a more complete approach by addressing additional aspects such as site effects, indoor air quality, and water and material use. While both energy related regulation and green building rating systems aim to reduce environmental effects, neither require significant or accurate quantification of actual environmental impacts.

Building stock modeling is a tool available to policymakers to make informed decisions about regulation. There are many models that have been developed to characterize national existing stock SE, some that also calculate associated global warming potential emissions (GWP) [2]. According to this type of analysis the Canadian residential sector in 2007 consumed 1447 PJ of SE, accounting for 16% [3] of total SE. The associated GWP at building site and electricity generation plants were 74.3 Mt [3], or 10% of total emissions [4]. While SE and associated GWP are responsible for a significant share of energy use and emissions within Canada, analysis with this system boundary can provide misleading conclusions about the sector as it does not account for upstream effects of energy production, the effects of constructing, maintaining, and disposing of dwellings, nor does it account for transportation-related energy use. Kohler et al. [5] concluded that future modeling should evolve to incorporate environmental, economic and societal implications of the built environment. One of the steps towards this goal is conducting building stock modeling according to life cycle assessment (LCA) methodology.

LCA is a methodology to quantify the environmental impact of a product or service typically from "cradle-to-grave", meaning that mass and energy flows to and from nature are quantified throughout the service life. LCA is a scientifically based, internationally recognized methodology, described by ISO standards 14040/44 [6,7]. This standardization provides credibility and a degree of predictability when reviewing or comparing studies. LCA provides the following improvements to typical energy end-use modeling:

- LCA quantifies environmental impacts and resource use in numerical terms; calculation of SE use is an intermediate step in this process;
- LCA considers not only service end-uses (operating energy consumption) but also product end-uses (embodied effects of dwellings). The relationship between material and energy use is therefore inherently considered;
- By considering all dwelling life cycle stages, more effects initiated by end-uses are captured. Decision makers therefore gain insight into how buildings influence other sectors (e.g. transportation, mining, energy and material production);
- The model provides a more rigorous environmental assessment since many building sector related impacts are dominated by material use;
- An environmental life cycle framework facilitates expansion of analysis scope to include life cycle costing (LCC) and social LCA.

Life cycle energy consumption and environmental performance of housing is a function of building-defined inputs such as material and fuel choice, and location and geometry. Performance can equally be influence by LCA practice, including choice of system boundary, life cycle inventory data sources and energy simulation software. While past research (see Section 2.2) has identified many key concepts and performance trends, performance is influenced by too many parameters to generally provide accurate conclusions beyond a particular study's scope. This disconnect between research and practice is further complicated by the intensive data and computational requirements which make dwelling analysis typically of limited scope. One of the inherent requirements of conducting LCA building stock modeling is a more extensive scope within a consistent methodological framework. This allows for analysis of national performance trends that can be relayed to building stakeholders. Another inherent requirement is that LCA performance of existing and/or current building practice is characterized according to statistical data. Benchmarking is a central step in the integration of whole building LCA into building codes, energy efficiency programs and green building rating systems such as LEED [8].

1.1 Problem Statement

Problem

For the building sector, higher level decision making with LCA has been difficult to implement due its interdisciplinary nature and intensive data and calculation requirements.

This thesis work outlines frameworks to conduct batch assessment of dwellings and building stock modeling according to LCA. The frameworks provide a means to break the barriers that currently exist between LCA practice and higher level decision making such as building code or green building standard development, urban planning, or policy writing.

1.2 Goals and Objectives

The goal of this work is to further research on LCA of Canadian housing and illustrate that it can be used to make higher level building sector decisions. The research purpose is not necessarily to make accurate predictions for the residential sector; rather, it is meant to provide new insights as to the impact of residential construction and the degree to which designers and policy makers can improve performance within current technological, manufacturing, and energy supply constraints. The objectives of this research are to:

1) Develop frameworks to conduct batch LCA of housing and bottom-up LCA building stock modeling;
2) Characterize new Canadian residential construction based on statistical data and building regulation (i.e. benchmark), and perform whole dwelling and building stock analysis;

3) Expand the scope of available LCA data to include the embodied effects of (i) other envelope assemblies (ii) electrical, plumbing, HVAC, and domestic hot water (DHW) systems, and the effects of wood combustion;
4) Develop a software program to facilitate batch dwelling and building stock LCA;
5) Explore the sensitivity of Baseline case dwellings and building stock with respect to (i) building material and operating fuel choice and (ii) energy efficient design initiatives.

Building stock modeling according to LCA methodology incorporates material usage into the established energy end-use modeling framework. This requires statistical analysis of Canadian construction practice and household energy use, the quantification of energy usage via simulation, and calculation of material quantities for archetype dwellings. The resulting database of dwelling information is aggregated in such a way to describe a building stock, or can be analyzed at the dwelling scale. The database of LCA data assembled is to be of sufficient breadth to cover the materials and fuels considered in research. For items currently not available in an LCA database, data is generated by modeling the process chain of the product or service throughout its life cycle, typically with proprietary LCA software. Sensitivity analysis of material and fuel choice is assessed by quantifying the effects of changes to design parameters. A literature and statistical review of available energy efficiency measures allows for an analysis of how these parameters influence dwelling and building stock performance.

1.3 Hypothesis

By illustrating the interdependent relationship between material and energy use, the significance of embodied and energy pre-combustion effects, and the sensitivity of results, it is expected that building stock modeling according to LCA methodology will prove to be a significant and appropriate improvement to the practice of end-use energy modeling. Benchmarking Canadian construction is expected to highlight the performance variation that exists in Canada and the reasons why.

1.4 Thesis Organization

Section 2 provides background information for the content of the research work. This includes a description of life cycle assessment methodology, past research highlights of residential dwelling LCA, energy end-use building stock modeling, and LCA building stock modeling. Wherever possible, background information presented is Canadian in scope. This was done in order to keep all information relative to the scope of this research. The aim of this section is to provide readers a rudimentary understanding of LCA, its applications in the residential sector, general performance characteristics, and conclusions that have been drawn from previous work.

Section 3 outlines the research scope, data sources, and introduces the database of dwelling LCA and how it is structured. These definitions are critical to understanding the research method and data presented in Section 4. The methodology describes data decisions for the database parameters location, archetype, material/fuel use, and energy design. Following that is an explanation of other important model characteristics such as LCA data, energy simulation assumptions, and construction forecast.

Section 5 presents Res-BEAT, the software developed to store the housing database and calculate and present results. Its structure and modeling capacity are explained. Sample output from the program is given in Section 6 according to the research objectives. Results include analysis at both the whole dwelling, provincial, and national scales. Section 6.2 presents the Baseline or "business as usual" case and then Sections 6.3 though 6.5 show the degree to which changes in material and fuel use, and operating energy efficiency influence results.

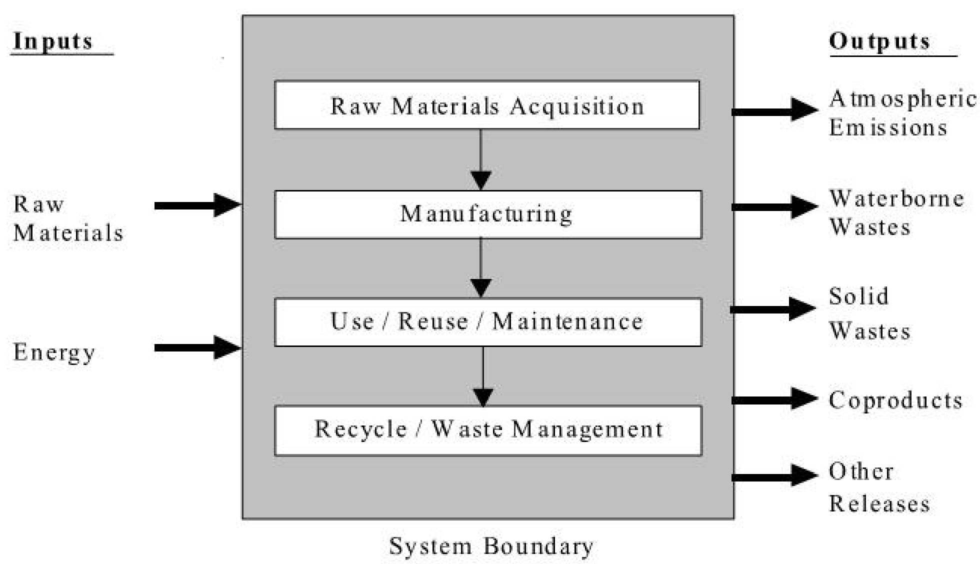
Section 7 provides additional commentary on the research topic and results, model limitations, and future work. Finally, a summary of research conclusions are presented in Section 8.

2.0 BACKGROUND

2.1 Life Cycle Assessment

Life cycle assessment is typically a “cradle-to-grave” approach for quantifying and interpreting environmental impacts associated with product and/or service systems. “Cradle-to-grave” refers to all industrial processes beginning with the raw resources harvested from earth and ending with materials returned to it. In quantifying the effects associated with each stage of the life cycle, LCA provides a comprehensive estimation of the cumulative environmental effects initiated by an end-use. Figure 2.1 shows the basis of an assessment. LCA is the process of quantifying an inventory of energy and resource inputs, as well as air, water, land emissions and other outputs within a system boundary for each stage of the life cycle. An environmental assessment is then evaluated based on these flows to and from nature. Inventory flows are quantified in terms of actual mass and energy balance relationships (i.e. the conservation of energy and mass) and impact assessment is evaluated with methodologies developed by scientific consensus. It can therefore be said that LCA aims to provide objective,

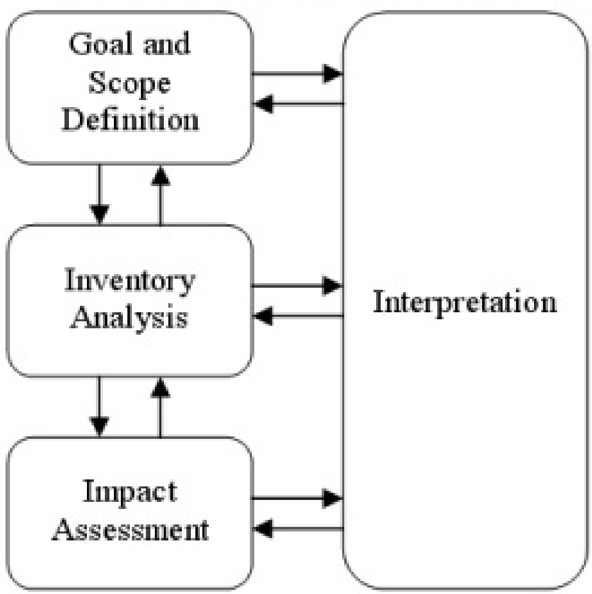
Figure 2.1: Life Cycle Stages [8]



scientifically based conclusions. Furthermore, burden-shifting to other parts of the product life cycle or other impacts of concern is avoided due to the breadth of analysis.

Current applications of LCA include product development and improvement, strategic planning, public policy making, and marketing. Although life cycle principles were used to calculate energy flows and resource use as early as the 1960's the methodological framework for conducting LCA wasn't formalized until the 1990's. Beginning in 1997, the International Organization for Standardization (ISO) began publishing LCA standards. A second edition of the standards was published in 2006 which includes ISO 14040, *Environmental Management - Life-cycle Assessment - Principles and Framework* [6], and ISO 14044, *Environmental Management - Life-cycle Assessment - Requirements and Guidelines* [7]. This standardization provides credibility to the methodology as studies are conducted in a consistent manner.

Figure 2.2: The Four Stages of Life Cycle Assessment [5]



2.1.1 ISO 14040/14044

ISO 14040 outlines LCA practice and its applications and ISO 14044 describes in detail the requirements for conducting an assessment. As illustrated in Figure 2.2, life cycle assessment according to ISO 14040/14044 standards is a four-stage iterative process consisting of goal and scope definition, inventory analysis, impact assessment, and interpretation. Conducting an LCA is not a linear process; each stage of a study may need to be revised several times before completion.

2.1.2 Goal and Scope Definition

The goal and scope definition stage outlines the purpose and methodology of the assessment. Goal defining includes stating the reasons for carrying out a study, its intended application and audience and whether results are to be used in comparative assertions disclosed to the public. There are many study scope items that need to be described so that it is clear what is being studied, how data is collected and manipulated and what measures are to be taken in order to ensure confidence in the study's conclusions and recommendations. Some important scope items related to inventory analysis to be defined include:

- **Functional unit:** the basis of comparison which can include a description of a product or service's function, performance quality and duration, physical or spatial concerns.
- **Reference flow:** relates the input and output relationships for processes in the product system to the functional unit.
- **System boundary:** the extent of processes included in scope, consistent with the goal of the study. The product system is evaluated based on mass, energy, or environmental significance cut-off criteria.
- **Allocation procedures:** the criteria by which inventory flows of a process or product system are partitioned between the system boundary and one or more other product systems. Allocation can either be avoided, based on physical relationships, or other relationships such as economic value.
- **Data quality requirements:** the characteristics of the data needed to produce credible study results. Data descriptions include age, geographical coverage, technology coverage, precision, completeness, representativeness, consistency, reproducibility, source of data and uncertainty.

The goal and scope definition stage details the methodology for impact assessment and what interpretation is to be conducted. Other study procedures such as assumptions, limitations, report format, and critical review (if any) are also explained.

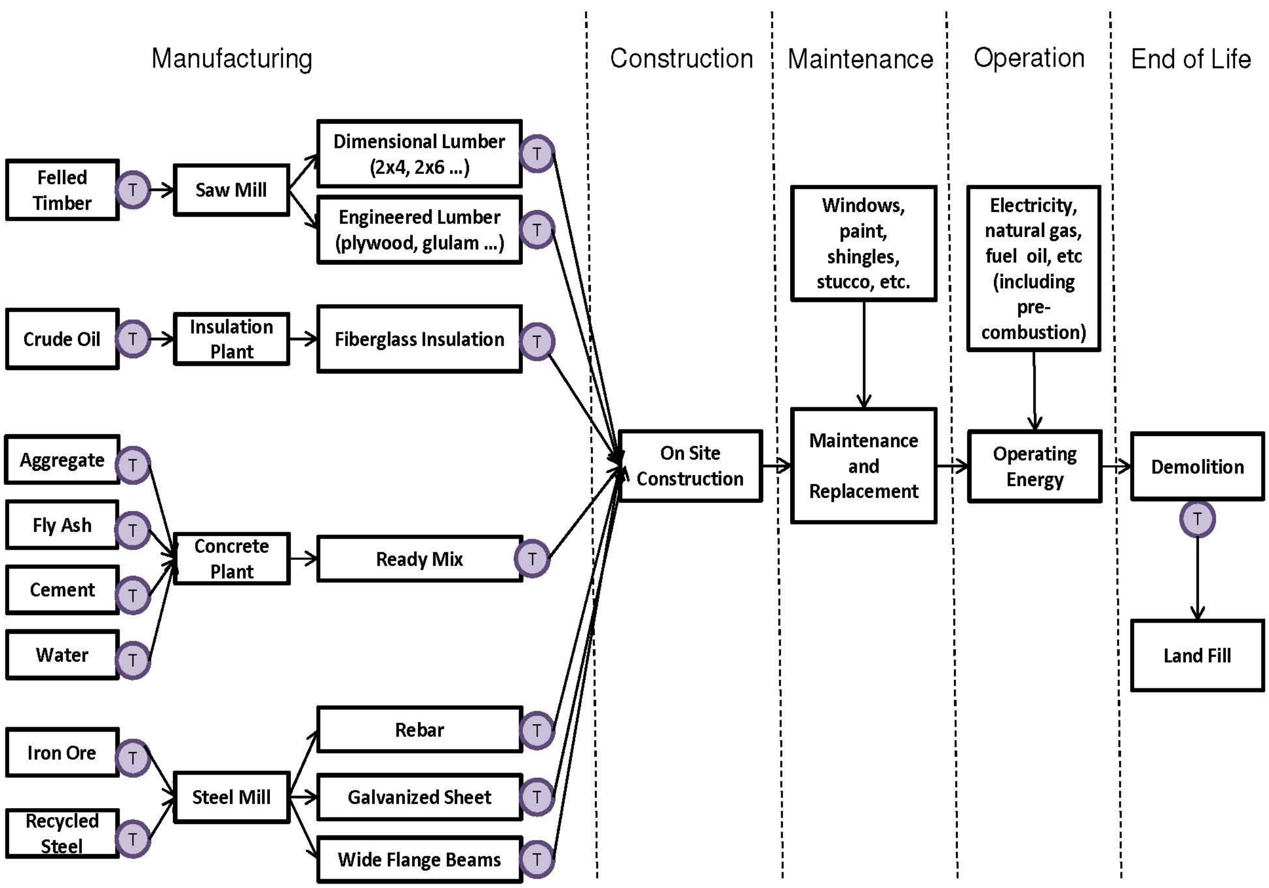
2.1.3 Inventory Analysis

The inventory analysis stage is where inventory flow data is collected and reported for each activity in the process chain (i.e. system boundary). Data is related to the functional unit and assessed based on the data requirements and procedures established in the goal and scope definition stage. One of the first steps of inventory analysis is typically to develop a detailed system flow diagram for the system studied. This not only identifies all the various processes involved in the products system, but also the relationship between them. A simplified diagram for a residential dwelling is presented in Figure 2.3, by life cycle stage. Data collection takes place at the unit process scale, defined as the smallest element considered in the life cycle inventory analysis for which input and output data are quantified. Examples of a unit process could be iron ore mining, ore transportation, steel smelting, etc. At this scale inventory flows are noted, including energy and material/product inputs, outputs to earth in the form of emissions to air, water, and land, and finished or intermediate products. When this has been completed for each unit process in the system boundary, results are validated and computed in relation to the reference flow of the functional unit. The resulting life cycle inventory (LCI) is a list of inputs and outputs to and from nature expressed in physical units such as mass, volume, joules, etc. LCI data can be organized according to process, process group or life cycle stage and further classified according to type of flow (e.g. energy vs. material input, emission to land vs. air).

2.1.4 Impact Assessment

The life cycle impact assessment (LCIA) stage involves evaluating environmental impacts from the LCI results. This first step is the selection of impact indicators and the assessment methodologies to be used in the study. The LCI data is then grouped (classified) among the various impacts and converted (characterized) to the common unit of each indicator. Characterization factors are applied to each inventory flow in order to relate the degree to which each flow contributes to the impact indicator. For example, global warming potential (GWP) is generally calculated on a mass of carbon dioxide (CO_2) equivalent basis. The characterization factor for CO_2 is therefore 1, whereas other greenhouse gas emissions contribute more or less to GWP per unit mass compared to CO_2. For example, on a 100 year time scale methane is 25 times as powerful an emission compared to CO_2 and its characterization factor is 25. Adding all characterized emissions gives the final impact result. Optional assessment procedures include normalization, grouping, weighting, and data quality analysis. These elements are generally meant to give more insight as to the relevance of the impact results.

Figure 2.3: Simplified Process Diagram for a Typical Residential Dwelling [10]



2.1.5 Interpretation

The objective of the interpretation stage is to provide credible and transparent conclusions and recommendations in accordance with the stated goals and scope. The ISO standard outlines a systematic process to analyze LCI and LCIA data in order to assess the quality and characteristics of the results. The first step is to review stages 1 through 3 in order to identify what elements contribute most to each product, service, or other process in the system boundary. This process is known as identifying “significant issues”. In order to facilitate analysis, the practitioner may employ several techniques to identify significant issues, including contribution analysis, dominance analysis, or anomaly assessment.

In the second step, the reliability and confidence in the data is assessed by checking its completeness, sensitivity, and consistency. The completeness check ensures that all data relevant for interpretation has been included and is typically assessed with a checklist of processes included in the LCI. The sensitivity check evaluates the reliability of the results by determining whether uncertainty in the significant issues identified allows conclusions to be drawn with confidence. Data quality techniques typically employed for this purpose includes contribution, uncertainty, and sensitivity analysis. Finally, the consistency check determines whether the study has been executed in a manner consistent with the goal and scope of the study for each process evaluated. If after completion of steps 1 and 2 it is determined that conclusions cannot be drawn with confidence, items in any of the first three stages of the study are revised and steps 1 and 2 are repeated. The final step of interpretation is to report study conclusions and provide recommendations in accordance with the defined goals. This might include an analysis of which product contributes least to specific human health and environmental impacts or the trade-offs associated with design decisions.

2.2 Residential Dwelling LCA

In the past fifteen years there has been a wealth of research conducted on LCA of residential dwellings, particularly single detached dwellings (SDDs) [11-21]. Assessments vary in terms of methodological considerations and data sources, yet a literature review of studies by Ramesh et al. [22] reveals that in cold climates primary energy consumption of conventional housing varies between 150-400 kWh/m^2/yr, 80-90% of which is related to building operational energy use. The remaining 10-20% is related to the other building activities such as material production and transport as well and construction and demolition. For the purpose of this thesis, these effects are called “embodied” effects.

As previously noted, there are many parameters that influence the environmental performance of residential dwellings. As such, an attempt has been made to isolate the following and discuss their significance individually: (i) geographic location, (ii) operating systems, (iii) building materials and (iv) energy efficiency initiatives.

2.2.1 Effect of Geographic Location

Two dwelling geographic location-related parameters that significantly influence dwelling life cycle effects are climate and upstream energy effects. Since the operating energy stage typically dominates life cycle primary energy consumption and greenhouse gas emissions, the degree to which a home needs to be heated and cooled is an important consideration. For example, Adalberth [23] compared life cycle energy use of three single detached dwellings (SSDs) in Sweden (Stockholm, 4,589 HDD [24]) with 50 year service life, and concluded that the operating energy stage generally accounted for 85% of total energy use. In contrast, Mithraratne et al. [25] compared three SDDs in New Zealand (Auckland, 1,166 HDD [26]) with 100 year service and concluded that operating energy accounted for 57% to 74% of total energy use. So despite the fact that the dwelling service life of [23] was twice that of [25], the percent operating effects was still lower due to in part to New Zealand’s climate. Canada is considered to have a cold climate but there is a large variation in heating degree days (HDD) with location. According to HOT2000 [24] energy simulation analysis if a 200m^2 SDD in Winnipeg (5,900 HDD) consumes 2,973m^3 of natural gas for space heating (SH), the equivalent home will use 2,264m^3 in Ottawa (4,600 HDD), and 1,297m^3 in Vancouver (2,925 HDD). In this case Ottawa and Vancouver consume 24% and 56% less SH energy, respectively, which can have considerable effect on life cycle impacts.

Dwelling location can dramatically affect the upstream effects associated with SE consumption. In the case of natural gas, the pipe system a dwelling draws from will determine the likely location(s) where it was produced and the distance it traveled to reach the user. Similarly, dwelling location influences from what refinery heating oil is likely produced and how it is delivered. Perhaps the most dramatic difference in upstream effects is related to electricity use. Table 2.1 shows the electricity generation fuel use mixes and the associated greenhouse gas emission fuel combustion intensities for each Canadian province from [4]. Depending on what province a dwelling is located in, consuming a kWh of electricity results in very different fuel mixes combusted at power plants and varying transmission losses. The resulting provincial greenhouse gas emissions vary considerably, from 4 to 870 g CO_2 eq./kWh, for Quebec and Alberta, respectively. To put this difference in context, according to the NRCan's *Comprehensive Energy Use Database* (CEUD) [3] the average annual per household electricity use for

Table 2.1: Canadian Electricity Generation Fuel Mixes (%)[1]

Province	Coal	Refined Petroleum Products	Natural Gas	Nuclear	Hydro	Biomass	Other Renew-ables	Other	GHG Intensity (g/kWh)
BC	0.0	0.1	5.7	0.0	94.2	0.0	0.0	0.0	20
AB	82.0	0.1	12.3	0.0	3.9	0.0	1.5	0.2	870
SK	59.6	0.2	16.5	0.0	20.7	0.0	3.0	0.0	760
MB	1.0	0.0	0.1	0.0	97.9	0.0	1.0	0.0	10
ON	17.1	0.0	6.1	53.9	22.6	0.0	0.3	0.0	180
QC	0.0	0.1	1.1	2.9	95.6	0.1	0.3	0.0	4
NB	17.9	19.0	13.1	25.0	21.2	0.0	0.0	3.8	390
NS	56.7	7.6	2.7	0.0	8.6	1.4	1.1	21.8	760
PE	0.0	14.3	0.0	0.0	0.0	0.0	85.7	0.0	180
NL	0.0	1.9	0.0	0.0	98.1	0.0	0.0	0.0	20

[1]percents add to 100% for each province

appliances and lighting (AL) in Canada in 2007 was 5,418kWh. This represents a difference of 4.7 tonnes of GWP emitted annually between a household in Quebec to one in Alberta. Variation in upstream effects for SE use also affects the industrial sector and hence the embodied effects of producing materials. Bowick et al [27] compared the embodied GWP of structural and envelope materials for an SDD dwelling in Montreal and Calgary and found the dwelling in Calgary embodied 52% more GWP.

A significant consideration for predicting future building life cycle impacts is the sensitivity of changes to electricity fuel mixes on impact. A British study [28] investigated the effect of a dynamic electricity generation model on the impact of a new semi-detached home. It found that an incremental reduction in electricity GWP intensity of 95% over 40 years (2010-2049) reduced dwelling operational effects by 50%.

2.2.2 Effect of Operating Energy Systems Choice

For any given dwelling the environmental impact of operating energy use is a function of equipment efficiency, occupant habits (i.e. consumption), and the type of fuels consumed. If fuel choice remains constant there is a direct relationship between equipment efficiency, occupant habits, and impact. For example, if a natural gas furnace with 85% AFUE is replaced with one with 90% AFUE, one can expect that SH emissions will be reduced by 5.6% (neglecting embodied effects). Similarly, if an occupant reduces the heating set point of their home, the reduction in emissions is proportional to the fuel use reduction. As noted in Section 2.2.1 dwelling location has a significant influence on the effect of energy use, particularly electricity consumption. The environmental profiles of differently fuelled appliances therefore cannot be compared based solely on efficiency ratings.

Bowick et al. [27] investigated the effects of changes to SH and DHW systems for a dwelling in Montreal, Toronto, and Calgary. An SDD was designed with both “standard” and “high” performance characteristics which approximate local building code and R2000 standard performance [29], respectively. For each performance design, the SH and DHW were parametrically varied between natural gas and electric fuelled systems. The study found that despite a reduction in SE use of approximately 27% for the “high” performance design, the “standard” design was responsible for less GWP, depending on the fuel choice case. In Calgary the natural gas systems performed better than electric systems due to the high GWP intensity of electricity generation, whereas electric systems performed better than natural gas systems in Montreal due to the low GWP intensity of electricity generation. In Toronto the “high” performance design generally performed better regardless of fuel use case due to the balanced electricity generation mix. This research underscores the importance of choosing heating systems with regard to regional electricity generation mix.

Other studies from North America confirm these results. For instance, Yang et al. [30] compared the performance of electric and natural gas fuelled hot water and forced air systems for a SDD in Montreal. In this case both electric fuelled systems were responsible for fewer GWP than natural gas fuelled systems. Kikuchi et al. [31] evaluated the SE consumption and related GWP for a SDD in five Canadian cities. A condensing natural gas SH/DHW boiler system was compared to the same system with a ground source heat pump (GSHP) as the primary SH appliance. The study found that annual reductions in GWP for the GSHP case were in the order of 45% in Vancouver and Montreal (hydro dominated electricity), 23% in Toronto and Ottawa (balanced electricity mix), but increased by 3% in Calgary due to the coal dominated electricity mix. The influence of regional electricity mix was also investigated by Shah et al. [32] for three HVAC system combinations, in four American cities. The research found that an air-to-air heat pump performed best in Oregon where electricity is dominated by hydro-power, and a natural gas furnace/air-conditioner combination performed best in the other three locations where electricity generation is dominated by coal.

The embodied effects of electrical, plumbing, HVAC, and DHW systems are often left out of whole dwelling analysis due to lack of public primary data on manufacturing processes. Nevertheless, these effects, or elements of them, have been estimated in several studies [33][34]. The Canada Mortgage and Housing Corporation’s (CMHC) report *A Life Cycle Environmental Assessment Benchmark Study of Six CMHC EQuilibrium™ Housing Initiative Projects* [35] quantified the effects of service equipment components for various dwelling designs. The study found that “cradle-to-gate” (i.e. cradle to manufacturing plant gate) effects of these components were in the order of 7-13%, 7-11%, 9%, and 5-8% of embodied GWP, primary energy use, photochemical smog, and solid waste, respectively, for building code compliant SDDs in Sherbrooke, Ottawa, and Edmonton. Embodied GWP of the hot water and forced air SH systems (including distribution systems) studied by Yang et al. [30] were estimated to be in the order of 6-7%, and 3%, respectively. The embodied effects of household appliances are other items typically left of building analysis. An LCA study [36] of a refrigerator, dryer, washing machine, and a dishwasher found that these appliances together consumed 19.8 GJ in production. Assuming 15-year service lives, the embodied energy of these four appliances (including periodic replacement) would account for a notable share of effects over the service life of a dwelling.

2.2.3 Effect of Building Material Choice

Building material related life cycle effects are a function of the choice of materials, the dwelling service life, as well assembly choice (i.e. material quantity, design). Bowick et al. [27] assessed the effect of structural and envelope material choice for a SDD with 150mm stud wall construction. The intent was to estimate the degree to which material choice can influence impact when envelope thermal performance does not change. Changes in envelope thermal resistance due different cladding, roofing, structural materials etc. was therefore negated. Each assembly choice was parametrically varied and a best and worst case material combination determined. The study found that dwelling embodied GWP varied by a factor of three. Material substitution in low energy housing was also investigated by Thormak et al. [37]. The study found that by substituting envelope materials while maintaining thermal performance embodied energy, initially 40% of total energy use, could be reduced by 17%.

Dwelling service life and the durability of its assemblies determine the rate at which materials are maintained and/or replaced. Materials commonly replaced, including glazing, cladding, and roofing products, are typically emission intensive and can lead to a significant share of embodied impact. For instance, Happio et al. [38] determined the embodied impacts of an SDD with various building envelope choices and service lives. Maintenance effects for the cases considered were in the order of a 35% to 61% increase when going from a 60 to 160 year service life. A similar analysis [27] found that the embodied GWP of a dwelling increased by 25% when its service life was changed from 60 to 100 years.

Envelope design not only influences thermal performance, but also material choice and quantities. A life cycle analysis illustrates the degree to which these embodied effects can change for different design decision. An Athena study [39] assessed the life cycle implications of wall envelope improvements of a SDD located in Montreal, Toronto, and Calgary with (i) 2x6 stud walls (ii) double stud walls (iii) structural insulated panel (SIP) walls. A different set of envelope improvements was applied to each such that thermal resistance increased by 0.9-1.4 RSI for walls, 1.2-1.7 RSI for foundation walls, and 0.25 RSI for windows. The resulting additional material usage increased total dwelling embodied GWP, primary energy use, smog potential, and solid waste by 7–8%, 9–10%, 16–22%, and 4-5%, respectively. Another study by Pierquet et al. [40] researched a SDD in Springfield and Minneapolis with 12 wall assemblies of different structure and thermal performance (15.5-44.8 R-value). Assemblies included various stud walls (2x4, 2x6, I-joist), double stud wall, straw bale, cordwood, insulated concrete forms and autoclaved insulated concrete. The embodied energy of the wall assemblies was found to vary by a factor 2.6, influencing the total dwelling embodied energy by a factor of 1.3.

2.2.4 Effect of Energy Efficiency Initiatives

Due to the current impetus to reduce energy consumption in housing one of the more researched aspects of dwelling LCA is the relationship between embodied (i.e. material) and operating energy impacts. Energy reduction initiatives include passive strategies such as better performing building envelopes, and active strategies such as more energy efficient appliances and HVAC systems, and renewable/energy efficiency technologies such as photovoltaic arrays. Generally speaking, these activities require additional material inputs compared to traditional construction. The move towards low energy housing therefore has two effects: the embodied component increases with increased material use and a reduction in operating energy stage impact increases the percent embodied of total effects. This trend was confirmed by Satori et al. [41], who conducted a review of 60 published LCAs on housing of varying efficiency.

The CMHC Equilibrium initiative is a demonstration project showcasing net-zero buildings across Canada. The life cycle impacts of six of the CMHC EQuilibrium dwellings were assessed and compared to equivalent minimum 2006 Ontario Building Code (OBC) and R2000 compliant designs [35]. Of the four SDDs considered, changes in life cycle impacts between building code compliant and net-zero (or near net-zero) designs varied by impact indicator; over the first 20 years of predicted dwelling operation, the net-zero designs showed reductions of primary energy and GWP of 70-87% and 62-90%, respectively. For impact indicators that can be dominated by material use such as photochemical smog, ozone depletion, solid waste, and water use, impacts were found to generally increase, depending on location. This illustrates the trade-offs that can exist for increased material usage and the need to analyze more than a single indicator in order to gain a balanced perspective on the environmental performance of design choices. Between building code compliant and net-zero designs, the embodied GWP emissions increased between 31% and 80%, with much of it attributed to increases in insulation quantities, the type of insulation used, and renewable energy systems such as solar thermal and photovoltaic arrays.

Bowick et al. [27] assessed an SDD in Toronto with six designs of incrementally better SE ranging from 163 to 40 kWh/m^2/year. Improvements include better performing envelopes through increased air tightness and thermal resistance, higher efficiency HVAC equipment, lower hot water and AL electricity use, and renewable energy systems such as solar thermal and photovoltaic arrays. Between best and worst designs over a 60 year life cycle, operating energy GWP reduced by 421 tonnes and embodied GWP increased by 38 tonnes. It therefore is a worthy investment impact wise as each ton of embodied investment yields a reduction of 11 tonnes operating impact. In doing so, the percent embodied GWP increased from 11% to 44% of the total.

2.3 Energy End-Use Building Stock Modeling

Modeling energy use of the residential sector can be done with either top-down or bottom-up approaches, the choice of which depends on the type of information sought. Top-down models do not differentiate between end-uses; these models generally analyze energy consumption of the entire sector with respect to changes in economical and technological conditions. Bottom-up models quantify energy consumption at the end-use or dwelling scale and extrapolate the results to the building stock scale using weighting factors. Energy consumption can be assessed by various statistical means or by calculating energy directly by using engineering principles (e.g. building energy simulation). A review of typical modeling techniques is presented by Swan et al. [42]. Bottom-up engineered energy end-use models have the significant advantage of being able to assess various upgrade scenarios and therefore provide a good framework for the inclusion of LCA methodology. A review of some of the engineered models developed thus far is provided by Kavgic et al. [2].

The first bottom-up model in Canada was developed in the late 1990's at the Canadian Residential Energy End-use Data Analysis Centre (CREEDAC) [43]. The Canadian Residential Energy End-use Model (CREEM) [44] characterizes the existing detached and attached housing stock with information from the NRCan's *1993 Household Survey of Energy Use* (SHEU) [45] and other database information on the Canadian housing stock. The resulting 8,767 house descriptions are simulated in a batch version of HOT2000; GWP associated with site fuel combustion and electricity generation are also calculated. CREEM has been used for various analyses of building stock upgrade scenarios. For example, Farahbakhsh et al. [44] analyzed the energy reduction of dwellings built after 1960 for various upgrade rates to R2000 and National Energy Code for Houses (NECH) standards. The study found that if 10 to 90% of the existing stock was retrofitted to R2000 and NECH standards total sector energy consumption would be reduced by 1-13% and 1-11%, respectively. Similarly, CREEM analysis by Guler et al. [46] included various retrofitting scenarios (e.g. increased wall insulation) for the reduction of SE use and GWP.

Another Canadian model is currently in development. The Canadian Hybrid Residential End-use Energy and Emissions Model (CHREM) is a hybrid bottom-up model that uses both statistical and engineering techniques [47]. Unit energy consumption for appliances, lighting and hot water use are determined from a calibrated neural network technique and then simulated along with SH and cooling using the software ESP-r. Model dwelling characteristics are from to the Canadian Single Detached and

Double/Row Housing Database (CSDDRD), a database consisting of 17,000 house descriptions representative of the Canadian housing stock. The CSDDRD is a subset of the EnerGuide for Homes database consisting of data for over 200,000 energy audits.

2.4 LCA Building Stock Modeling

The CMHC report *Life-cycle Environmental Impacts of the Canadian Residential Sector* [48] estimates impacts related to Canadian residential housing, infrastructure, and transportation for the period 2004-2025. This report is the only work in Canada on the life cycle impacts of the residential sector. National dwelling energy consumption was calculated according to a bottom-up approach assuming existing dwellings undergo renovation/retrofitting activities and efficiency improvements. New dwellings were assessed based on the latest energy use data available, with adjustments made to account for current construction trends. The report estimates that new construction for the period 2004- 2025 will represent 25% of the Canadian housing stock. Building material usage was estimated only for new construction from a single archetype for each dwelling type. Energy and material (i.e. operational and embodied) related impacts were calculated based on national average LCA profiles. The results therefore do not take into account regionalized manufacturing practices and differences in provincial electricity generation mixes with respect to dwelling distribution. The report concluded that 75%-95% of housing impacts were related to the operating energy stage during the study period.

The study classifies housing according to both dwelling and neighborhood type. It was found that single detached dwellings contributed significantly more to life cycle emissions, approximately 1.3 times that of semi-detached/row housing, and twice that of low and high-rise apartments and condominiums. Similarly, it was found that dwellings in outer suburbs on average accounted for 25% more emissions than inner suburbs and 50% more than inner city neighborhoods. This was attributed to differences in transportation habits and distances, as well as dwelling type distribution (i.e. more detached dwellings).

A bottom-up LCA of the European Union (EU) building stock was prepared for the European Commission's Integrated Product Policy framework [49]. The objective of the report was to estimate impacts of residential buildings in the EU-25, identify improvement options, and analyze the environment benefits and costs. Buildings in the EU were characterized by 72 archetypes representing 80% of the European stock. Archetypes were classified by single-family, multi-family and high-rise dwelling types and by southern, middle, and northern European climatic zones. The study found that newer dwellings generally performed better and northern zone buildings are responsible for more impact (per dwelling) due to climate. The use stage was identified as the dominant cause of emissions due to SH needs, whereas the construction stage (i.e. cradle to gate embodied effects) was more important in new dwellings. Use stage impacts were broken down by building element in order to assess potential improvement options. For existing dwellings, improvement options identified were replacement of windows, additional roof insulation, additional façade insulation, and new sealings to reduce ventilation. For new dwellings, substitution of conventional building materials with wood was identified as an effective construction stage emission reduction strategy. The study concluded that the proposed improvements could reduce GWP by 30-50% over a 40 year period.

3.0 RESEARCH SCOPE

3.1 Functional Unit and System Boundary

The research functional unit is the housing of inhabitants in a conditioned dwelling(s) along with plumbing and electrical services. The scope includes new Canadian detached, semi-detached and row housing. Based on CMHC housing completion data [50], these dwelling types represent 73% of Canadian residential construction over the period 1999-2009. While multi-unit residential buildings represent a significant share of dwelling completions, their construction is different from standard detached/attached housing in terms of building assemblies and HVAC systems and have therefore not been considered. The service life of dwellings is assumed to be 60 years. The product system encompasses the life cycle effects of all structural, envelope, interior finish, plumbing/electrical and HVAC materials, as well as annual operating energy use by application (SH, space cooling (SC), DHW, and AL). Manufacturing practice and energy supply characteristics (including electricity generation mix) are assumed to be static over the service life.

Items left out of the research scope include the embodied effects of floor finishes, furniture, electrical and plumbing fixtures, millwork and household appliances. Also not considered are renewable energy systems (e.g. photovoltaic arrays, solar thermal systems), household water use (with the exception of energy use for hot water), and household solid waste.

A brief description of each life cycle stage considered and their scope follows**:**

- **Manufacturing:** primary resource harvesting and mining, manufacturing of materials into products, and transportation effects related to these activities.
- **Construction:** transportation of finished products to site, and site related energy use and solid waste.
- **Maintenance and replacement:** all manufacturing, construction, and end of life impacts related to replacing and maintaining dwelling assemblies during its operation. Also known as “recurring embodied effects”.

- **Operating energy:** impacts associated with energy end-uses of dwelling operation. This includes SH, SC, DHW, and AL.

  End of life: dwelling demolition energy use and solid waste, and transportation of waste to land fill. Effects of material reuse, recycling, and land filling not considered.

For the purpose of this report, environmental effects originating from the manufacturing, construction, maintenance and replacement, and end of life stages are called "embodied effects". Since the operating energy stage dominates total primary energy and GWP impacts, these effects have been typically further disaggregated into the constituent end-uses noted above.

3.2 LCA Data Sources

The Athena Sustainable Materials Institute is a not-for-profit organization that has developed LCA databases and software, and consulted on various projects for two decades. The primary source of LCA data for the research is derived from the Institute's Environmental Impact Estimator (EIE) software database [51], which contains life cycle inventory (LCI) data for various building sector related materials and fuels. The data is periodically updated as it becomes available; currently, the oldest data is from 1996. The LCI data is characterized by the EIE to mid-point impacts indicators according to the Environmental Protection Agency's (EPA) *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts* (TRACI) [52], a common impact assessment methodology, particularly in North America. A description of some of the impact indicators considered is presented in the report Glossary. The EIE database also provides life cycle primary energy and resource use results.

The LCA data generally represents average effects associated with materials manufacturing or fuel combustion at the regional or national scale. For this reason, it can be argued that LCA is well suited for benchmarking construction performance and building stock modeling since they aim to assess average performance. The EIE database has data for approximately 95% of the structure, envelope, and finish materials considered in scope, and all fuels with the exception of wood combustion. Life cycle data for items currently not available in the EIE database were estimated as described in Section 4.6.

3.3 Dwelling Database

In order to perform the various analyses described, whole building LCA must be conducted on a scale beyond what is typically practiced. The information required for the research therefore was organized in a database. The database of whole dwelling LCA includes permutations of 36 cities, 29 dwelling archetypes, 3 material and fuel choices cases, and 6 energy efficiency design scenarios, totaling 18,792 assessments. Analysis can be conducted at the dwelling scale, or when dwellings are aggregated and weighted, at local, provincial or national building stock scales. The database has the capacity to quantify midpoint environmental impact indicators, non-renewable (NRPE) and renewable (RPE) primary energy use and resource consumption, as well as SE and building product use.

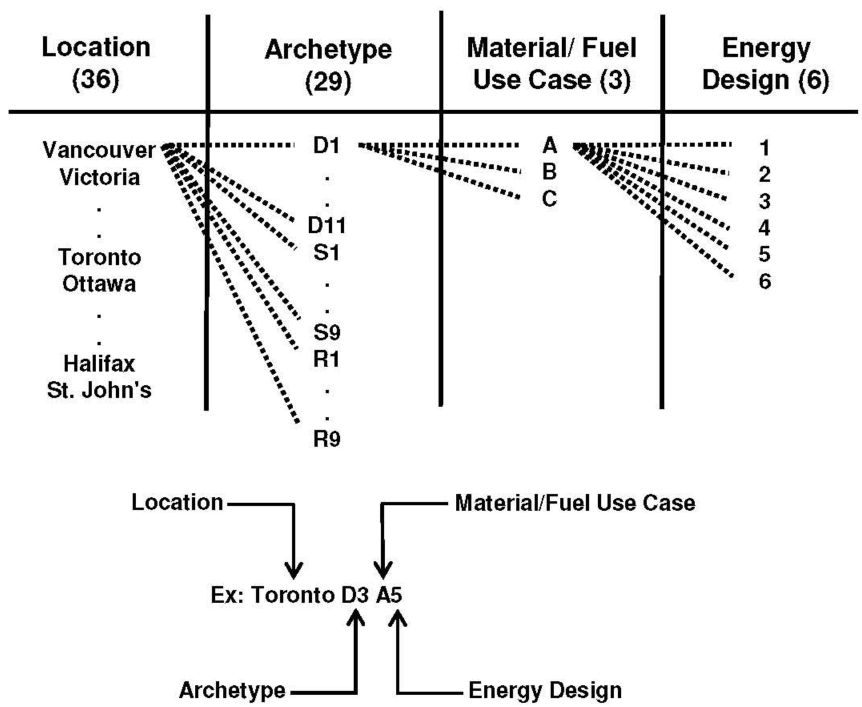
Figure 3.1 shows how the data is organized with four parameters that identify a dwelling's characteristics:

1) **Location:** identifies in which city a dwelling is located.
2) **Archetype**: identifies dwelling type with a letter (D for detached, S for semi-detached and R for row) and dwelling size with a number.
3) **Material/Fuel Use Case:** identifies the mix of building materials and operating fuels used. There are three material/fuel use "Cases". Case A represents the best case, Case B is the Baseline from statistical analysis, and Case C is the worst case material/fuel mix.
4) **Energy Design**: identifies dwelling energy performance, including envelope characteristics (e.g. insulation quantities), service equipment efficiencies and household energy use (e.g. lighting). There are 6 energy "Designs". Design 1 is the Baseline reflecting current OBC requirements and energy efficiency standards, and household energy use from statistical analysis. Design 6 is the best performing design assessed according to current advanced energy efficient

envelopes and equipment efficiency, and minimum household energy use. The performance of Designs 2 through 5 are linear variations of Designs 1 and 6.

For the purpose of this report, dwellings are labeled by location, archetype, followed by material/fuel case letter with energy performance deign number (e.g. Toronto D3 A5).

Figure 3.1: Database Structure



4.0 METHOD AND DATA

This section provides an outline of the methodology and assumptions used to compile the dwelling database (4.1 to 4.5), estimate a construction forecast for the purpose of building stock modeling (4.6), and generate additional LCA data (4.7).

4.1 Geographic Locations

The locations selected for inclusion in scope are meant to be characteristic of Canadian demographics and climate. Primary location selection is based on 2009 housing completion data for 59 urban areas [50]; these areas together accounted for 69% of detached, 83% of semi-detached, and 86% of row housing completions. An analysis of long-term climatic conditions was conducted for each location with Environment Canada climate normals data (averages based on climate stations with at least 15 years of data) [53]. Where two or more locations in the same province have similar climatic characteristics (i.e. HDD, latitude, etc.) only one was kept for inclusion. Generally speaking, HDD differences for cities omitted from scope are less than 100 with respect to their surrogate city. For example, Medicine Hat (4632 HDD, 49.6˚ latitude) was used as a surrogate for Lethbridge (4600 HDD, 50.0˚ latitude). The resulting 36 cities considered in scope are shown in Table 4.1, by province.

4.2 Dwelling Archetypes

An archetype for each dwelling type was developed in order to characterize average construction in Canada. Housing characteristics conform to the Canadian archetypes developed for the CMHC report on life cycle effects of the residential sector [48]. Each dwelling is a two storey, 3 bedroom dwelling with full basement and pitched roof. Detached dwellings have a two car garage, 2 bathrooms, a length-to-width ratio of 1.3, and load bearing line at mid-width. Semi-detached and row housing (i.e. attached housing) have a one car garage, 1.5 bathrooms, a length-to-width ratio of 2, and structure was assumed to span the width. Garages are assumed to have uninsulated 150mm walls with interior finishes.

Table 4.1: Database Locations

Province	City	Province	City
BC	Kamloops	ON	Kingston
	Kelowna		Kitchener
	Prince George		London
	Vancouver		Ottawa
	Victoria		Peterborough
AB	Calgary		Sarnia
	Edmonton		Sault Ste Marie
	Grand Prairie		Sudbury
	Medicine Hat		Thunder Bay
	Red Deer		Toronto
SK	Regina		Windsor
	Saskatoon	QC	Bagotville
MB	Winnipeg		Gatineau
NB	Moncton		Granby
NS	Halifax		Montréal
	Sydney		Québec
PE	Charlottetown		Sherbrooke
NL	St. John's		Trois Rivieres

The ground floor has a clear height of 3.05m and the basement and second floors have a clear height of 2.44m. Given the lack of statistical data on typical window-to-wall ratios, it was assumed that that the front and rear walls have a ratio of 0.3 (30%) and side walls 0.1 (10%). This generally conforms to NRCan's best practice guidelines of ±0.15 for total wall area [54]. Since there are no windows located on party walls, the window-to-exposed wall ratio is higher for semi-detached and row housing. Windows are assumed to be 50% fixed picture and 50% operable casement.

The household size (i.e. number of residents) for each dwelling type presented in Table 4.2 was assessed provincially according to 2006 census information from Statistics Canada [55]. The attached dwelling household sizes include apartment buildings of five or less storeys and are therefore likely an underestimate actual number of residents.

Table 4.2: Household Size (people/dwelling)

Province	Detached	Attached
BC	2.8	2.3
AB	2.9	2.0
SK	2.7	1.8
MB	2.8	2.0
ON	2.9	2.4
PQ	2.7	2.0
NB	2.6	2.0
NS	2.6	2.0
PE	2.7	1.9
NL	2.6	2.2

In order to characterize the size of dwellings currently constructed in Canada, each dwelling type was assessed provincially by isolating new construction floor areas from NRCan's *Provincial Comprehensive Energy Use Database* (PCEUD) Tables 16 and 17. To smooth out irregularities in the data, a five year average (2003-2007) dwelling size was considered. The resulting average above grade floor areas are presented in Table 4.3. Archetypes were developed according to the above assumptions in increments of $10m^2$ above grade floor area. Tables 4.4 and 4.5 show designations and footprint dimensions for the resulting 11 detached and 9 semi-detached/row archetypes. The ranges of housing size were selected in order to be inclusive of the average floor areas noted in Table 4.3 and to allow for building stock modeling that considers changes in dwelling size (future work). As shown in Table 4.3, each province was allotted the archetypes (1 per dwelling type) closest in size; these dwelling sizes are used for all research analysis unless otherwise noted.

Table 4.3: Average Above Grade Floor Areas and Research Archetypes

Province	Detached (m^2)	Semi-Detached and Row (m^2)	Detached Archetype	Semi-Detached and Row Archetype
BC	213	149	D7	S6/R6
AB	164	127	D2	S4/R4
SK	151	99	D1	S1/R1
MB	143	113	D1	S2/R2
ON	197	147	D6	S6/R6
QC	154	141	D1	S5/R5
NB	151	125	D1	S4/R4
NS	185	158	D5	S7/R7
PE	165	113	D3	S2/R2
NL	159	110	D2	S2/R2

Table 4.4: Attached Housing Archetype Dimensions

Archetype	Above Ground Floor Area (m^2)	Width (m)	Length (m)
S1/R1	100	4.88	10.25
S2/R2	110	5.10	10.77
S3/R3	120	5.33	11.25
S4/R4	130	5.56	11.69
S5/R5	140	5.79	12.09
S6/R6	150	6.02	12.46
S7/R7	160	6.25	12.80
S8/R8	170	6.48	13.12
S9/R9	180	6.71	13.42

Table 4.5: Detached Housing Archetype Dimensions

Archetype	Above Ground Floor Area (m^2)	Width (m)	Length (m)
D1	150	7.63	9.84
D2	160	7.84	10.21
D3	170	8.05	10.56
D4	180	8.27	10.89
D5	190	8.48	11.20
D6	200	8.69	11.50
D7	210	8.91	11.79
D8	220	9.12	12.06
D9	230	9.33	12.32
D10	240	9.55	12.57
D11	250	9.76	12.81

4.3 Material/Fuel Cases A, B, C

Three building material and operating fuel (i.e. SH and DHW system) use Cases are included in the research scope in order to estimate the degree to which these design choices affect life cycle greenhouse gas emissions at the dwelling and building stock scale. As previously noted, Case B is the Baseline assessed based on statistical data, whereas Cases A and C represent best- and worst-case scenarios, respectively.

4.3.1 Material Choice

The intent of the research is to create a model that provides conclusive and explainable results about the basic relationship between building material use (e.g. insulation level) and associated SE use. A couple assumptions were made about wall assemblies for this purpose. All above-grade walls are assumed to be single or double stud construction in order to (i) provide the 6 energy Designs a linearly increasing thermal resistance (see Section 4.4.1) and (ii) avoid discontinuities in results due to changes insulation type or systems. For database dwellings, in order to assess an incremental improvement to a wall assembly, either a single stud system is replaced with a double stud system or the double stud walls are placed further apart and insulation increased. Other wall systems, including structural insulated panel (SIP) and above grade concrete block wall were not considered as they do not conform to single/double stud construction. Foundation walls are similarly assumed to be insulated on the inside with varying insulation between inner stud wall and foundation wall. Other foundation wall systems such as insulated concrete form were therefore not considered.

All dwellings in the database are assumed to have any combination of:

- Concrete footings and slab on grade;
- 200mm cast-in-place concrete or concrete block foundation walls and 90mm interior stud walls;
- 150mm (nominal) or 2-90mm (double stud) above grade stud walls;
- 2 – 90mm party (i.e. shared) stud walls with cavity insulation and type X gypsum board for fire and sound proofing purposes;

- 250-300mm deep floor joists;
- Structural framing: sawn lumber, engineered lumber products, light gauge steel, structural steel (beams and columns only) and/or concrete block (basement columns only).
- Insulation in wall cavities and ceiling joists.

Each structural system was independently designed according to the OBC [56], national construction codes, and/or proprietary design literature. Structural design was carried out for each archetype; therefore, the effect of dwelling type and size (i.e. structural span) is accounted for.

As part of this research, a spreadsheet program named the *Residential Archetype Materials Calculator* (RAMC) was developed for the purpose of facilitating calculation of structural, envelope, and finishes bills of materials for each of the 29 archetypes and associated designs. RAMC relates geometric and structural information to detailed assembly quantities and allows for any combination of assembly choices to be proportioned by percent usage. This enables the user to input for example 50% brick veneer, 20% vinyl cladding, 15% wood siding and 15% fibreboard cladding in order to arrive at an "average" dwelling material use. The program also calculates other important information such as maintenance stage material quantities (by replacement period) and structural assembly areas for the purpose of construction stage impact calculations. A screenshot of RAMC is shown in Appendix C.

Service equipment quantities were estimated according to several sources. The various electrical wire gauges, number of receptacle and lighting boxes, and electrical resistance heater wattage requirements for each archetype were calculated using a spreadsheet program developed for the research by Professor Frank Bowick (Algonquin College, Ottawa) [57]. The spreadsheet estimates these quantities based on the geometrical layout of a dwelling and its appliance use. Copper water supply and ABS drain, waste and vent plumbing lengths were estimated based on a house survey conducted for the research by Grant Finlayson of the Athena Institute. Plumbing lengths for other dwelling sizes were scaled according to floor area. Plumbing lengths for radiant heating systems were calculated based the methodology presented in [58], and radiator weights were calculated by taking an average of material use from [30] and [32]. Total radiator weight was apportioned to the various archetypes based on floor area. Finally, ductwork for both forced air and radiant HVAC systems were estimated from material takeoffs noted in [32] and [33].

Case B: a detailed literature review found no public records on residential material use rates in Canada. Envelope and structural use rates for the benchmark case is based on survey data provided by the National Home Builder's Association [59] and consultation with building industry experts. The resulting envelope materials mix includes 9 cladding, 6 roofing, 4 insulation, and 4 window frame types. The Baseline assembly mix is shown in Table 4.6; structural items are not categorized by resulting materials mix but by design intent. This was done for two reasons: (i) it was deemed a more accurate method for building experts to weigh in on current construction practices and (ii) this reflects the way structure input is defined in RAMC.

Cases A and C: the life cycle GWP of each type of envelope and structural assembly considered in scope was quantified separately for a detached dwelling located in Toronto with a 60 year service life. The best- and worst-performing combinations of assemblies for each category (i.e. cladding, structure, roofing, etc.) were then noted. Case A dwellings were allotted all the best performing assemblies whereas Case C dwellings were allotted the poorest performing assemblies. The 60 year service life was chosen in order to account for maintenance stage effects of the various envelope assemblies considered. Previous research [27] indicates that despite changes in embodied GWP with location, best- and worst-case assembly mixes do not change. The material mixes presented in Table 4.7 are therefore the same for each province. Generally speaking, wood products perform best and precast concrete, structural steel, and light gauge steel products perform poorest. It should be noted that these results are only for the research functional units (detached and attached housing), and therefore do not necessarily apply to other situations.

Table 4.6: Case B Material/Assembly Use

Item	Material/Assembly	%	Item	Material/Assembly	%
Foundation Walls	cast in place concrete	79.6	Cladding	brick veneer	26.5
	concrete block	20.4		wood siding	10.6
Above-grade Walls	sawn lumber stud wall	92.3		vinyl siding	32.8
	engineered lumber stud wall	3.9		metal siding	4.1
	light gauge steel stud wall	3.8		natural stone	4.0
Partitions	sawn lumber stud wall	95.0		manufactured stone	4.8
	engineered lumber stud wall	0.7		fibre cement board	4.0
	light gauge steel stud wall	4.3		stucco	6.3
Joists	sawn lumber[1]	53.7		EIFS	7.1
	I-joists	43.3	Window Frame	aluminum	10.8
	light gauge steel	3.0		PVC, PVC clad wood	72.7
Beams - Lintels	sawn lumber[2]	61.0		fibreglass	5.3
	engineered lumber[3]	32.4		wood	11.2
	light gauge steel[3]	6.6	Roofing	concrete tile	1.2
Beams - Ground Floor	sawn lumber[2]	42.8		clay tile	1.5
	engineered lumber[3]	44.3		cedar shake/shingle	6.3
	structural steel	12.9		asphalt shingles	82.5
Beams - 2nd, 3rd Floor	sawn lumber[2]	45.5		slate	1.5
	engineered lumber[3]	45.4		metal roofing	7.1
	structural steel	9.1	Cavity Insulation	polyurethane	6.4
Columns - Above Grade	sawn lumber[2]	67.8		cellulose	5.9
	engineered lumber[3]	22.0		fibreglass batts	69.0
	structural steel	10.2		rockwool batts	18.7
Columns - Basement	sawn lumber[2]	46.9			
	engineered lumber[3]	15.5			
	structural steel	31.6			
	concrete block	6.0			

[1] I-joists where structurally required
[2] engineered lumber or steel where structurally required
[3] structural steel where structurally required

Table 4.7: Case A and C Material/Assembly Use

Building Component	Case A	Case C
Foundation Walls	cast in place concrete	concrete block
Above-grade Walls	sawn lumber stud wall	light gauge steel stud wall
Partitions	sawn lumber stud wall	light gauge steel stud wall
Joists	sawn lumber[1]	light gauge steel
Beams - Lintels	sawn lumber[2]	light gauge steel[3]
Beams - Ground Floor	sawn lumber[2]	structural steel
Beams - 2nd, 3rd Floor	sawn lumber[2]	structural steel
Columns - Above Grade	sawn lumber[2]	structural steel
Columns - Basement	sawn lumber[2]	structural steel
Cladding	wood siding	manufactured stone
Window Frame	wood	aluminum
Roofing	cedar shake/shingle	clay tile
Cavity Insulation	cellulose	polyurethane

4.3.2 Space Heating and Hot Water System Choice

Case B: during the literature review, no statistical data was found on average distribution or efficiency of service equipment commonly used in current or future construction. System use rates were therefore assessed based on statistical data of the existing stock (i.e. the entire building stock, including 100 year old dwellings and 1 year old dwellings). Table 4.8 presents the space heating equipment considered in the Baseline case and their provincial distribution by dwelling type. While the NRCan's 2007 *Survey of Household Energy Use* (SHEU) [45] has detailed information about Canada's SH stock, there are data gaps and therefore it was not used to determine equipment distribution. Instead, the distribution by fuel was determined from tables 22, 23 of NRCan's Provincial *Comprehensive Energy Use Database* (PCEUD) [3].

The category "other", defined as coal and propane, was assumed to be only propane as no information is available to disaggregate the two. For dual systems, 50% of the stock was allocated to each fuel and electric systems were assumed to be baseboard. Since the database does not differentiate between furnace and boiler use rates, a ratio of furnace to boiler was calculated from Table 3.2 of the SHEU.

Table 4.8: Case B Space Heating System Stock Distribution

Province	Detached Dwellings (% of stock)[1]								
	Natural Gas Furnace	Oil Furnace	LPG Furnace	Wood Furnace	Natural Gas Boiler	Oil Boiler	LPG Boiler	Electric Base-board	Heat Pump
BC	42.1%	4.2%	1.3%	4.7%	11.6%	1.1%	0.4%	31.1%	3.5%
AB	81.4%	0.7%	1.1%	0.3%	10.9%	0.1%	0.2%	2.9%	2.4%
SK	74.6%	3.3%	1.5%	2.6%	9.0%	0.4%	0.2%	5.5%	2.9%
MB	50.8%	1.9%	0.8%	3.9%	6.2%	0.2%	0.1%	33.1%	3.0%
ON	58.1%	6.1%	1.0%	3.7%	8.7%	0.9%	0.2%	13.4%	8.0%
QC	2.9%	10.0%	0.1%	13.5%	1.4%	4.7%	0.0%	57.5%	9.8%
NB	0.1%	12.2%	0.9%	15.6%	0.1%	8.4%	0.6%	58.8%	3.3%
NS	0.0%	33.1%	1.1%	10.9%	0.0%	22.8%	0.8%	26.3%	5.0%
PE	0.0%	46.7%	0.7%	14.0%	0.0%	32.2%	0.5%	3.6%	2.3%
NL	0.0%	17.2%	0.3%	10.2%	0.0%	11.8%	0.2%	59.2%	1.1%
Province	Attached Dwellings (% of stock)[1]								
	Natural Gas Furnace	Oil Furnace	LPG Furnace	Wood Furnace	Natural Gas Boiler	Oil Boiler	LPG Boiler	Electric Base-board	Heat Pump
BC	44.7%	3.5%	1.3%	4.6%	12.3%	1.0%	0.4%	30.1%	2.3%
AB	83.1%	0.7%	1.1%	0.3%	11.1%	0.1%	0.2%	2.9%	0.5%
SK	77.7%	3.1%	1.5%	2.2%	9.4%	0.4%	0.2%	5.6%	0.1%
MB	51.1%	1.6%	0.8%	3.0%	6.2%	0.2%	0.1%	34.1%	2.9%
ON	61.8%	5.8%	1.0%	2.7%	9.3%	0.9%	0.2%	15.2%	3.2%
QC	3.4%	8.7%	0.1%	7.8%	1.6%	4.1%	0.0%	70.2%	3.9%
NB	0.2%	11.1%	0.9%	18.7%	0.1%	7.7%	0.6%	57.3%	3.5%
NS	0.0%	33.5%	1.1%	11.6%	0.0%	23.0%	0.8%	24.9%	5.1%
PE	0.0%	48.6%	0.7%	13.4%	0.0%	33.5%	0.5%	3.3%	0.0%
NL	0.0%	17.0%	0.3%	13.9%	0.0%	11.7%	0.2%	56.8%	0.0%

[1]all SH systems add to 100% for each province

While there is sufficient information to calculate ratios for each province, the statistical data is not complete enough to do this for each different fuel type. The ratios therefore do not consider that furnaces and boilers of different fuels will have different distributions. Boilers are assumed to deliver heat via piping and radiators rather than radiant floor systems as there was no statistical information found on radiant floor system rates. Electric boilers and furnaces were omitted from the research scope as they are not specifically noted in the CEUD. The SHEU notes that there are 743,169 and 145,221 electric boilers and furnaces in Canada, respectively, yet this anomaly could not be reconciled due to discrepancies between the two sources. All heat pumps are assumed to be air-to-air units and have a temperature cut-off at the balance point. For lack of information, back-up for these units is assumed to be electrical baseboard.

Table 4.9: Case B DHW System Stock Distribution[1]

Province	Electricity	Natural Gas	Heating Oil
BC	37.0%	61.7%	1.4%
AB	6.7%	92.6%	0.7%
SK	18.9%	80.3%	0.8%
MB	46.2%	53.5%	0.3%
ON	25.5%	71.8%	2.7%
QC	90.6%	5.6%	3.7%
NB	92.3%	0.0%	7.7%
NS	53.2%	0.0%	46.8%
PE	19.4%	0.0%	80.6%
NL	87.6%	0.0%	12.4%

[1]all systems add to 100%

As shown in Table 4.9, DHW systems included in the research scope are natural gas, electric, and oil fuelled, as per PCEUD Tables 28. Wood and “other” systems account for approximately 1% of the stock nationally and were omitted. Unlike SH, the CEUD only has DHW stock shares aggregated at the residential sector. System distribution therefore could not be determined by dwelling type. All systems are assumed to be 189L (50 gallon) storage tanks; storage tanks were the only type of system included in scope for simplicity; they currently account for over 80% of those currently used in Canada [60].

Cases A and C: SH and DHW system distribution for Cases A and C were determined by analysis of a detached dwelling located in Toronto. Annual fuel consumption for the dwelling was noted for each type of SH and DHW system. Fuel totals were then multiplied by life cycle GWP emissions data (kg CO_2 eq./unit fuel) for each province and the resulting best-performing and worst-performing systems allotted to Cases A and C, respectively. Only one dwelling type and location was required for analysis since these parameters do not influence relative fuel use between the various systems. With respect to GWP, wood fuelled SH systems perform best but were not considered as a best case. Instead, the best case SH was assumed to be a combination of Case B wood use rates and the system otherwise found to perform best. Table 4.10 shows the Case A and C system distributions by province.

Table 4.10: Case A and Case C Space Heating and DHW Stock Distribution

Province	Space Heating		DHW	
	Case A	Case C	Case A	Case C
BC	Heat Pump	Oil Furnace	Electric	Oil
AB	Natural Gas Furnace	Electric Baseboard	Natural Gas	Electric
SK	Natural Gas Furnace	Electric Baseboard	Natural Gas	Electric
MB	Heat Pump	Oil Furnace	Electric	Oil
ON	Heat Pump	Oil Furnace	Electric	Oil
QC	Heat Pump	Oil Furnace	Electric	Oil
NB	Natural Gas Furnace	Electric Baseboard	Natural Gas	Electric
NS	Natural Gas Furnace	Electric Baseboard	Natural Gas	Electric
PE	Natural Gas Furnace	Electric Baseboard	Natural Gas	Electric
NL	Heat Pump	Oil Furnace	Electric	Oil

4.4 Energy Designs 1 through 6

The six energy Designs included in the research scope are meant to provide the framework to explore how energy efficiency measures influence dwelling and building stock life cycle performance. As previously noted, designs describe the envelope characteristics, service equipment efficiencies and household energy use of a particular dwelling. Design 1 is the Baseline design, assessed based on minimum efficiencies and statistical data and Design 6 is a proposed best-case design. Unless otherwise noted, the general methodology for determining Design 6 characteristics was to estimate how dwellings could perform over the course of the next 40 years based on current available technology. The intent of this approach is to maintain conservative model assumptions. Designs 2 through 5 are linear interpolations of Designs 1 and 6 and are therefore not discussed in depth. This methodology for allotting dwelling performance characteristics to Designs 2 through 5 was chosen since an in-depth study of likely combinations of design parameters was not in the research scope. It should be noted that with the exception of SH and DHW system efficiency, design characteristics relating to energy use (e.g. effective envelope RSIs, airtightness, household electricity use) are the same for material/fuel Cases A, B and C. `

4.4.1 Envelope Design

Characterizing the effect of insulation choice on dwelling life cycle performance is an important model assumption but complicated by the fact that (i) insulations are proprietary products of varying thermal resistance and (ii) insulation type influences a dwelling's infiltration rate. A manufacturer literature review was conducted by Athena [39] which indicates that at present air-based insulants such as cellulose, fiberglass, and rockwool all have similar thermal properties, whereas polyurethane foams are generally twice as resistant. Also, it was noted that many cavity wall products have higher resistances than ceiling products; for these reasons the values presented in Table 4.11 were chosen for the study. Dwelling infiltration rates are a function of not only material/assembly choice, but construction practice and quality. For this reason, and for lack of better information on the topic, it was assumed that insulation choice had no incremental influence on dwelling infiltration rate.

Non-insulation envelope elements such as cladding, sheathing, and gypsum wall board were assumed to have a constant thermal resistance, regardless of assembly type. For above-grade wall assemblies, these elements comprise a total of 0.29 RSI, or at most 9% of the effective thermal resistance.

Design 1: Table 4.12 presents the thermal characteristics for Design 1. Since no data on actual "average" current construction practice was found, these design parameters reflect minimum OBC requirements. Envelope thermal resistances were assigned according to the prescriptive requirements of clause 12.3.2.1 of the OBC. For simplicity, it was assumed that all dwellings are located in cities below 5,000 HDD and no additional envelope insulation was considered for electric SH. Windows and patio doors are double glazed with low e coating and have an effective resistance of 0.5 RSI, in accordance with clause 12.3.2.6 of the OBC. Window frame thermal resistance is based on typical RSI values noted in the Passive House Planning Package (PHPP) software [61] and material type was assumed not to influence thermal performance. Analysis of other provincial minimum envelope design requirements was not in the research scope. Design 1 has 150mm stud walls with cavity insulation, reflecting the most common wall type currently constructed. Cavity wall insulation material use rates are proportioned according to Table 4.11 in quantities that provide effective envelope assembly thermal resistances according to Table 4.12. Design 1 dwellings have an infiltration rate of 3.0, a value in general agreement with [24], [62] for current construction.

Table 4.11: Thermal Resistance (RSI/m) of Insulation

Insulation Type	Resistance (walls/ceiling)
Cellulose	27/23
Rockwool Batt	27/23
Fibreglass Batt	27/23
EPS	29
XPS	34
Polyurethane	49

Table 4.12: Envelope Assembly Effective Thermal Resistances (RSI)

Envelope Element	Design 1	Design 6
Roof	6.9	15.0
Above-grade Wall	3.4	8.0
Foundation Wall	2.1	6.5
Slab on Grade	0.0	5.0
Glazing	0.5	1.7

Design 6: Five of the CMHC EQuilibrium initiative dwellings were analyzed in order to assess current Canadian advanced envelope design. With the exception of glazing the Design 6 envelope performance for each component was determined by averaging

effective thermal resistance of the five designs. Window performance was assumed to be the best performing Energy Star [63] triple glazed unit available (at time of inquiry). Finally, the Passivehaus low energy building standard [64] requirement for airtightness of 0.6 ACH @50Pa was adopted for Design 6 since there have been a significant number of dwellings built to this criterion since the standard's inception.

A summary of the envelope design characteristics for material/fuel Cases A and C are provided in Table 4.13. Case B envelopes are similar to Case A, but with the material mix noted in Section 4.3.1.

4.4.2 Space Heating and Domestic Hot Water System Efficiencies

Design 1: the Design 1 SH equipment efficiencies noted in Table 4.14 are the minimum annual fuel utilization efficiencies (AFUE) prescribed by the Office of Energy Efficiency (OEE) Energy Efficiency Regulations (EER) [65]. Wood furnaces in Canada are currently not required to have a minimum AFUE but the Canadian Standard Association (CSA) has adopted a standard (CSA B415.1-00 - Performance Testing of Solid-Fuel-Burning Heating Appliances) which recommends particulate emissions limits. An American study has found [66] that this performance criterion corresponds to an AFUE of roughly 50%, or that of a conventional wood furnace.

The Baseline heat pump has a heat season performance factor (HSPF) is 6.7 according to [67]. Unit energy factors (EF) for each type of DHW system were assessed based on minimum EER requirements. For natural gas and oil tanks the minimum EFs are 0.67 – 0.0005V and 0.59 – 0.0005V, respectively, where V is the tank volume in liters. Minimum EER requirements for electric tanks are based on maximum standby loss. In order to estimate an appropriate EF for the Baseline the minimum EF required by the US Department of Energy was used. The minimum EF is 0.97 - (0.00132*VG), where VG is the tank volume in gallons. No insulation blanket is assumed for Design 1 tanks.

Table 4.13: Research Envelope Properties

Design	Material /Fuel Case	Slab on Grade	Foundation Wall	Above-grade Wall	Roof
1	**RSI**	**0.0**	**2.1**	**3.4**	**6.9**
	A	No Insulation	2x4 SL wall, 90mm CE	2x6 SL wall, 140mm CE	SL joists, 300mm CE
	C	No Insulation	41X92 LGS wall, 90mm PU	41x152 LGS wall, 88mm PU + 25mm XPS	LGS joists, 218mm PU + 25mm XPS
2	**RSI**	**1.0**	**3.0**	**4.3**	**8.5**
	A	36mm EPS	2x4 SL wall, 125mm CE	2-2x4 SL wall, 180mm CE	SL joists, 370mm CE
	C	29mm XPS	41X92 LGS wall, 100mm PU	41x152 LGS wall, 129mm PU + 25mm XPS	LGS joists, 285mm PU + 25mm XPS
3	**RSI**	**2.0**	**3.9**	**5.3**	**10.1**
	A	72mm EPS	2x4 SL wall, 155mm CE	2-2x4 SL wall, 220mm CE	SL joists, 440mm CE
	C	58mm XPS	41X92 LGS wall, 115mm PU	2-41x92 LGS wall, 185mm PU + 25mm XPS	LGS joists, 354mm PU + 25mm XPS
4	**RSI**	**3.0**	**4.7**	**6.2**	**11.8**
	A	108mm EPS	2x4 SL wall, 185mm CE	2-2x4 SL wall, 255mm CE	SL joists, 515mm CE
	C	87mm XPS	41X92 LGS wall, 133mm PU	2-41x92 LGS wall, 206mm PU + 25mm XPS	LGS joists, 425mm PU + 25mm XPS
5	**RSI**	**4.0**	**5.6**	**7.1**	**13.4**
	A	144mm EPS	2x4 SL wall, 220mm CE	2-2x4 SL wall, 290mm CE	SL joists, 585mm CE
	C	116mm XPS	41X92 LGS wall, 150mm PU	2-41x92 LGS wall, 227mm PU + 25mm XPS	LGS joists, 493mm PU + 25mm XPS
6	**RSI**	**5.0**	**6.5**	**8.0**	**15.0**
	A	180mm EPS	2x4 SL wall, 255mm CE	2-2x4 SL wall, 325mm CE	SL joists, 655mm CE
	C	145mm XPS	41X92 LGS wall, 170mm PU	2-41x92 LGS wall, 246mm PU + 25mm XPS	LGS joists, 555mm PU + 25mm XPS

CE = Cellulose Insulation, PU = Polyurethane Insulation

EPS = Expanded Polystyrene Insulation, XPS = Extruded Polystyrene Insulation

SL = Sawn Lumber, LGS = Light Gauge Steel

Design 6: Table 4.14 also presents Design 6 efficiencies for SH and DHW systems. AFUE for natural gas, propane and oil SH systems, as well as central air-conditioning unit SEER were assumed to be the best performing Energy Star appliances currently available. Heat pump HSPF is 8.6, taken from [67] and wood furnace AFUE for Design 6 is assumed to be as per the best performing wood stove from [68]. Energy factors for electric and natural gas DHW tanks are assumed to be the best performing systems noted in [58], whereas the oil DHW tank EF factor was assumed to be the best performing product available from the Air-conditioning, Heating and Refrigeration Institute's (AHRI) product database [69]. All DHW tanks have a 2.0 RSI insulation blanket, whereas Designs 2 through 5 have insulation between 0.4 and 1.6 RSI.

Table 4.14: Space Heating and DHW Efficiencies

Equipment Type		Design 1	Design 6
Space Heating	Natural Gas Furnace (AFUE)	90%	98%
	LPG Furnace (AFUE)	90%	98%
	Oil Furnace (AFUE)	78%	96%
	Wood Stove (AFUE)	50%	80%
	Natural Gas Boiler (AFUE)	80%	98%
	LPG Boiler (AFUE)	80%	98%
	Oil Boiler (AFUE)	80%	92%
	Electric Baseboard (AFUE)	100%	100%
	Heat Pump (HSPF)	6.7	8.6
DHW	Natural Gas (EF)	0.58	0.90
	Electric (EF)	0.90	0.95
	Oil (EF)	0.50	0.68

4.4.3 Space Cooling Efficiencies and Use Rates

In order to simplify modeling the only type of SC considered in the research are central air-conditioners. These units currently account for 61% of existing SC units in Canada [3]. Without proper data on SC use rates those of the existing stock had to be used. Use rates per dwelling were determined from PCEUD Tables 27 by adding central and window unit rates. The window unit stock was divided by the average number of window units (1.24) per dwelling calculated from SHEU Table 4.3 in order to get the equivalent central unit stock rate per dwelling. Linear regression then was performed on total SC stock from PCEUD Tables 27 for the years 1990-2007, revealing that use rates have increased dramatically in each province. It was therefore decided that this phenomena was to be accounted for within the six designs.

Design 1: the regression trend line was extrapolated to the year 2010 to the determine Baseline stock rates. Design 1 air-conditioners are assumed to have a seasonal energy efficiency ratio (SEER) of 13, according to minimum energy efficiency regulations [67].

Table 4.15: Percent of Dwellings with Air Conditioning

Province	Design Number					
	1	2	3	4	5	6
BC	18%	23%	28%	32%	37%	42%
AB	19%	22%	25%	29%	32%	35%
SK	54%	64%	74%	84%	94%	100%
MB	75%	89%	100%	100%	100%	100%
ON	77%	92%	100%	100%	100%	100%
QC	41%	53%	64%	75%	87%	98%
NB	26%	34%	41%	49%	57%	64%
NS	16%	20%	25%	29%	33%	38%
PE	14%	18%	22%	26%	30%	34%
NL	4%	5%	6%	7%	9%	10%

Design 6: the regression trend line was extrapolated to the year 2049 to determine the Design 6 stock rates. Certain provinces reach their market saturation point (i.e. 100% of homes have an A/C unit) before 2049, as reflected in Table 4.15. It was assumed that Design 6 air-conditioners have a SEER of 24.5, according to the best performing Energy Star appliance.

4.4.4 Appliance Energy Consumption

For the purpose of determining electricity consumption, appliances were subdivided into major and minor types. Major appliances include refrigerators and freezers, stoves, washing machines and dryers, and dishwashers. Minor appliances are all other appliances common to homes such as computers, televisions, and hair dryers.

Design 1: existing stock data for major appliances was deemed inappropriate for characterizing the Baseline design as (i) energy intensities of these products have significantly dropped over the past 30 years and (ii) service lives tend to be long (9 to 15 years[70]). Table 38 of NRCan's *Canadian Comprehensive Energy Use Database* (CCEUD) [3] notes new average unit energy consumption (UEC) rates for each major appliance at the national scale. These UECs were multiplied by provincial per dwelling stock rates (i.e. number of each type of appliance per dwelling) from PCEUD Tables 31 to arrive at final household energy intensity. Minor appliances generally have shorter service lives and quicker penetration rates into the existing stock. This is exemplified by the near doubling of energy intensity for these components during the period 1990-2007 in Canada as new products came into the market. For this reason it was deemed acceptable to use existing stock energy intensity data for the Baseline case. Rolled up minor appliance energy intensities for each province were assembled from PCEUD Tables 13. Data for appliances is only available for the residential sector so the influence of dwelling type is not accounted for. A summary of electricity and natural gas appliance use by province, normalized to kWh/day, is provided in Table 4.16.

Design 6: a linear regression analysis of the average energy use for new major appliances for the years 1990-2007 from CCEUD Table 38 reveals that each type of appliance underwent different rates of energy efficiency improvement. When energy intensities were extrapolated into the future at the same rate, most appliance energy intensities became zero prior to 2049 (the study end year). It was therefore concluded that energy efficiency improvements could not continue at the same pace. Instead, it was assumed that major appliances could at least improve as much as the percent difference between best and worst Energy Star qualified products. Since many major appliances come in different sizes (and hence different energy use ratings), when appropriate, Energy Star energy use values were normalized to product volume (e.g. refrigerator volume) prior to computing the percent difference. Percent reductions with respect to Design 1 are 42% for refrigerators, 47% for freezers, 52% for dishwashers, 75% for clothes washers, 29% for clothes dryers and 13% for ranges. No energy efficiency improvements were assumed for natural gas dryers and ranges since there was no improvement according to CCEUD Table 38 for the years 1996-2007.

A similar linear regression analysis of minor appliance energy consumption for the years 1990-2007 (CCEUD Table 18) shows that this energy use has increased dramatically, nearly doubling during the period. For this reason, minor appliance use was assumed to increase but not at current rates. Instead, the study follows the same 20 year forecast as [48], namely that television and peripherals, and computers and peripherals energy use increase 162 and 170 kWh/year, respectively. A summary of electricity and natural gas appliance use by province, normalized to kWh/day, is provided in Table 4.17.

4.4.5 Lighting Energy Consumption

Design 1: PCEUD Tables 3 present provincial lighting electricity use for the residential sector. Per dwelling lighting intensities were calculated by taking a five year average (2003-2007) as there were significant irregularities in yearly energy use. While using the existing stock to estimate Baseline lighting use is not ideal, it is assumed that much of the current lighting technology usage, such as compact fluorescent bulb use rates, is reflected in the existing stock since they can be used in existing lighting fixtures. In order to account for the fact that larger dwellings are likely to have more lighting, overall energy use was first normalized on a provincial per m^2 floor area basis and then multiplied by the floor area of each archetype considered. The resulting lighting energy intensities are shown in Table 4.18, normalized to kWh/dwelling/day.

Design 6: no source of information on future lighting energy was found and a detailed analysis of lighting penetration rates and possible reduction was within the scope of the research. Lighting was assumed to decrease at an annual rate of 0.2% as per [71] over the 40-year study period. Design 6 was assigned the resulting lighting energy use, as presented in Table 4.19.

Table 4.16: Design 1 Appliance Energy Use (kWh/dwelling/day)

Province	Major Appliances								Minor Appl-iances	Total
	Electric						Natural Gas			
	Refrig-erator	Freezer	Dish-washer	Washer	Dryer	Range	Dryer	Range		
BC	1.64	0.54	0.10	0.05	1.99	1.26	0.02	0.37	3.81	9.78
AB	1.68	0.68	0.11	0.05	2.17	1.28	0.20	0.34	3.55	10.08
SK	1.79	0.81	0.09	0.05	2.20	1.35	0.20	0.19	3.50	10.18
MB	1.71	0.74	0.08	0.05	1.99	1.39	0.12	0.10	5.35	11.53
ON	1.74	0.53	0.09	0.05	1.96	1.25	0.08	0.42	3.36	9.47
QC	1.64	0.54	0.08	0.05	2.13	1.41	0.00	0.03	4.47	10.35
NB	1.57	0.72	0.08	0.06	2.19	1.42	0.00	0.00	4.41	10.44
NS	1.55	0.68	0.08	0.05	2.02	1.40	0.00	0.00	4.76	10.54
PE	1.53	0.73	0.08	0.05	2.09	1.38	0.00	0.00	1.68	7.55
NL	1.56	0.84	0.07	0.06	2.27	1.42	0.00	0.00	4.03	10.24

Table 4.17: Design 6 Appliance Energy Use (kWh/dwelling/day)

Province	Major Appliances								Minor Appl-iances	Total
	Electric						Natural Gas			
	Refriger - ator	Freezer	Dish-washer	Washer	Dryer	Range	Dryer	Range		
BC	0.87	0.26	0.03	0.04	1.72	1.26	0.02	0.37	4.72	9.28
AB	0.90	0.33	0.03	0.04	1.88	1.28	0.20	0.34	4.46	9.46
SK	0.95	0.39	0.02	0.04	1.90	1.35	0.20	0.19	4.41	9.46
MB	0.91	0.35	0.02	0.04	1.73	1.39	0.12	0.10	6.26	10.92
ON	0.93	0.26	0.02	0.03	1.70	1.25	0.08	0.42	4.27	8.95
QC	0.87	0.26	0.02	0.04	1.84	1.41	0.00	0.03	5.38	9.85
NB	0.84	0.34	0.02	0.04	1.90	1.42	0.00	0.00	5.32	9.88
NS	0.82	0.32	0.02	0.04	1.75	1.40	0.00	0.00	5.67	10.03
PE	0.82	0.35	0.02	0.04	1.81	1.38	0.00	0.00	2.59	7.01
NL	0.83	0.40	0.02	0.04	1.97	1.42	0.00	0.00	4.94	9.62

Table 4.18: Design 1 Lighting Energy Use (kWh/dwelling/day)

Above Grade Floor Area (m2)	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
100	3.03	3.02	3.15	3.53	2.56	3.31	3.11	2.89	1.15	2.76
110	3.34	3.32	3.47	3.89	2.82	3.64	3.43	3.18	1.27	3.03
120	3.64	3.62	3.79	4.24	3.07	3.97	3.74	3.47	1.38	3.31
130	3.94	3.92	4.10	4.59	3.33	4.31	4.05	3.76	1.50	3.58
140	4.25	4.22	4.42	4.94	3.58	4.64	4.36	4.05	1.61	3.86
150	4.55	4.53	4.73	5.30	3.84	4.97	4.67	4.33	1.73	4.14
160	4.85	4.83	5.05	5.65	4.10	5.30	4.98	4.62	1.84	4.41
170	5.16	5.13	5.36	6.00	4.35	5.63	5.29	4.91	1.96	4.69
180	5.46	5.43	5.68	6.36	4.61	5.96	5.61	5.20	2.07	4.96
190	5.76	5.73	5.99	6.71	4.86	6.29	5.92	5.49	2.19	5.24
200	6.07	6.03	6.31	7.06	5.12	6.62	6.23	5.78	2.30	5.52
210	6.37	6.34	6.62	7.42	5.38	6.95	6.54	6.07	2.42	5.79
220	6.67	6.64	6.94	7.77	5.63	7.29	6.85	6.36	2.53	6.07
230	6.98	6.94	7.26	8.12	5.89	7.62	7.16	6.65	2.65	6.34
240	7.28	7.24	7.57	8.48	6.14	7.95	7.47	6.93	2.76	6.62
250	7.58	7.54	7.89	8.83	6.40	8.28	7.79	7.22	2.88	6.89

Table 4.19: Design 6 Lighting Energy Intensities (kWh/dwelling/day)

Above Grade Floor Area (m2)	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
100	2.78	2.77	2.89	3.24	2.35	3.04	2.86	2.65	1.06	2.53
110	3.06	3.04	3.18	3.56	2.58	3.34	3.14	2.92	1.16	2.78
120	3.34	3.32	3.47	3.89	2.82	3.65	3.43	3.18	1.27	3.04
130	3.62	3.60	3.76	4.21	3.05	3.95	3.71	3.45	1.37	3.29
140	3.90	3.88	4.05	4.54	3.29	4.25	4.00	3.71	1.48	3.54
150	4.17	4.15	4.34	4.86	3.52	4.56	4.29	3.98	1.58	3.80
160	4.45	4.43	4.63	5.18	3.76	4.86	4.57	4.24	1.69	4.05
170	4.73	4.71	4.92	5.51	3.99	5.17	4.86	4.51	1.80	4.30
180	5.01	4.98	5.21	5.83	4.23	5.47	5.14	4.77	1.90	4.55
190	5.29	5.26	5.50	6.16	4.46	5.77	5.43	5.04	2.01	4.81
200	5.57	5.54	5.79	6.48	4.70	6.08	5.72	5.30	2.11	5.06
210	5.84	5.81	6.08	6.81	4.93	6.38	6.00	5.57	2.22	5.31
220	6.12	6.09	6.37	7.13	5.17	6.68	6.29	5.83	2.32	5.57
230	6.40	6.37	6.66	7.45	5.40	6.99	6.57	6.10	2.43	5.82
240	6.68	6.64	6.95	7.78	5.64	7.29	6.86	6.36	2.53	6.07
250	6.96	6.92	7.24	8.10	5.87	7.60	7.14	6.63	2.64	6.33

4.4.6 Hot Water Use

Design 1: daily hot water use rates were determined from the default equation of HOT2000 with household sizes from Table 4.2:

Hot Water (Liters/Day) = 85 + 35 * (number of occupants in the house)

The resulting hot water use rates for each province are presented in Table 4.20.

Table 4.20: Design 1 Hot Water Use (L/dwelling/day)

Province	Detached	Attached
BC	178.0	160.5
AB	181.5	150.0
SK	174.5	143.0
MB	178.0	150.0
ON	181.5	164.0
QC	174.5	150.0
NB	171.0	150.0
NS	171.0	150.0
PE	174.5	146.5
NL	171.0	157.0

Design 6: a detailed analysis was required in order to estimate hot water reduction potential for Design 6. First, municipal per capita water use from Environment Canada's *2010 Municipal Water Use Report* [72] was disaggregated into end uses according to [73]. The percent of hot water was then estimated for each end use. Showers and baths are assumed to be 88% hot water according to [74], dish washer are 100% and other domestic, leaks, and faucet 40% according to DeOreo and Mayer [60]. The clothes washer was then allotted the remaining hot water not accounted for. Percent reduction of hot water was evaluated for each end use. Showerhead flow rate were assumed to go from 17.1 liters per minute (lpm) flow rate to 9.5 lpm, and faucet flow rates assumed to go from 13.5 to 6 lpm according to [75]. Clothes washer and dish washer water reduction was estimated by calculating the percent difference between best and poorest performing Energy Star products. Finally, it is assumed that 50% of hot water use from

leakage is fixed and no hot water reduction assumed for other domestic and baths. These initiatives together account for a 49% reduction in hot water use for Design 6. Table 4.21 summarizes the assumptions described above and Table 4.22 shows the resulting Design 6 hot water use rates.

Table 4.21: Hot Water Analysis Assumptions

Water Use	Percent Municipal Water	Percent Hot Water	Percent Reduction
Dish Washer	1%	100%	60%
Washer	22%	44%	60%
Shower	16%	88%	45%
Faucet	17%	40%	56%
Leak	14%	40%	50%
Other	2%	40%	0%
Bath	2%	88%	0%
Toilet	26%	0%	0%

Table 4.22: Design 6 Hot Water Use (L/dwelling/day)

Province	Detached	Attached
BC	91.4	82.4
AB	93.2	77.0
SK	89.6	73.5
MB	91.4	77.0
ON	93.2	84.2
QC	89.6	77.0
NB	87.8	77.0
NS	87.8	77.0
PE	89.6	75.3
NL	87.8	80.6

4.4.7 Air Tightness and Mechanical Ventilation

All dwellings in the research have mechanical ventilation in accordance with Clause 9.32.1.2 of the OBC. The ventilation rates for detached and attached (i.e. semi-detached, row) archetypes are 60L/s and 55 L/s in conformance with clause 9.32.33; size of dwelling does not affect the ventilation rate since each archetype has the same number rooms.

Design 1: Clauses 9.32.3.6 and 9.32.37 stipulate that dwellings must have a heat recovery ventilator if the heating source is a solid fuel (i.e. wood) or if there is no forced air system (i.e. boilers and electric baseboard), respectively. An analysis of Baseline HVAC use reveals that these systems represent approximately 43% of the existing stock; in order to simplify modeling, an HRV with 55% efficiency is considered for all Baseline designs in accordance with clause 9.32.3.11. of the OBC.

Design 6: the HRV for Design 6 is 80% efficient, in accordance with the best performing Energy Star unit.

4.5 Energy Simulation

All energy simulations were carried out with the program HOT2000 V10.51 [24]. Since here is no difference in effective resistance for envelope components between material/fuel cases A, B, and C, the number of total simulation files was reduced by a third to 6,264. All SH and DHW systems considered in scope were simulated for each file, resulting in 10 separate computations per file. Creation of each HOT2000 file and execution and storage of output was made possible with a keyboard macro recorder.

HOT2000 has long term weather files for 30 of the 36 locations considered in the research scope; six new files therefore had to be created. For these cities weather data was estimated from the closest available city, substituting heating degree day, latitude and average dry bulb monthly temperatures from Environment Canada [53] and calculating monthly wet bulb temperatures using wet bulb depressions from the surrogate city. This methodology for estimating an annual weather profile is as per correspondence with Brian Bradley of NRCan [76]. Each simulation was assumed to have an indoor set point temperature of 21ºC and cooling set point of 25ºC. All HVAC equipment was sized by HOT2000 according to programs defaults.

4.6 Construction Forecast

A 40-year time frame was chosen for the research in order to place results within the context of the Intergovernmental Panel on Climate Change's (IPCC) recommendation of an 80-95% reduction in GWP by 2050 for industrialized countries [77]. Allowing sufficient time to analyze maintenance stage effects was also valued. A literature review was conducted to find a suitable long term housing construction demand forecast through 2050. While there are publically available 20-year [78] and 25-year [79] forecasts, no forecast could be found for construction through 2050. A more simple approach was therefore taken to estimate the degree of construction that could take place in the study period. A constant growth rate was assumed based on average annual demand during the period 1999-2009 from [50]. This was deemed acceptable since the objective of the research is to provide a framework to analyze Canadian construction rather than provide accurate forecasts.

Annual construction includes 105,801 single detached, 12,605 semi-detached, and 18,320 row units. Over period 1999-2009, these completions represented 73.1% of all residential construction, with the remaining 26.9% being apartment dwellings. The housing totals were apportioned to the 36 locations considered (see Section 4.1) according to the 2009 distribution of construction in 59 urban areas from [50]. Since row buildings were assumed to be comprised of 5 units [48], 2/5 of these units were assigned as semi-detached. This reflects the fact that the end units of row housing have similar thermal and material use characteristics. Table 4.23 summarizes the resulting annual housing completions, by dwelling type and location.

After 40 years of construction 4,232,048 detached, 504,201 semi-detached and 732,802 row housing units are constructed. These 5,469,051 dwellings will represent a significant share of the dwelling stock in 2050. According to the CEUD tables in 2007 the existing non-apartment building stock was 8,947,000 units. An analysis of the tables reveals that between 1997-2007 approximately 56,500 dwellings on average were demolished each year. If this rate is assumed constant over the next 40 years, new construction post 2010 would represent 45% of the existing stock by 2050 according to the forecast assumed.

Table 4.23: Annual Dwelling Completions[1]

Province	City	Detached	Semi-Detached	Row
BC	Kamloops	409	134	41
	Kelowna	1,372	265	115
	Prince George	429	18	20
	Vancouver	7,506	1,991	1,559
	Victoria	1,139	254	67
AB	Calgary	9,887	1,456	633
	Edmonton	7,159	1,629	588
	Grand Prairie	1,433	55	17
	Medicine Hat	2,115	183	68
	Red Deer	518	90	51
SK	Regina	1,094	106	46
	Saskatoon	1,359	227	197
MB	Winnipeg	3,122	180	90
ON	Kingston	1,847	194	106
	Kitchener	3,032	608	604
	London	7,647	1,002	1,190
	Ottawa	5,340	1,331	1,359
	Peterborough	1,055	74	80
	Sarnia	319	8	6
	Sault Ste Marie	207	0	0
	Sudbury	754	53	17
	Thunder Bay	348	12	3
	Toronto	17,429	6,241	2,966
	Windsor	1,835	276	208
QC	Bagotville	664	12	0
	Gatineau	2,051	737	104
	Granby	1,141	122	9
	Montreal	10,724	1,195	518
	Quebec	3,439	571	75
	Sherbrooke	1,615	77	15
	Trois Rivieres	898	93	0
NB	Moncton	2,551	359	90
NS	Halifax	2,552	126	88
	Sydney	330	41	6
PE	Charlottetown	558	85	24
NL	St. John's	1,923	125	32
Total		**105,801**	**19,933**	**10,992**

[1] completions noted assume row end-units are semi-detached

4.7 LCA Data

4.7.1 Envelope Materials

Envelope materials/assemblies common to residential construction but currently not in the EIE database include weeping tile, dimpled waterproof membrane, slate roofing, cedar shake/shingles, exterior insulated finishing systems (EIFS), and fiberglass window frames. These building products were deemed worthy of inclusion in the research scope and therefore LCA data was assessed for each. Weeping tile and dimpled waterproof membranes are both made of high density polystyrene (HDPE) and undergo an extrusion process during manufacture. Quantities of HDPE per functional unit of product were estimated from product manufacturer literature [80] and [81]. These quantities were then modeled at the national scale in the proprietary LCA software SimaPro [82] with data from the US LCI [83] and Ecoinvent [84] databases. Transportation is assumed to be via truck in accordance with average haul distance data from Statistic Canada [85]. Slate roofing assembly quantities were calculated with information from the National Federation of Roofing Contractors (NFRC) [86] and cedar roofing quantities determined with information from the Cedar Shake and Shingle Bureau [87]. Ancillary materials and roofing felt data are as per the EIE database. Slate roofing tile and cedar shingle/shake profiles were estimated by proportioning by weight and functional units EIE data for natural stone and cedar bevel siding, respectively. Constituent EIFS material quantities were provided by the Athena Institute and the final LCA profile for the assembly was calculated by adding EIE data of each material. The EIFS profile therefore does not include the effects of manufacturing the wall assembly at plant. Finally, a national scale fiberglass window frame profile was developed from data provided by the Athena Institute modeled in SimaPro.

4.7.2 Building Service Systems

In an effort to capture more of the embodied effects of residential construction, a database of electrical, plumbing, HVAC, and DHW systems (i.e. building service equipment) was developed in SimaPro. The Athena Institute has since drawn on the database for use in whole building analysis studies [35, 39]; a brief description of data sources and assumptions follows.

Since there is currently no available data on manufacturing these products, estimates are meant to reflect average national practice. Building service equipment is generally any combination of steel, aluminum, copper, and plastics. Steel and aluminum LCI data is from the Athena database and plastics from the US LCI database. North American primary copper data comes from the Ecoinvent LCI database. All copper used in the products is assumed to be primary; for electrical wire this assumption is valid, as primary copper is required for good conductivity [88]. One source estimates that over 2/3 of copper pipe is recycled content [89]. While this will significantly change the environmental profile, further research is beyond scope. Manufacturing process data for service equipment products are also from the Ecoinvent database. Since the data is European in scope, each process was altered to reflect Canadian fuel combustion, electricity generation and in some cases, material production (e.g. lubricating oil). All transportation was assumed to be by truck, with average shipping distances estimated from [85].

There are 10 types of electrical wire considered:

- 14/2,14/3, 12/2, 10/3, and 8/3 NMD90 wire
- 6, 3, and 00 AWG bare wire
- 3 and 00 AWG R90 insulated conductor wire

Reference [90] provides copper cross sectional areas for each gauge. This was used to calculate total copper wire weight per unit length for each of the ten electrical wires considered. These copper quantities undergo a wire drawing process to become copper wire. Insulation quantities for each wire type were determined by subtracting copper weights from total wire weights noted in [90]. A bill of materials (BOM) for typical non metallic (NM) insulation is given in [91]; this information was used to estimate the material effects and a plastic extrusion process was used as a proxy for insulation extrusion. Galvanized sheet metal electrical boxes for receptacles, switches, and lighting were also evaluated, based on unit weights from [92].

The following pipes are considered in the research:

- 13mm and 19mm type L copper water supply pipe
- 40mm, 50mm. 75mm, 100mm ABS drain, waste, and vent pipe
- 40mm PVC electrical conduit pipe

Unit weights for copper pipes are taken from [58] and undergo an extrusion process. A report on plastic pipes [93] provided the life cycle inventory (LCI) data required for ABS and PVC pipes. The data is rolled up to plant gate and therefore include all material and manufacturing (e.g. plastic extrusion) processes. The data is presented on the basis of specific pipe sizes and therefore data was normalized on a per kg basis prior to being input in SimaPro. Unit weights for each size of pipe taken from [58] were used to determine effects for the various sizes.

The following HVAC and DHW components are considered, along with the source for the BOM:

- DHW tank, HRV unit, natural gas furnace [33]
- Natural gas boiler, central air-conditioner, heat pump, radiators [32]
- Baseboard heaters [94]

Each component is a mixture of various metals and plastics. Since none of the sources provided any detail as to the type of product each material was, manufacturing processes allotted to materials were based on a best guess. For example, any quantities labeled galvanized steel were assumed to be sheet, copper quantities (when in small amounts) were assumed to be wire, etc. DHW tanks, furnaces, and boilers were assumed to be the same for each fuel type as specific bills of materials could not be found. No BOM was found for electric baseboard heating units. The LCA data for these units is based on average total weight (per W of output) from product literature, assuming an 80%/20% mix of steel to aluminum plate.

4.7.3 Wood Combustion

A wood combustion profile (including resource harvesting) for Canada was estimated by adjusting European Ecoinvent data; for the purpose of this research, combustion is assumed to be carbon neutral according to [95].

5.0 RESIDENTIAL BATCH ENVIRONMENTAL ASSESSMENT TOOL (Res-BEAT)

LCA is a powerful tool for building designers and policymakers because it can provide a significant amount of information to the practitioner, whether that be life cycle impact or resource use results, or secondary energy or material use quantities. Yet its data, calculation and results intensiveness can make it difficult to apply in practice. No truer is this for research such as this where more than one dwelling case is considered. One of the most important aspects of this work was therefore to come up with a platform to be able to store data, perform calculations, and display results based on queries. A Microsoft Excel based program with this capacity called the Residential Batch Environmental Assessment Tool (or Res-BEAT) was developed by the author in collaboration with the Athena Sustainable Materials Institute. Res-BEAT is the first program specifically designed to conduct batch dwelling LCA and bottom-up engineered LCA building stock modeling.

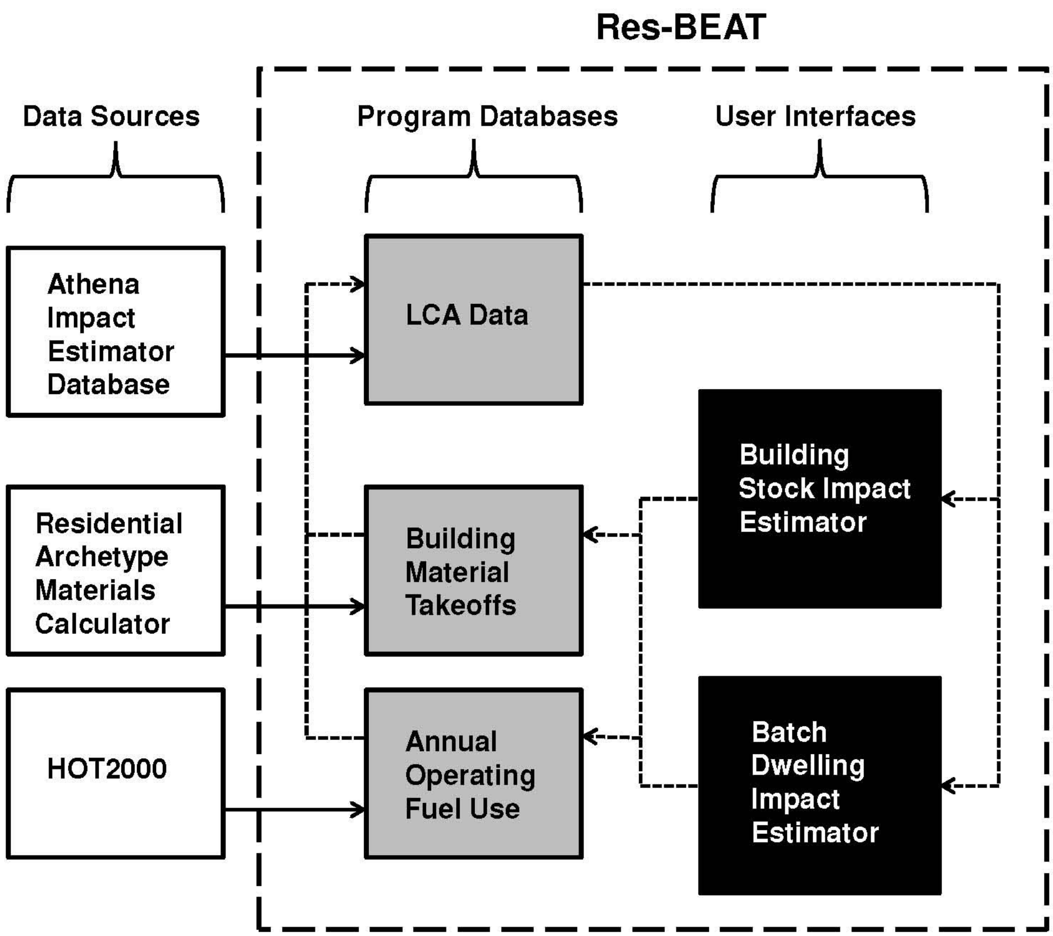
5.1 Program Structure

The program comprises databases of design and LCA information, and input and user forms to prompt which analysis is desired. This database structure facilitates updates and evolution of the program to include new dwelling design descriptions, material types, and technologies. The program structure of Res-BEAT is shown in Figure 5.1; an explanation of each module follows.

LCA Data: this module is where region-specific LCA data for materials and fuels are stored. The program primarily draws on data comprising the Athena Impact Estimator software, as well as other databases maintained by the Athena Institute. As new LCA data emerges in the future, the program can be easily updated.

Building Material Takeoffs/Annual Operating Fuel Use: these two modules are where dwelling design information is stored. This information includes building material and service equipment takeoff quantities (e.g. 20m^3 of lumber, 1 hot water tank) from the Residential Archetype Materials Calculator, as well as annual operating energy use results (e.g. 20,000kWh electricity for space heating, 600m^3 natural gas for domestic water heating) from HOT2000. If the user wishes to add a new design to the program, material and fuel quantities are added here.

Figure 5.1: Res-BEAT Program Structure



Building Stock Impact Estimator: this worksheet is the input interface where a building stock is created and results are displayed. Figure C2 of Appendix C shows the input table where a building stock is defined. The first four columns labeled "archetype", "design", "province", and "city" identify which dwelling design the user wants to add to the stock (see Section 3.3 for description). These parameters are used to call on material and fuel take-off data. The "service life" column defines the service life of the respective dwelling design and serves to tell the program when to initiate end of life effects and terminate annual operating energy effects. The final section of the input form is where the number of dwelling completions, for each design and for each year of the model period is allocated. For example, if the user wants to add 500 units of a certain design to the stock in 2025, 500 is input in the appropriate cell.

The buttons labeled “Clear Input” and “Reset Worksheet” clears the input table and allows the user to start a new analysis. The “Execute Analysis” button opens a user form where the locations, designs, and results to be calculated are selected. From the user form a button begins execution of analysis by way of a macro. The macro loops through the housing start data (i.e. the user input) of the first year, calculates the appropriate material and fuel quantities via the four design identifiers, and then multiplies these quantities by the LCA data to get final results. Once results for the first year are finished the macro loops to the next year and performs the same routine. After passing through each year of the model, the building stock analysis is complete.

Batch Dwelling Impact Estimator: this worksheet form allows the user to select designs from the database for batch LCA analysis. Results are calculated in a similar way to the Building Stock Impact Estimator.

5.2 Results and Uses

The program currently contains information for 29 archetypes, 36 cities, 3 material/fuel cases, and 6 energy designs, allowing for batch analysis or building stock modeling with over 18,000 dwelling options. Res-BEAT calculates the following results, which are similar to those calculated by the Athena Impact Estimator:

- **8 impact measures**
  Ex: kg CO_2 eq. global warming potential, kg NO_x eq. smog potential
- **30 raw resource uses**
  Ex: MJ total primary energy (TPE), m^3 wood, kg limestone, litres crude oil
- **Bill of materials – 110 building and 38 service equipment products**
  Ex: m^3 small dimension lumber, m^2 brick veneer, m 13mm copper pipe
- **Operating (i.e. secondary) energy use**
  Ex: kWh electricity, m^3 natural gas, litres of diesel

Building stock results are presented as both dynamic (i.e. as a function of time) and static, whereas batch dwelling results are static only. Building stock modeling can be applied at various scales, including national, provincial, municipal or community levels. Given the many types of results and scales available to the user, the program can be put to various uses, some of which are outlined below:

Product Research: with this program the influence of a particular building product on the building sector can be investigated. Examples include the increased use of wood products and renewable energy systems (i.e. photovoltaic arrays).

Housing Developments: the majority of new homes are constructed in large housing developments. Conducting LCAs at this scale is an arduous and costly task; with a platform to do this analysis quickly based on archetypes, developers could use LCA to help make more informed design decisions.

Urban Planning: by modeling building stocks with various dwelling types and densities, urban planners could better understand the impact of their decisions at the community level.

Policy Development: LCA is a tool that aims to predict all the effects associated with an end-use. Building stock modeling according to LCA provides an effective means to analyze any number of proposed incentive programs, subsidies or taxes.

Building Code Development and Analysis: building code development would be well served by an analysis that considers the holistic nature of building performance and provides a dynamic assessment based on more than operating energy consumption.

Energy Analysis: for typical energy end-use modeling why not generate a more complete environmental profile using LCA? Since the building sector is a significant consumer of electricity, stock modeling also provides a useful tool to understand the relationship between consumption and the effect of changes to electricity generation mixes.

6.0 RESULTS

6.1 Introduction

The following section presents a sample of Res-BEAT dwelling and building stock output. Section 6.2 looks at Baseline results in detail followed by sensitivity analysis of material and fuel choice (Section 6.3), and energy efficiency implications (Section 6.4). Section 6.5 then explores the absolute upper and lower bounds of GWP within the research scope. Results are presented in graphical form in order to highlight findings, whereas tables with the associated data are found in Appendix B. The analysis focuses on the variation of effects by location, design, etc., rather than the environmental implications of the effects. GWP is the primary metric for analysis and is therefore analyzed with the most detail. Detailed graphs for TPE are given in the Appendices but are generally not discussed. Normalized impact indicators and resource use graphs accompany each section for the purpose of highlighting the breadth of Res-BEAT analysis and basic environmental profile characteristics in a concise manner.

All whole dwelling results presented are static, based on an assumed service life of 60 years. Unless otherwise noted, dwelling results are given for 10 cities across Canada, representing the largest cities of each province. All building stocks considered are 40 years of construction (2010-2049) at the national scale as per the demand forecast outlined in Section 4.6. It is assumed that the service life of constituent dwellings is greater than 40 years and therefore no end of life is considered. The building stock results presented are both static and dynamic.

As previously noted, Res-BEAT calculates results based on database information at the dwelling scale. The database dwellings are therefore the basis for both batch assessments or building stock modeling. Figures 6.1 and 6.2 show 60 year dwelling database embodied and operating energy GWP results in Toronto for material/fuel Case B and energy Design 1, for each of the 29 archetypes considered. Tables 4.4 and 4.5 show the size of each archetype considered.

Observed Trends - GWP of Toronto Database Dwellings

- The manufacturing stage dominates embodied emissions, contributing 59-62%.
- SH represents 45-64% of operating energy GWP.
- Embodied GWP is generally 9-10% of total life cycle impact for the 60 year service life, or 6-7 years of annual operating effects.
- For both embodied and operating energy effects, row and semi-detached housing perform better than detached housing since material usage and energy consumption is reduced due to shared party walls. For instance, archetypes R6 and S6 (150m^2 floor area) are responsible for 88% and 71% the GWP of D1 (150m^2 floor area), respectively. These differences can be traced primarily to SH demand.
- Between smallest and largest dwelling sizes total GWP increases by 23-27%, illustrating the degree to which dwelling size influences impact.
- Embodied effects increase more on a percent basis than operating effects since dwelling size not only affects the quantity of materials, but in the case of structure, the size and type of members due to increased floor and roof spans.

Figure 6.1: Case B, Design 1 Toronto Database Dwelling Operating Energy GWP

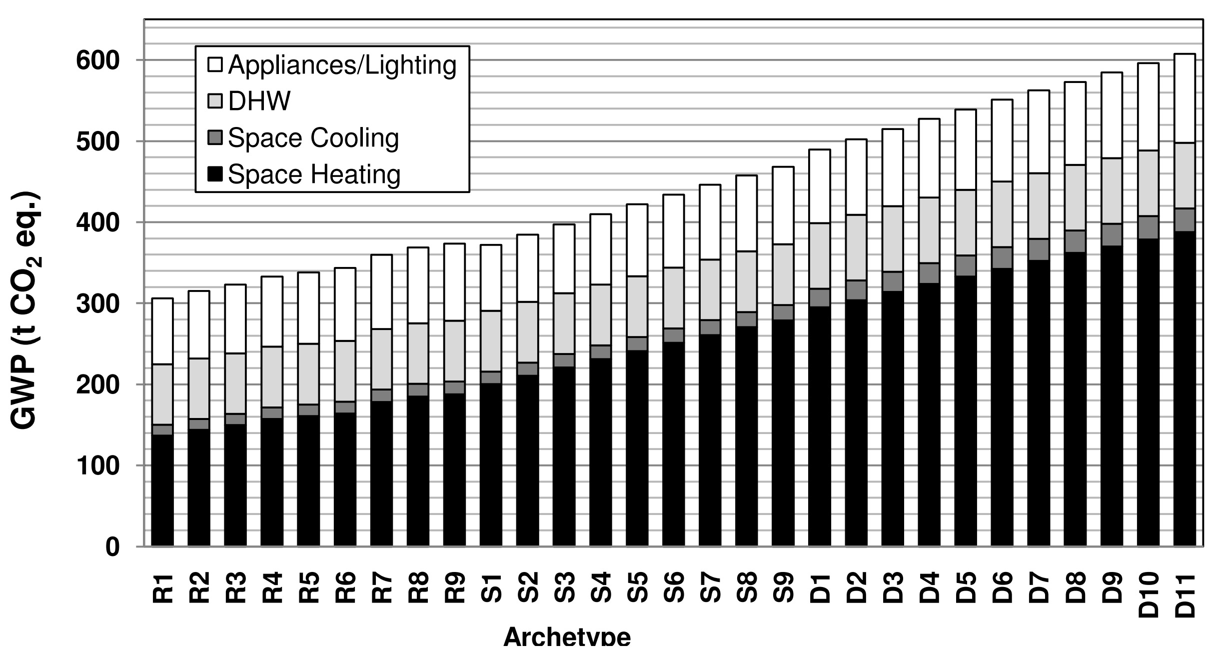
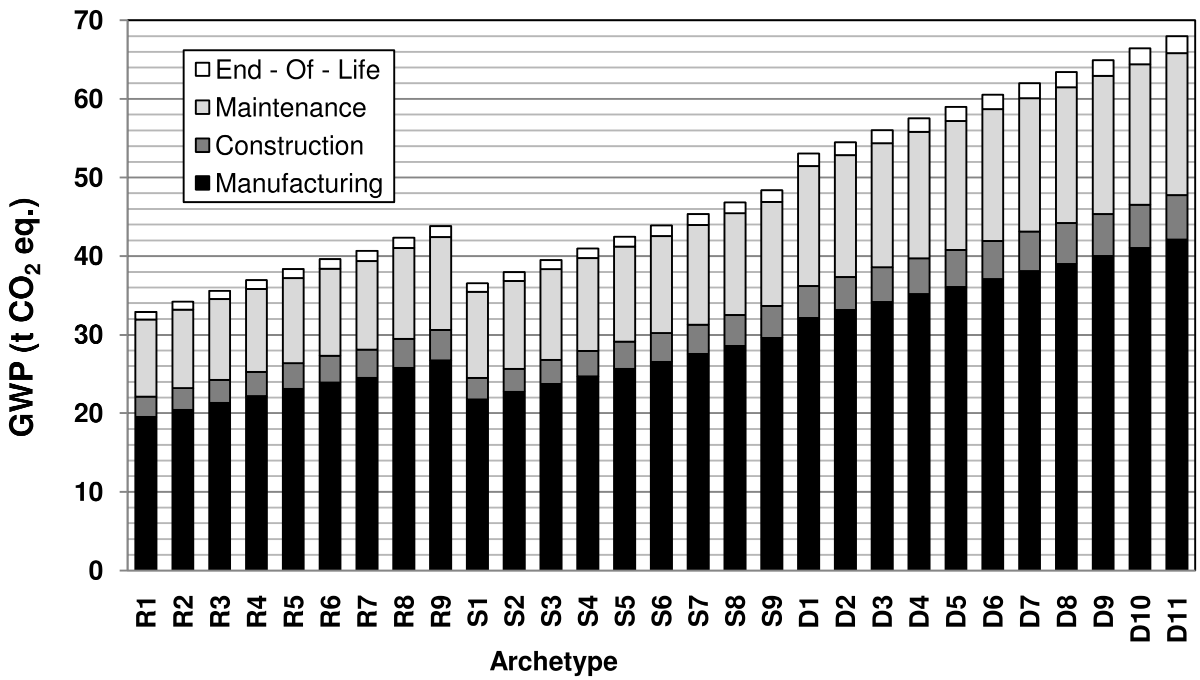


Figure 6.2: Case B, Design 1 Toronto Database Dwelling Embodied GWP



6.2 Baseline

The "Baseline" refers to material/fuel Case B and energy Design 1, thereby representing current minimum construction practice and typical occupant behavior. As previously noted, each archetype in Case B is allotted the average materials mix and SH and DHW stock distributions noted in Sections 4.3.1 and 4.3.2, and therefore represent not a specific design, but an average one. All results for the baseline and subsequent Sections (6.3- 6.5) are based on the provincial archetypes presented in Table 4.3.

6.2.1 Dwelling Scale

Figures 6.3 to 6.5 show annual SE simulation results for the Baseline archetypes in 10 cities. Row and semi-detached units require less energy to operate, between 55-63% and 71-82% that of detached units, respectively. Due to Canada's cold climate, SH is the largest contributor to SE, comprising 61-78%, 54-72%, and 41-65% of total SE for detached, semi-detached, and row housing, respectively. SH energy use is primarily a function of climate and heating system efficiency. For example, there is almost a threefold increase in SH use between Vancouver and Saskatoon due to differences in HDD (2925 vs. 5950 [24]) and the fact that British Columbia has a higher percentage of electric heating systems (100% efficient) compared to Saskatchewan. Figure 6.5 illustrates the differences in fuel use across Canada, in particular the use of (i) natural gas in western provinces, (ii) heating oil in eastern provinces, and (iii) generally higher rates of electricity in provinces with significant hydroelectric generation.

Life cycle building material usage varies according to the size of dwelling assumed for each province and dwelling type. BOM results for Toronto Baseline detached, semi-detached, and row unit s are presented in Table B8 of Appendix B.

Figure 6.3: Baseline Dwelling Annual SE, by dwelling type

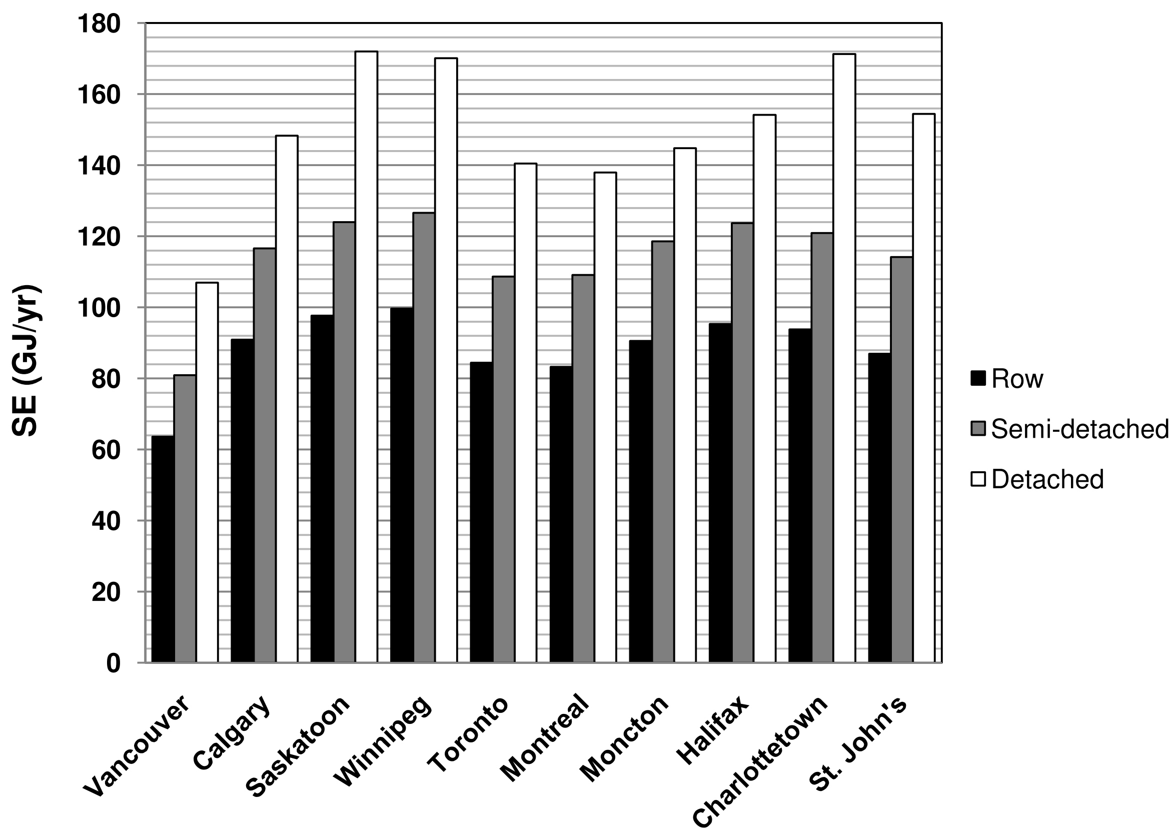


Figure 6.4: Baseline Detached Dwelling Annual SE, by end-use

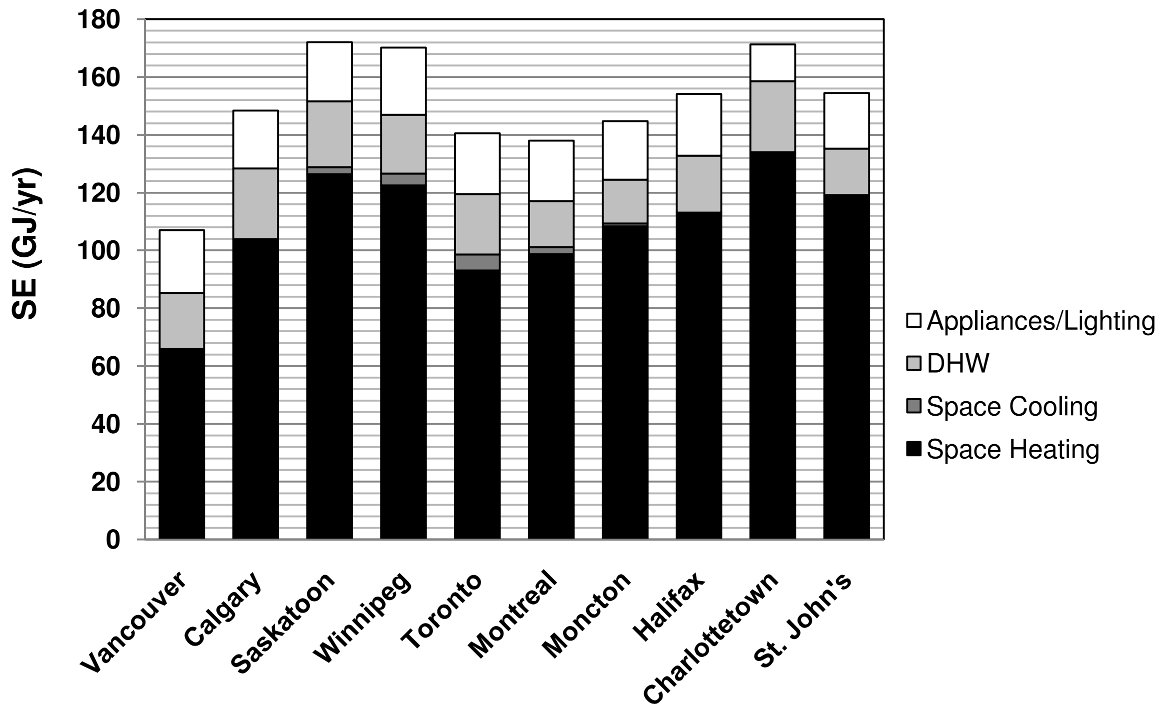


Figure 6.5: Baseline Detached Dwelling Annual SE, by fuel

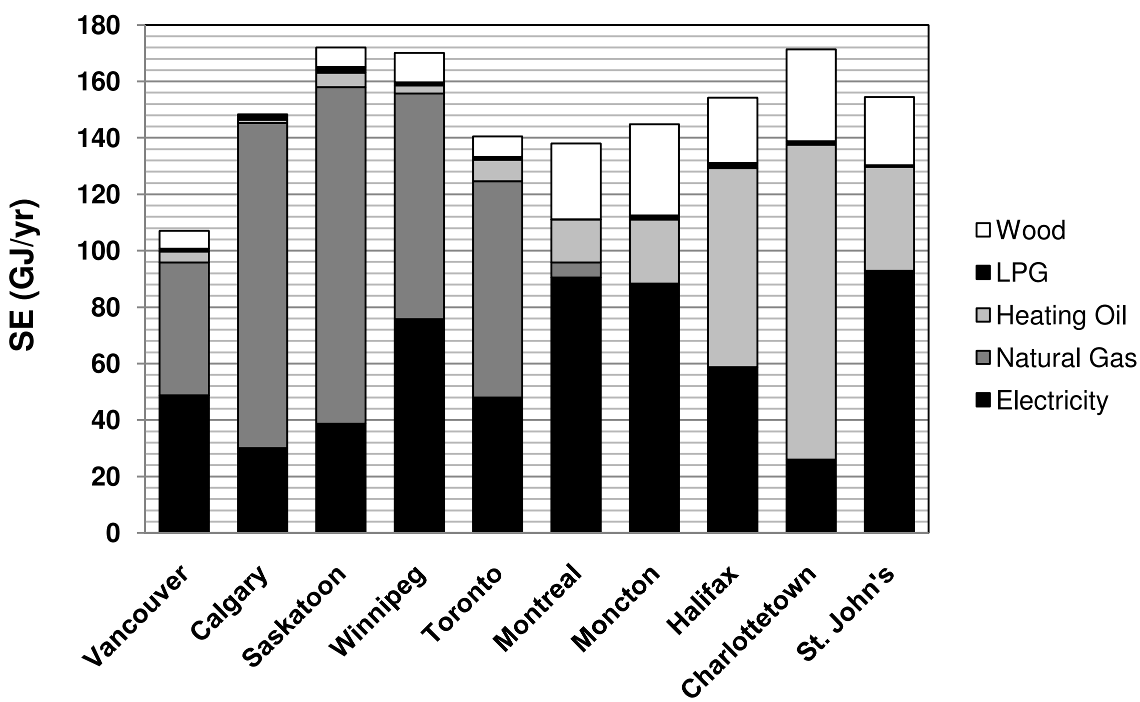


Figure 6.6 presents Baseline GWP for row, semi-detached, and detached housing in 10 cities across Canada. In order to illustrate the difference in GWP results between typical and LCA methodologies, detached housing emissions have been disaggregated into three components in Figure 6.7: embodied emissions, and operating energy stage emissions from site combustion and electricity generation (OE_1), and emissions related to pre-combustion (OE_2). Typical GWP analysis only accounts for GWP emissions from site combustion and electricity generation (OE_1); OE_2 effects are those related to the production and transport of SE. Figures 6.8 and 6.9 show detached operating energy and embodied results by end-use and life cycle stage, respectively, in order to provide further insight into the source of emissions.

Observed Trends - Baseline Dwelling GWP

- Dwelling type has a significant influence on life cycle GWP; row and semi-detached designs emit 54-71% and 70-81% that of detached dwellings, respectively. GWP reductions are less than corresponding SE reductions.
- SH contributes most to GWP, 36-60% for row, 45-68% for semi-detached, and 50-71% for detached.
- SC is currently not a large contributor to GWP as it is responsible for less than 4% of emissions for all dwelling types.
- Total emissions across cities vary considerably, 88-915 tonnes for row, 116-1,098 tonnes for semi-detached and 152-1,340 tonnes for detached housing. The lowest emissions are in Montreal and the highest in Halifax.
- The percent embodied emissions is 5-39% for row, 4-33% for semi-detached, and 5-32% for detached housing. The lowest percent is in Halifax and the highest in Montreal.
- Pre-combustion (OE_2) of detached dwellings is 11-19% of operating energy stage GWP.
- EE and OE_2 are the value added of conducting analysis according to LCA; together they are responsible for 17-47% of detached emissions. In other words, LCA analysis accounts for 1.2 to 1.9 times the impact as typical analysis.

- Detached operating energy emissions across cities vary by a factor of over 12. This large difference is particularly influenced by provincial electricity generation mix and SH and DHW system distribution.
- Detached embodied emissions across cities vary by a factor of 1.3, much less than the operating energy stage. This result is due to variations in dwelling size and the fact that the Case B materials use mix does not vary by province as fuel use mix does.
- Differences in AL-related effects across the ten detached designs illustrate the concept of how not all fuels are created equal. These electricity related emissions vary between 2.2 tonnes in Montreal to 344 tonnes in Halifax.

In general,

Dwellings in Montreal are low impact because:

(i) Quebec electricity generation is very low in GWP.

(ii) Quebec dwellings rely heavily on electricity for SH and DHW.

Dwellings Halifax are high impact because:

(i) Nova Scotia electricity generation is primarily coal based.

(ii) Nova Scotia dwellings rely heavily on heating oil and electricity for SH and DHW. Emissions from the Calgary and Saskatoon dwellings would be of similar or greater magnitude if not for the dominance of natural gas for SH and DHW in Alberta and Saskatchewan.

Figure 6.6: Baseline Dwelling GWP, by dwelling type

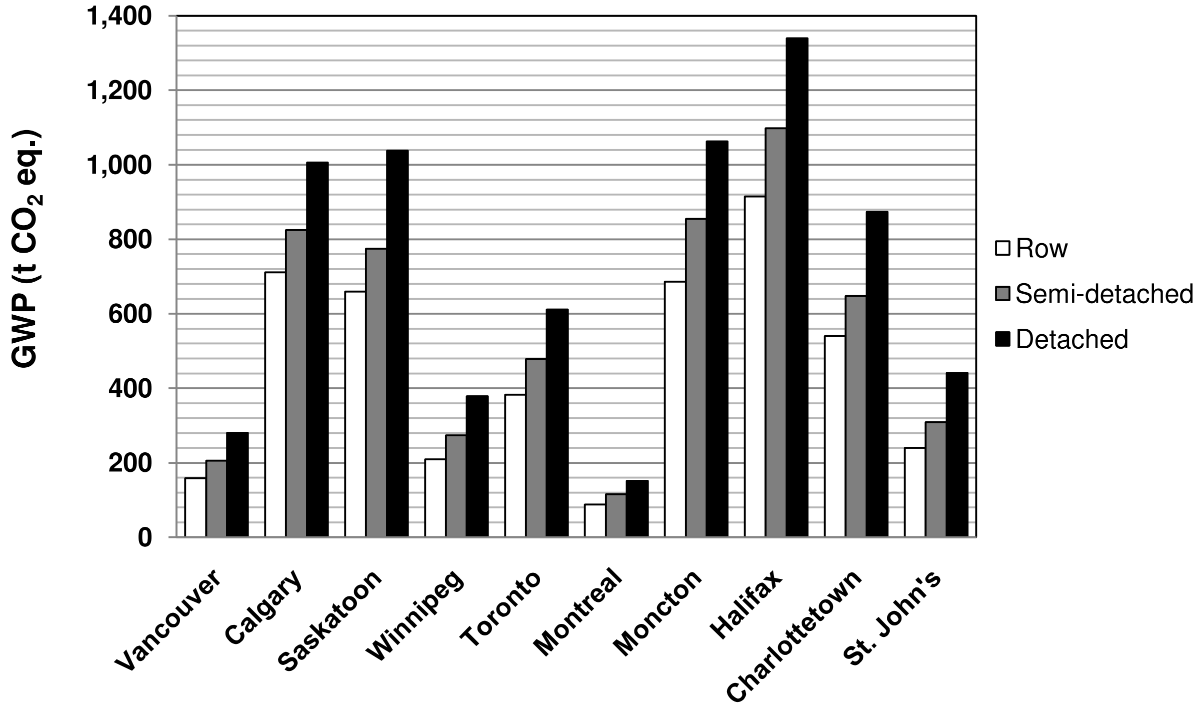


Figure 6.7: Baseline Detached Dwelling GWP, by component

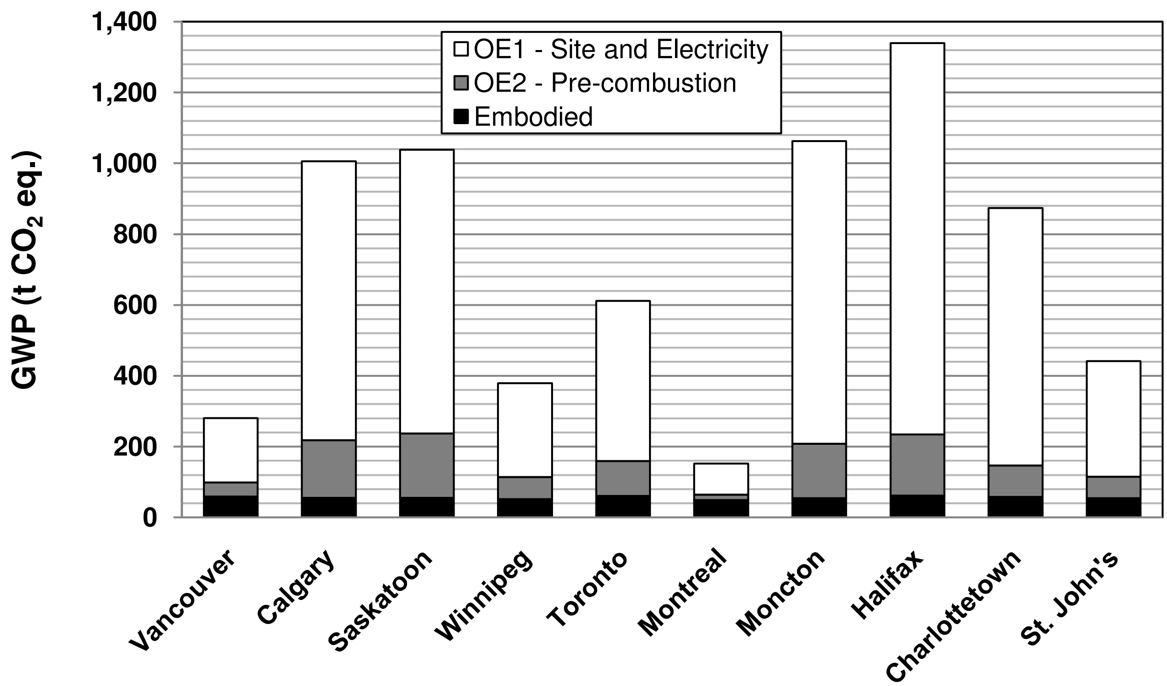


Figure 6.8: Baseline Detached Dwelling Operating Energy GWP, by end-use

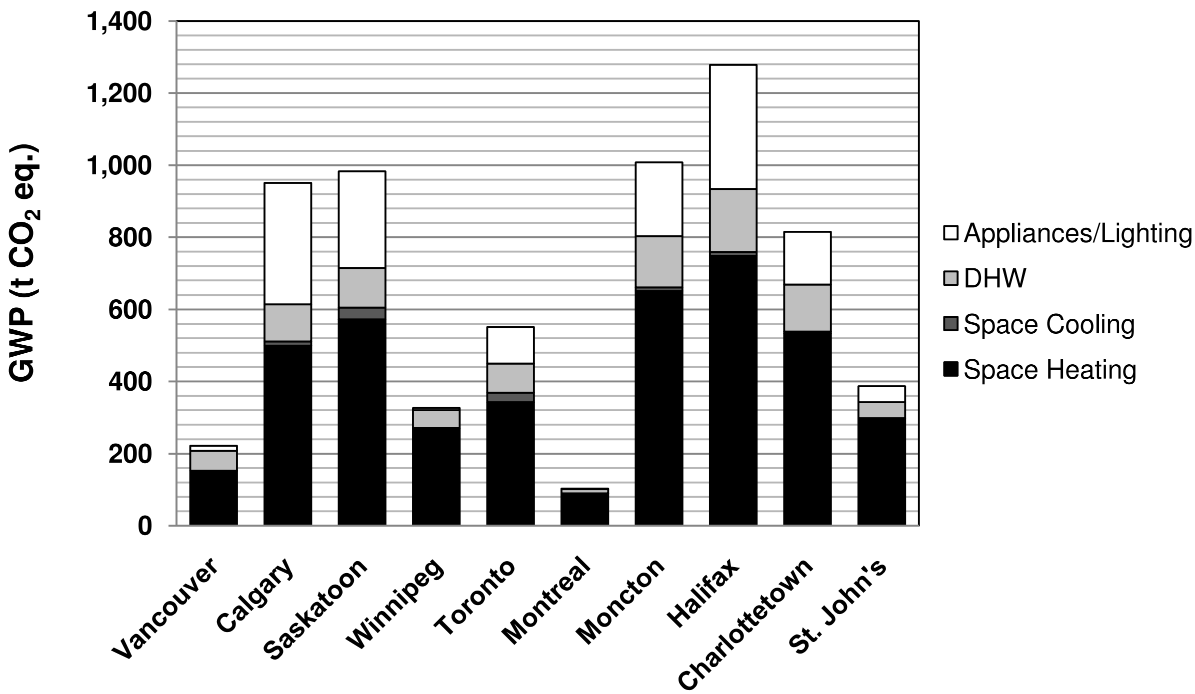


Figure 6.9: Baseline Detached Dwelling Embodied GWP, by stage

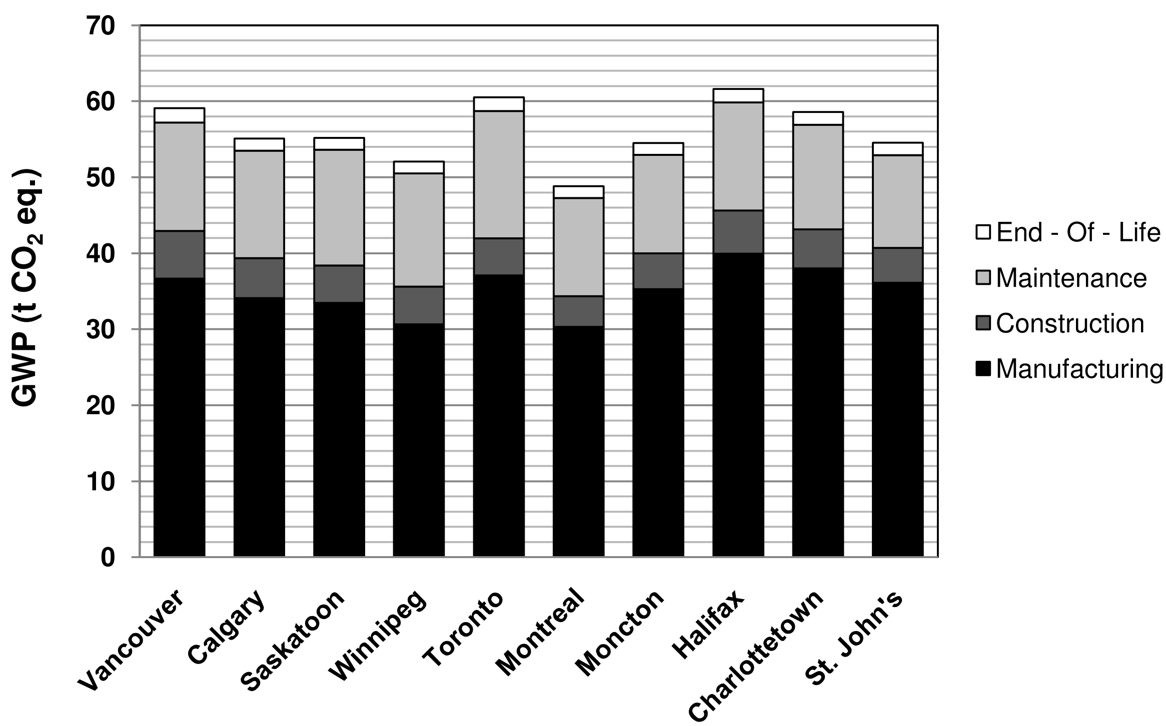


Figure 6.10 presents 7 normalized impact indicator results for the Toronto Baseline detached dwelling, by stage. With the exception of eutrophication, ozone depletion and solid waste, SH generally contributes most to impacts, between 37-56%. Refrigerant used in heat pumps and air conditioners is responsible for the majority of ozone depletion potential, which is why manufacturing and maintenance stages contribute nearly 100% of emissions. Solid waste predominantly comes from demolition and disposal in the end of life stage (59%). Embodied stages together contribute 13%, 26%, 92% and 28% to acidification, human health (HH) respiratory effects, eutrophication and smog, respectively.

Figure 6.11 shows normalized life cycle energy resource use for the same detached dwelling in Toronto. Over the course of 60 years, this dwelling consumes 15,930 GJ of TPE (295 kWh/m2/yr), 89,469 kg of coal, 27,074 liters of crude oil, 166,607 m^3 of natural gas, 15 kg of uranium, 47 tonnes of wood, and 772 GJ of RPE. Similar to impact indicators, SH is generally responsible for the most resource use, between 36% and 67%. Embodied resource use is 6-7% for coal, natural gas, and RPE, 1% for uranium whereas it accounts for 32% and 60% of crude oil and wood consumption, respectively. 33% of embodied crude oil use is for feedstock purposes in plastic and bitumen based building materials.

Graphs for Montreal and Calgary similar to Figures 6.10 and 6.11 are included in Appendix A to illustrate the influence of location on impact and resource use characteristics. In particular, these graphs show how hydroelectric and coal dominated electricity generation influence environmental profiles in Quebec and Alberta, respectively.

Figure 6.10: Baseline Toronto Detached Dwelling Impacts, by stage

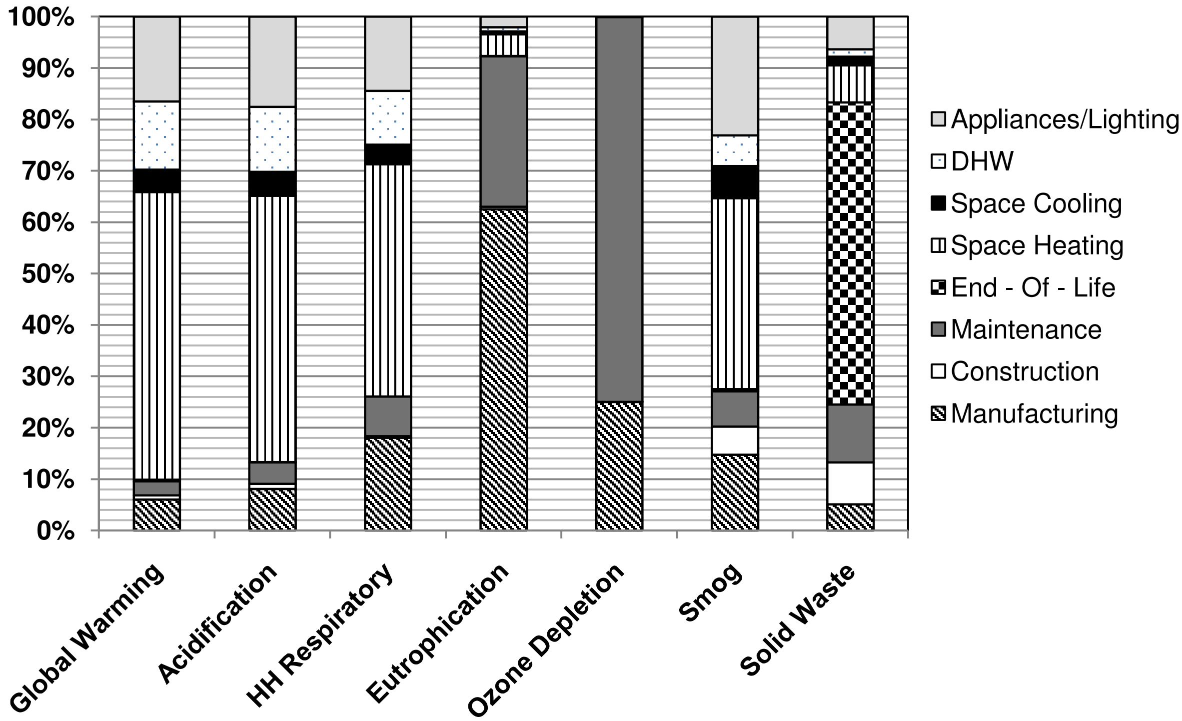
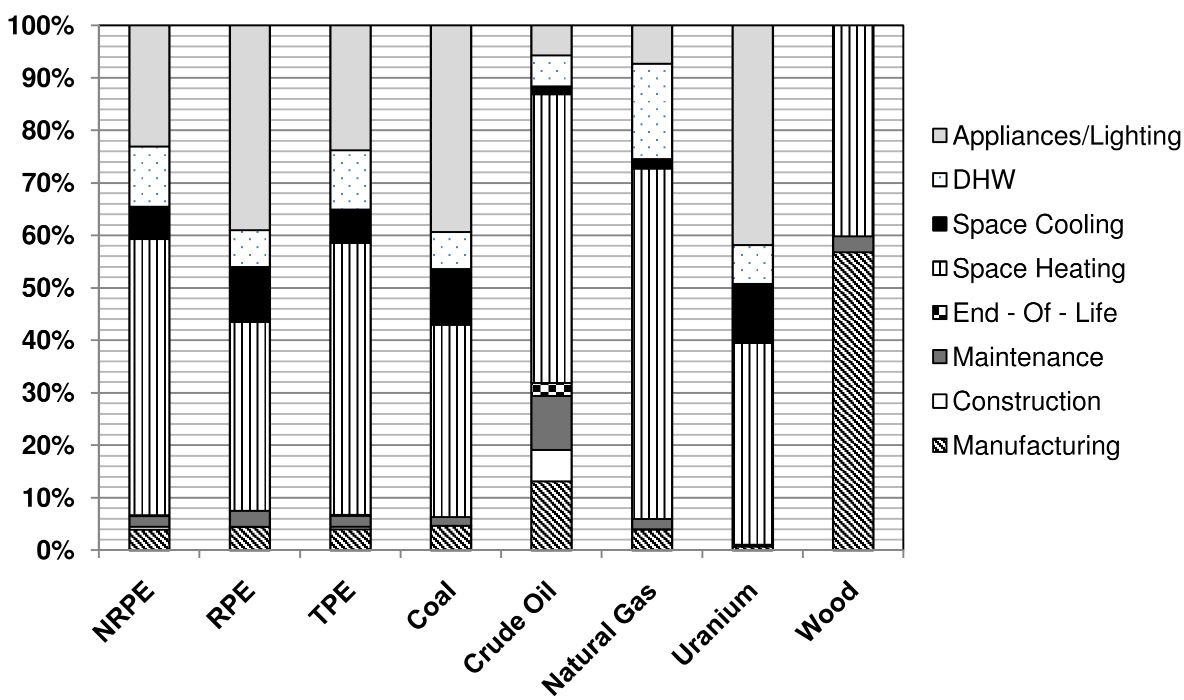


Figure 6.11: Baseline Toronto Detached Dwelling Resource Use, by stage



6.2.2 Building Stock Scale

Accumulated Baseline building stock inputs SE and BOM are given in Appendix B Tables B6 and B11, respectively.

Figure 6.12 presents dynamic Baseline annual GWP emissions for Canada with the same components (EE, OE_1, and OE_2) considered in Figure 6.8 for dwellings. Figure 6.13 then presents the corresponding dynamic Baseline accumulative GWP; the percent contribution of each component is plotted over time in Figure 6.14. Finally, 40-year national GWP is plotted by province in Figure 6.15.

Observed Trends – Baseline Building Stock GWP

- By 2050, annual GWP due to post 2010 construction is 54.1 Mt CO_2 eq. This represents 7% of the estimated 747Mt GWP emissions in Canada in 2007 [4].
- Pre-combustion (OE_2) accounts for 17% of operating energy stage GWP.
- Annual embodied emissions are 5.10 Mt CO_2 eq. in 2010 and rise to 6.46 Mt by 2049 due to maintenance and replacement effects (i.e. recurring embodied).
- By 2049, annual OE_1 and OE_2 rise to 39.5Mt and 8.2Mt, respectively. OE_1 and OE_2 overtake embodied in 2015 and 2038, respectively.
- After 40 years, new construction is responsible for 1,201Mt of GWP, with 809Mt, 168Mt, and 224Mt accounted for by OE_1, OE_2, and embodied, respectively. OE_1 overtakes accumulated embodied in 2019.
- In 2010 the embodied component is 81% and reduces to 19% after 40 years. This phenomenon is the consequence of the high emissions from manufacturing materials and constructing buildings relative to the annual operational emissions of those dwellings at the start of the study period.
- EE and OE_2 impacts together account for 84% in 2010 and 33% in 2049 of total accumulated GWP. After 40 years the GWP accounted for by the LCA building stock model is 1.5 times that of typical energy end-use modeling.
- After 40 years, Ontario and Alberta together are responsible for 73% of total emissions and all other provinces contribute each less than 6%. The driving factors for this are (i) the number of dwellings constructed in Ontario and Alberta,

(ii) the high GWP intensities of dwellings constructed in Alberta and (iii) the low GWP intensities of dwellings constructed in British Columbia and Quebec.

- Provincial percent embodied GWP ranges from 10% in Nova Scotia to as high as 51% in Quebec.

Figure 6.12: Baseline Stock GWP

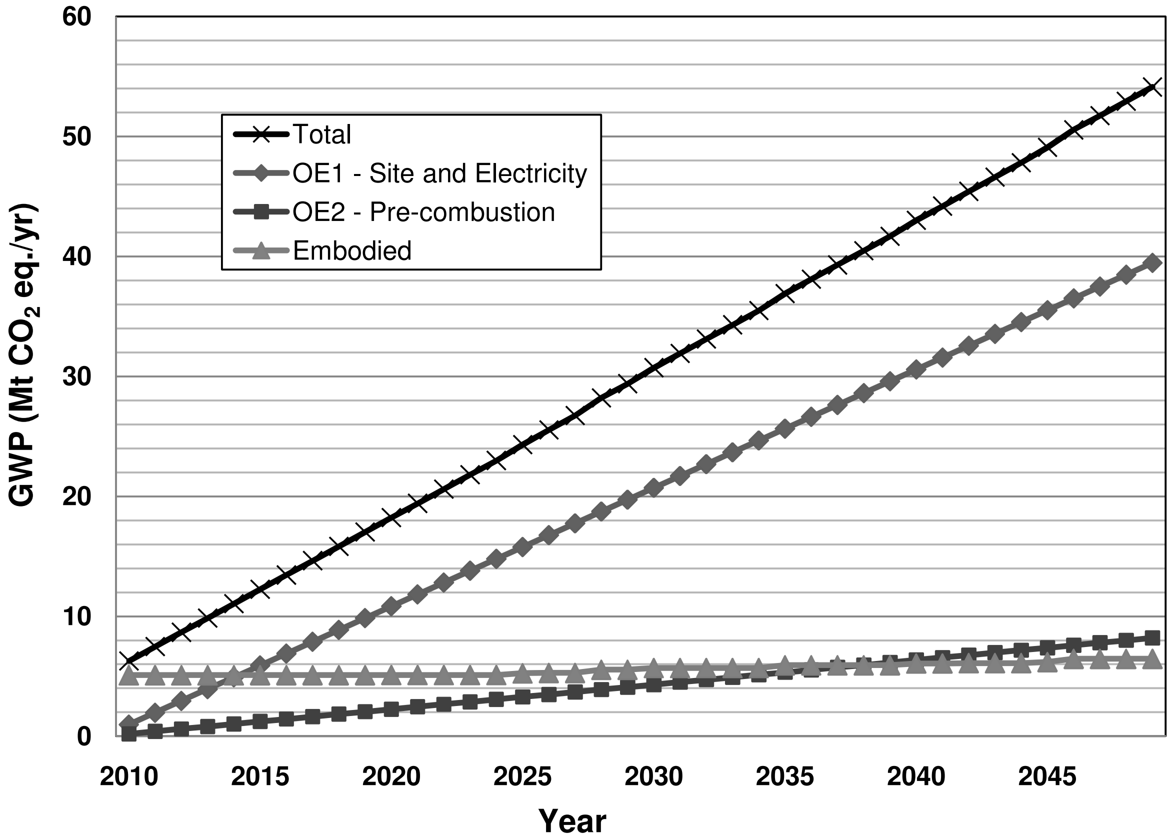


Figure 6.13: Baseline Stock Accumulative GWP

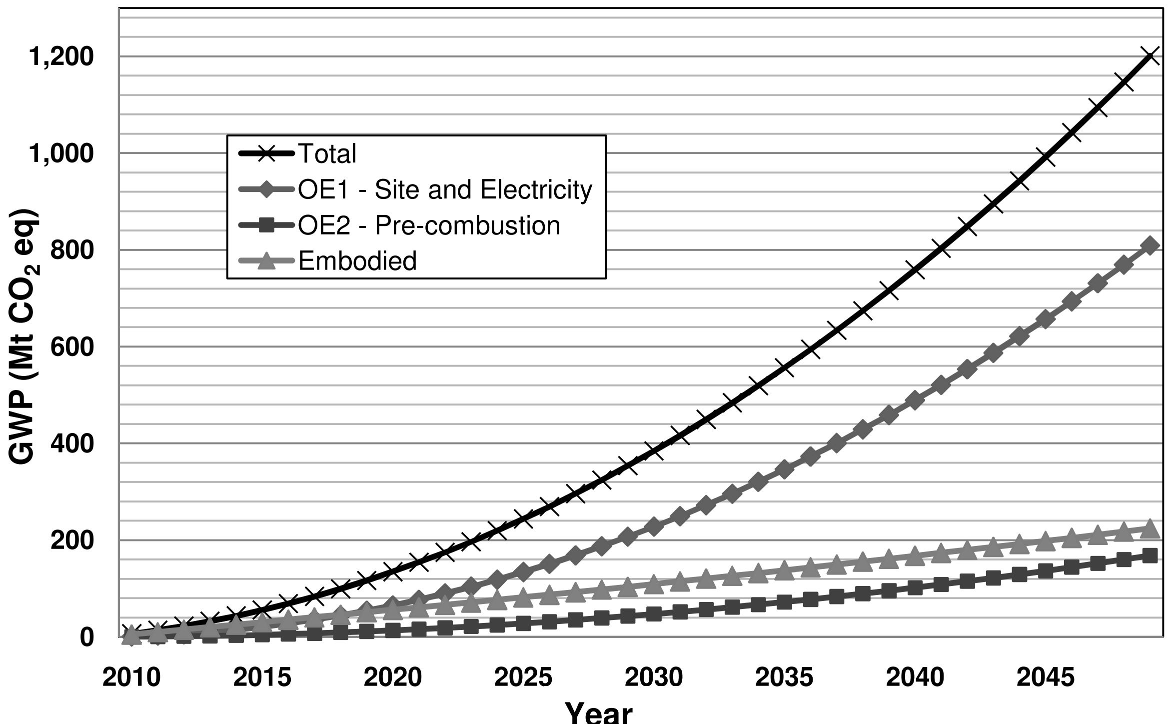


Figure 6.14: Baseline Stock Percents of Total Accumulative GWP

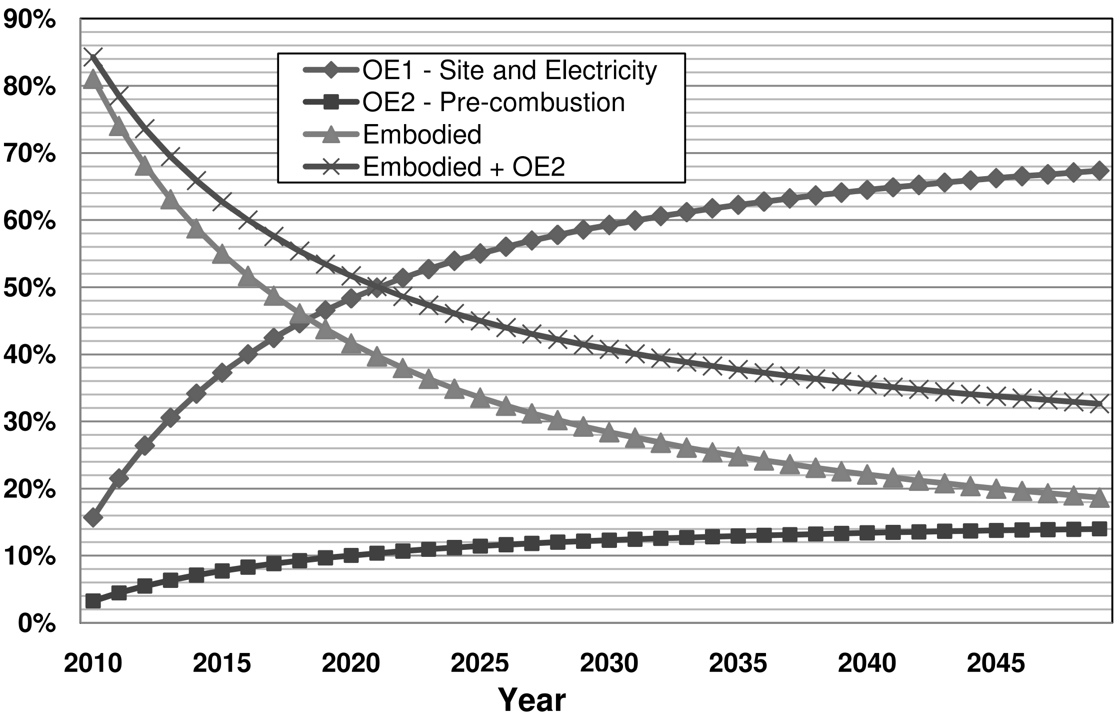
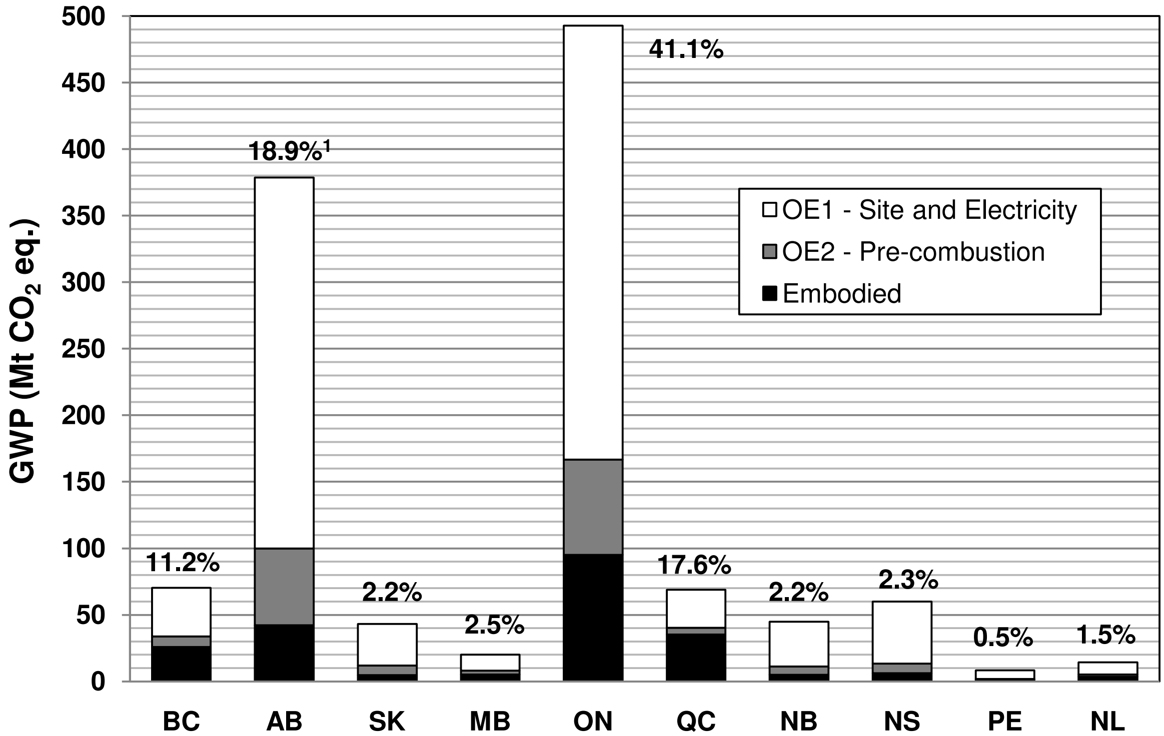


Figure 6.15: Baseline Stock GWP (2010-2049), by province



[1]percentage of total national annual completions

Normalized static building stock impact indicator results are presented in Figure 6.16 and resource use in Figure 6.17, by life cycle stage. With the exception of eutrophication, ozone depletion and solid waste, SH is a significant contributor to impacts, accounting for between 29% and 48% of total effects. Embodied effects together contribute 96% of eutrophication, 100% of ozone depletion, 69% of solid waste and between 19% and 44% of other impacts. SC accounts for less than 3% to any impact. With the exception of eutrophication and ozone depletion, DHW and AL account for 2.3-11.2% and 15-21% of effects, respectively.

In 2049 the Baseline building stock is predicted to consume 1,094 PJ of NRPE and 175 PJ of RPE, or 1,270 PJ TPE. This is equivalent to 10% of the estimated 12,786 PJ TPE consumed in Canada in 2007 [96]. Forty years of building stock TPE use amounts to 27,538 PJ. Over the course of 40 years the building stock is predicted to consume approximately 190,000 Mt of coal, 82 ML of crude oil, 270,000 Mm^3 of natural gas, 12

Mt of uranium, and 175 Mt of wood. Again, SH is generally the leading contributor to resource use, responsible for 27-62% of consumption. Embodied stages account for significant crude oil (36%) and wood (73%) due to feedstock use, and lesser contributions to coal and natural gas, at 10% and 14%, respectively. DHW contributes most to natural gas (17%) and RPE (12%) use due to the domination of these sources as heating fuel. Finally, AL accounts for significant coal, uranium, and RPE (29-47%), fuels generally used exclusively for electricity generation.

Figure 6.18 illustrates that provincial contributions to other impact indicators are of a similar order of magnitude as GWP; one exception to this is ozone depletion due to the high percentage of air conditioning use in Ontario. The relationship between provincial SH and DHW stock distribution, electricity generation mix, and energy resource use is illustrated Figure 6.19. Provinces with coal fired electricity generation such as Alberta, Saskatchewan, Ontario, New Brunswick, and Nova Scotia show the most significant use of this resource. A similar observation can be made with respect to those provinces that have significant hydroelectric generation (RPE), which include British Columbia, Manitoba, Ontario, Quebec, and Newfoundland. Ontario dominates uranium consumption (91%) due to its high construction rate and use of nuclear generated electricity. Despite low construction rates in Atlantic Canada, these provinces consume 31% of crude oil as a result of reliance on heating oil for SH and DHW. In contrast, Atlantic Provinces are responsible for only 1.9% of natural gas consumption.

Figure 6.16: Baseline Stock Impacts (2010-2049), by stage

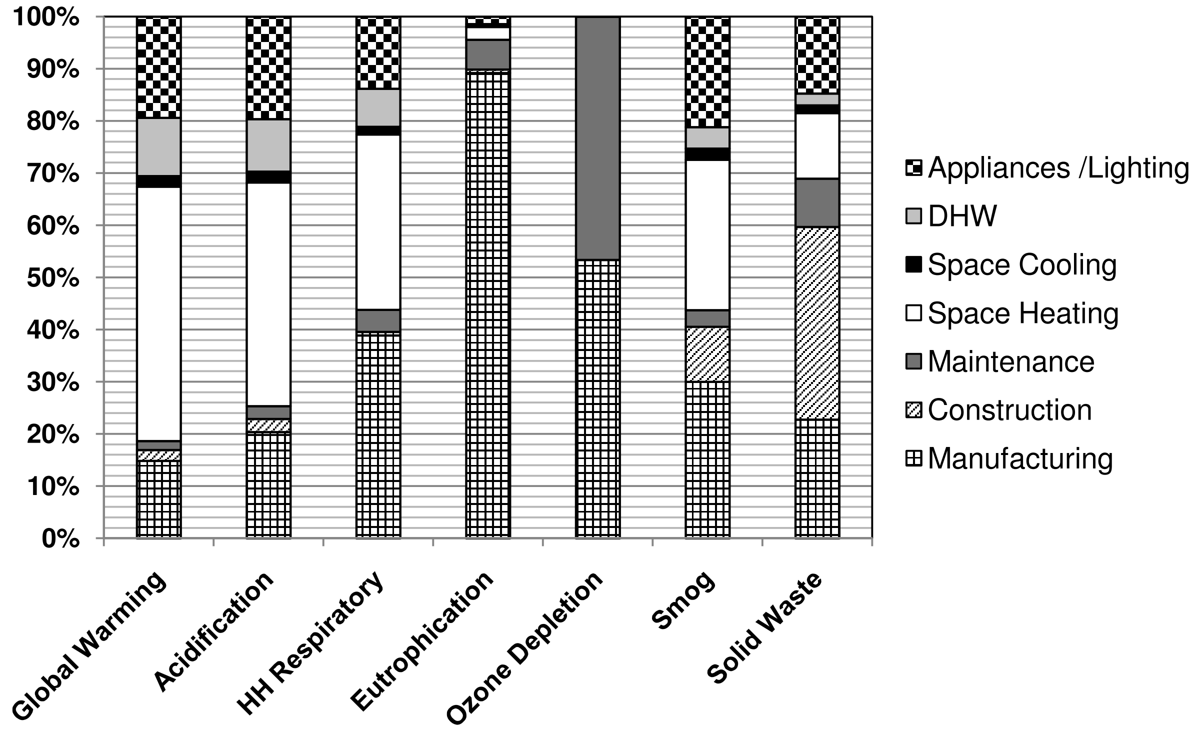


Figure 6.17: Baseline Stock Resource Use (2010-2049), by stage

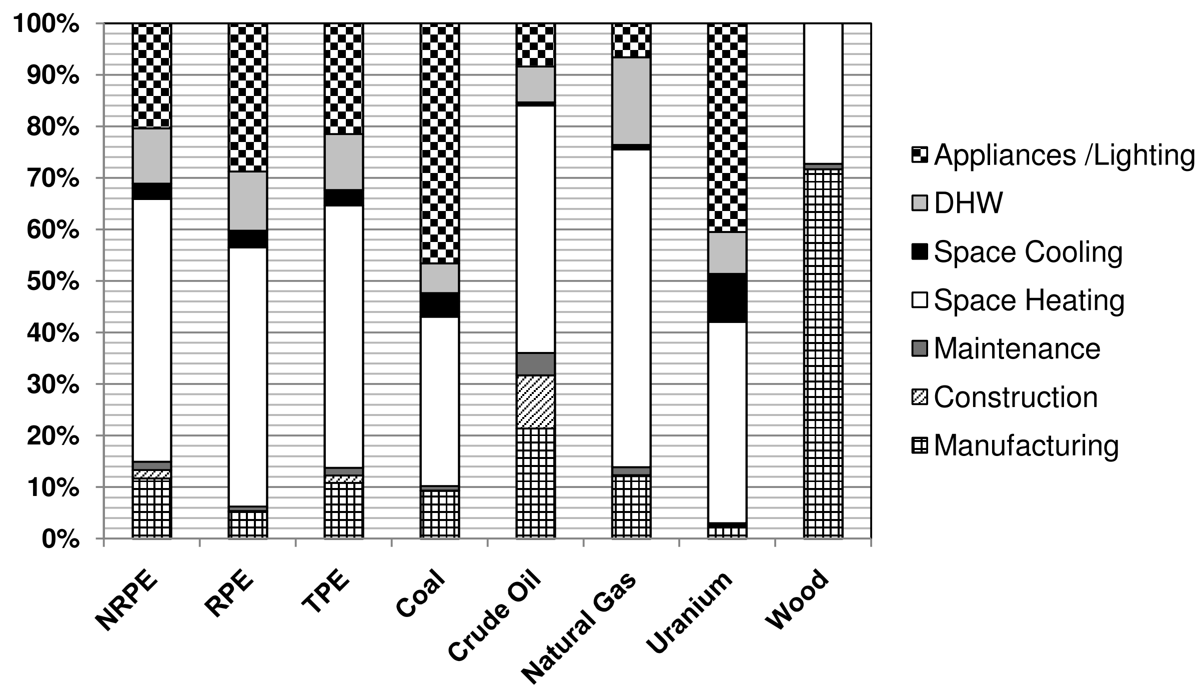


Figure 6.18: Baseline Stock Impacts (2010-2049), by province

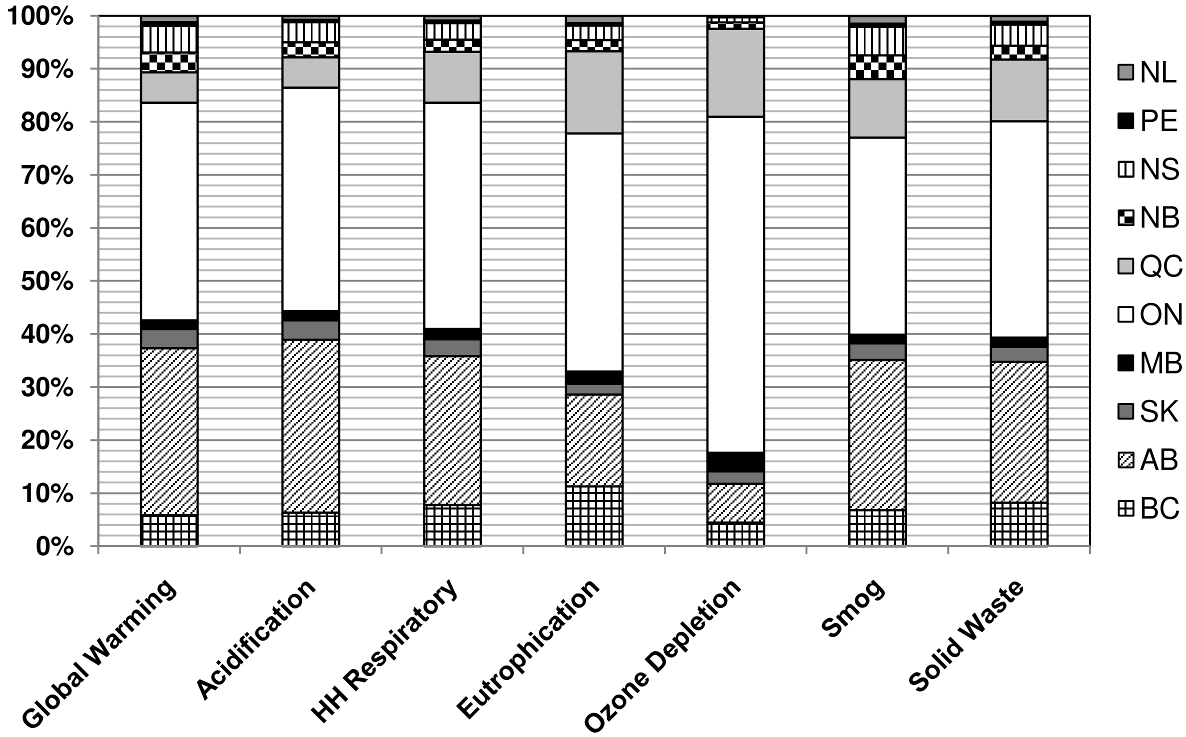
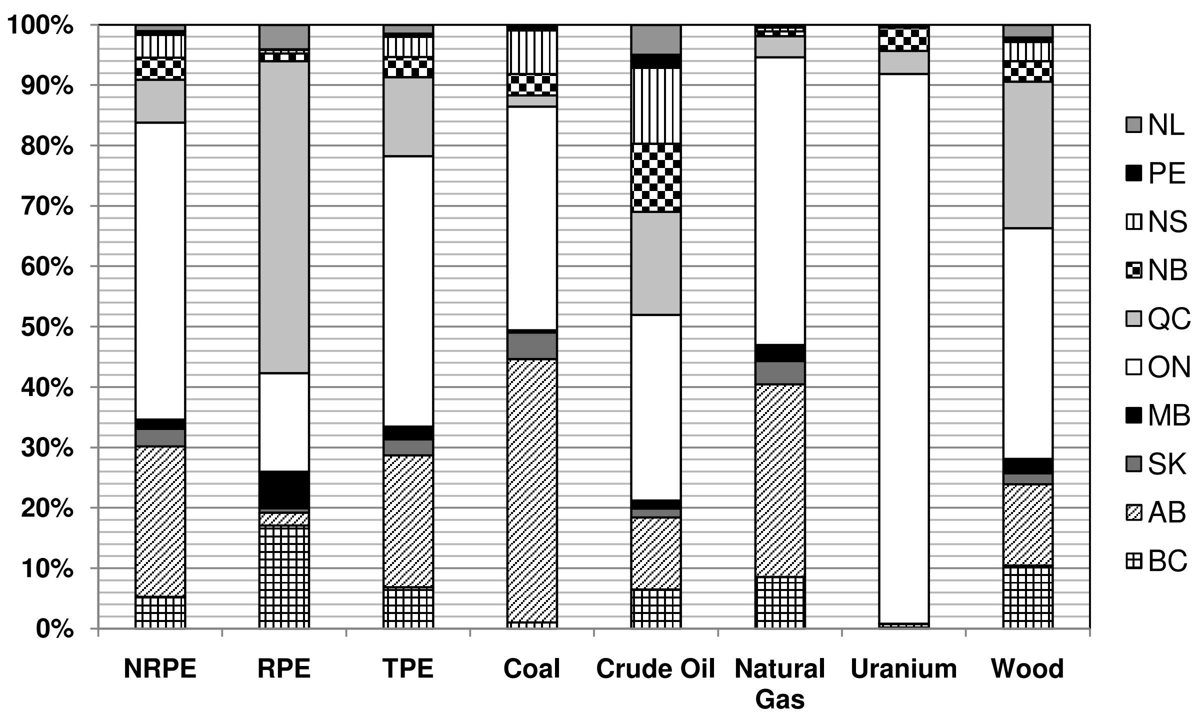


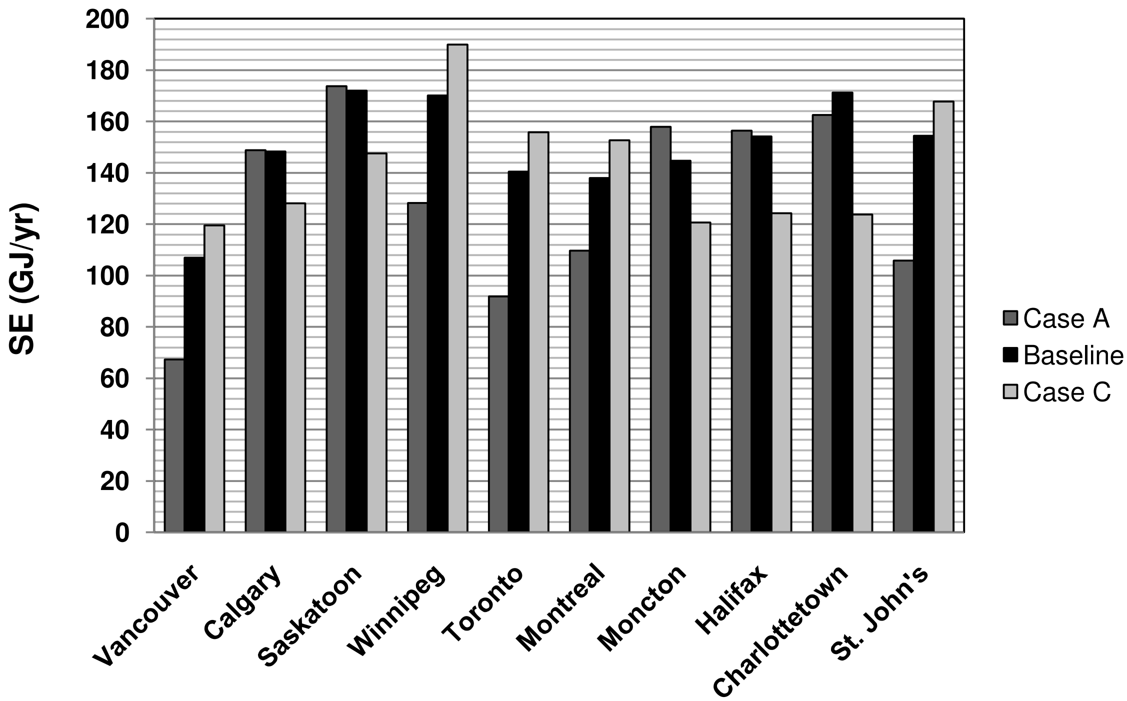
Figure 6.19: Baseline Stock Resource Use (2010-2049), by province



6.3 Sensitivity to Material and Fuel Choice

This section presents results for material/fuel Cases A and C, or the best and worst performing combinations with respect to GWP, as outlined in Section 4.3. All dwellings and building stocks are Design 1 energy performance. The Baseline refers to material/fuel mix Case B and is the same as presented in Section 6.2. The extent of GWP between Case A and Case C represents the range that can be expected for any design currently constructed to Design 1 energy performance standards.

Figure 6.20: Detached Dwelling Material/Fuel Use Case Annual SE



6.3.1 Dwelling Scale

A comparison of detached dwelling annual SE for the Baseline, Case A and Case C is shown in Figure 6.20. The results illustrate that reductions in GWP from fuel choice do not necessarily translate to reductions in SE on a per-Joule basis. Case A and C annual SE is further broken down by fuel type in Figures 6.20 and 6.21. Case A fuel use is primarily electricity in provinces with clean electric generation and natural gas in provinces dominated by fossil fuel electric generation. In contrast, Case C fuel use is primarily heating oil in provinces with clean electric generation and electricity in provinces dominated by fossil fuel electric generation. The resulting BOM for each case in Toronto is presented in Table B8 of Appendix B.

Figure 6.21: Detached Dwelling Material/Fuel Use Case A Annual SE

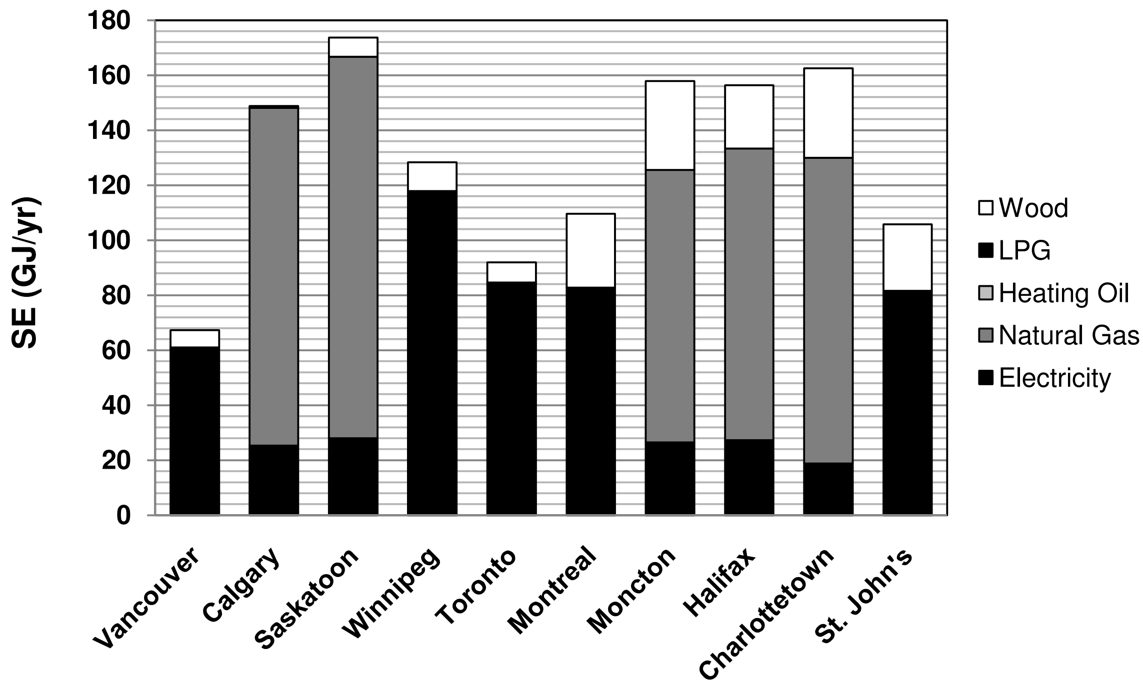


Figure 6.22: Detached Dwelling Material/Fuel Use Case C Annual SE

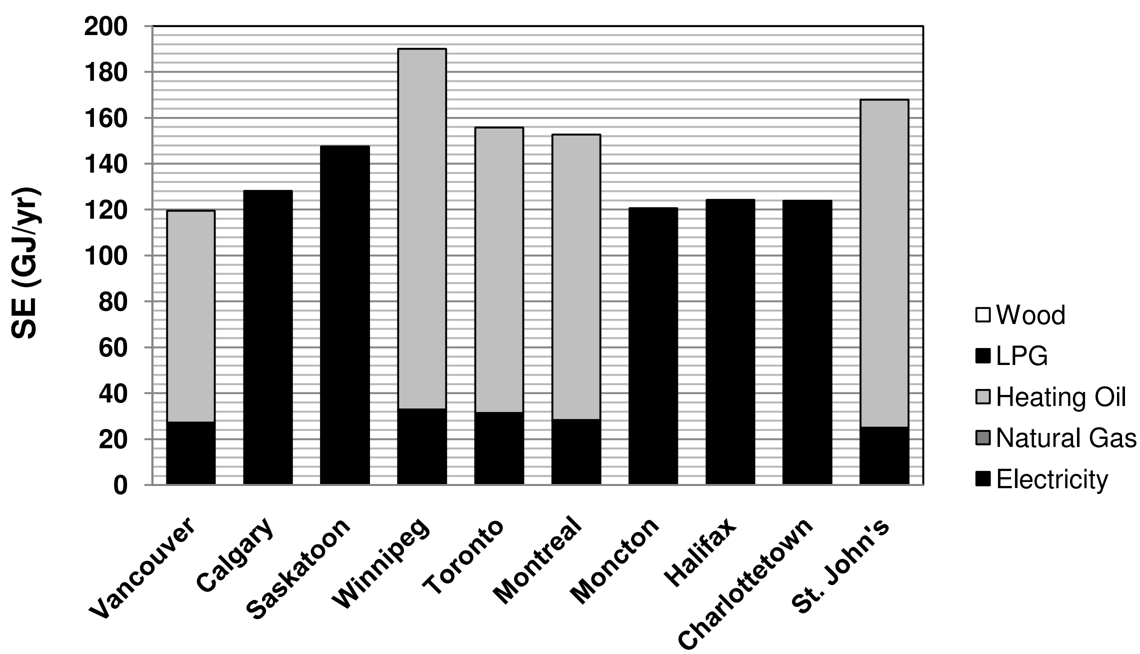


Figure 6.23 shows the 60 year detached dwelling Baseline GWP for 10 cities including bars depicting the sensitivity with respect to material and fuel choice. A breakdown of the sensitivity by life cycle stage for detached dwellings is provided in Figure 6.24.

Observed Trends – Dwelling Material/Fuel Use GWP Sensitivity

- The extent of dwelling sensitivity is 179-713 tonnes for row, 246-1,013 tonnes for semi-detached and 344-1,373 tonnes for detached housing, or 47-401%, 51-415%, and 56-387% of the Baseline, respectively.
- The total extent of sensitivity is highest in Calgary to lowest in Toronto. These findings generally reflect:
  (i) the dominance of fuel choice (i.e. operating energy) sensitivity;
  (ii) the large difference in emissions between electric and natural gas fuelled systems in Alberta;
  (iii) the small difference in emissions between electric and natural gas fuelled systems in Ontario.
- Relative to the Baseline there is a 4-21% and 4-78% reduction for Case A embodied and operational effects, respectively. Similarly, there is a 47-68% and 17-333% increase for Case C. Operating energy GWP varies considerably more than embodied GWP.
- With the exception of Moncton, the difference between Baseline and Case C is greater than Baseline and Case A. In other words the Baseline tends to be closer to the best case.
- Montreal is the best performing Case A detached dwelling at 57 tonnes and Calgary is the poorest performing Case C dwelling at 2,303 tonnes. It can therefore be said that 60-year GWP varies by a factor of at least 40 for dwellings constructed in Canada.

Figure 6.23: Dwelling Material/Fuel Use GWP Sensitivity, by dwelling type

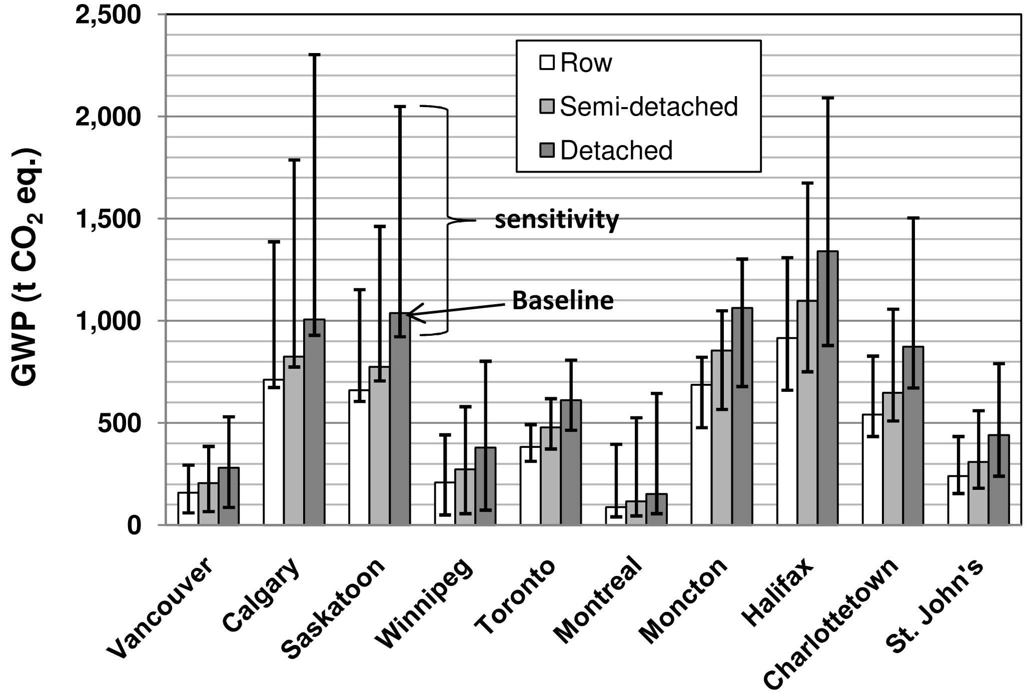
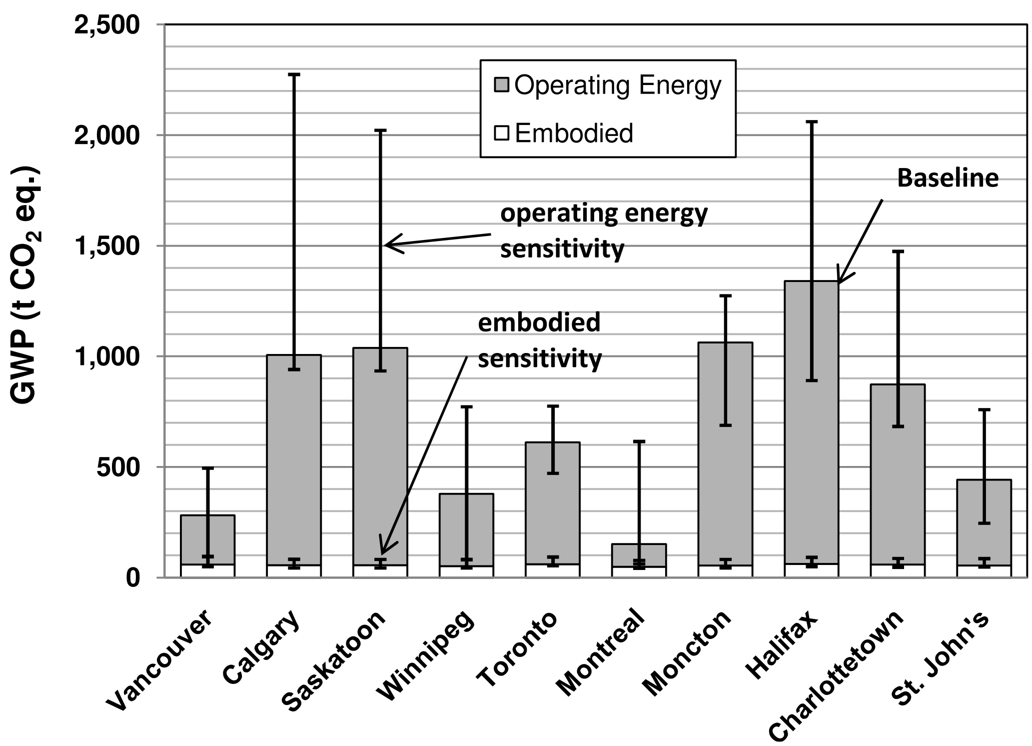


Figure 6.24: Detached Dwelling Material/Fuel Use GWP Sensitivity, by stage



6.3.2 Building Stock Scale

Tables B6 and B11 in Appendix B show SE and BOM for Case A and Case C over the 40-year period. This analysis serves to illustrate the degree of secondary resource use by the residential sector in the long term. Figure 6.25 presents annual GWP for the 3 material/fuel choice Cases; the resulting accumulated results are shown in Figure A5 of Appendix A. Figures 6.19 and 6.20 then show the associated annual operating energy and embodied GWP.

Observed Trends – Building Stock Material/Fuel Use Sensitivity

- The extent of sensitivity is 6.5 Mt in 2010 and increases to 59 Mt CO2 eq. in 2049.
- Case C represents a ± 82% increase and Case A represents a ± 25% decrease relative to the Baseline. Similar to the dwelling analysis, the Baseline is closer to the best case.
- The 2049 range of 41-100 Mt CO_2 eq. represents 5.5% to 13% of Canadian emissions in 2007.
- After forty years the extent of accumulated sensitivity is 1,316 Mt, with Case A responsible for 910 Mt and Case C 2,226 Mt of GWP emissions. The extent of sensitivity is therefore 115 Mt greater than the Baseline emissions.
- The percent embodied contribution to accumulated GWP is in the same order of magnitude for each case, beginning at 80-87% in 2010 and ending at 17-19% in 2049.
- All three cases exhibit linearly increasing operating energy impacts (between 0.90 Mt and 2.25 Mt CO_2 eq. per year) since dwellings of equal energy performance are added at a constant rate over the 40 year period.
- Embodied emissions gradually increase as maintenance stage emissions occur over time:
    (i) The Baseline exhibits many small increases in embodied GWP since its material mix includes various assemblies that are replaced at different times.

(ii) Case A shows spikes in embodied effects at 15-16 years due primarily to the beginning of heat pump and window replacement and at 25 years due to cladding and roofing replacement.

(iii) Case C sees its most significant increase at 25 years when aluminum windows begin to be replaced in the stock.

- Over the study period, maintenance effects increase embodied GWP by a factor of 1.4, 1.3, and 1.2 for Case A, the Baseline, and Case C material/fuel choice combinations, respectively. The higher percent increase for Case A can be attributed to the use of wood products with higher replacement rates. Much of the envelope replacement for the Baseline and Case C occur after the 40 years.

Figure 6.25: Building Stock Material/Fuel Use GWP Sensitivity

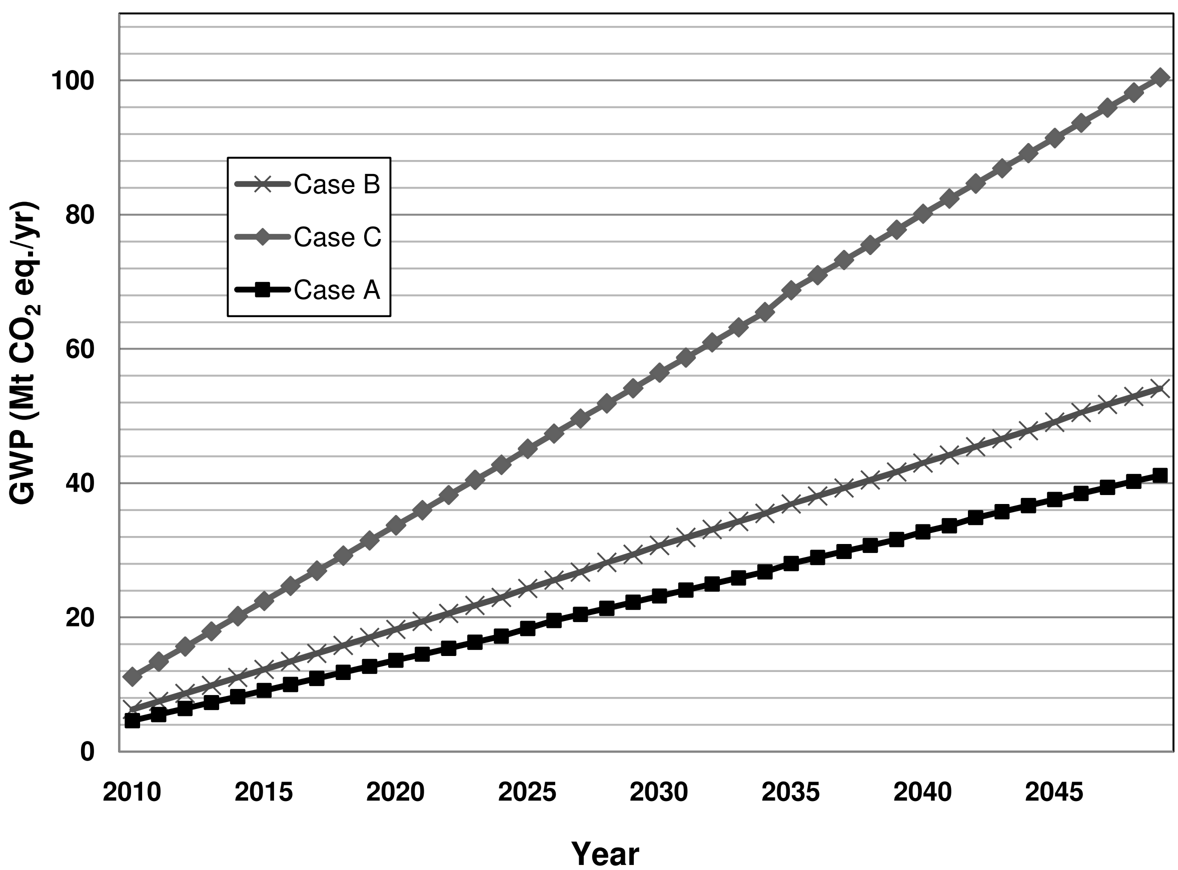


Figure 6.26: Building Stock Material/Fuel Use Operating Energy GWP Sensitivity

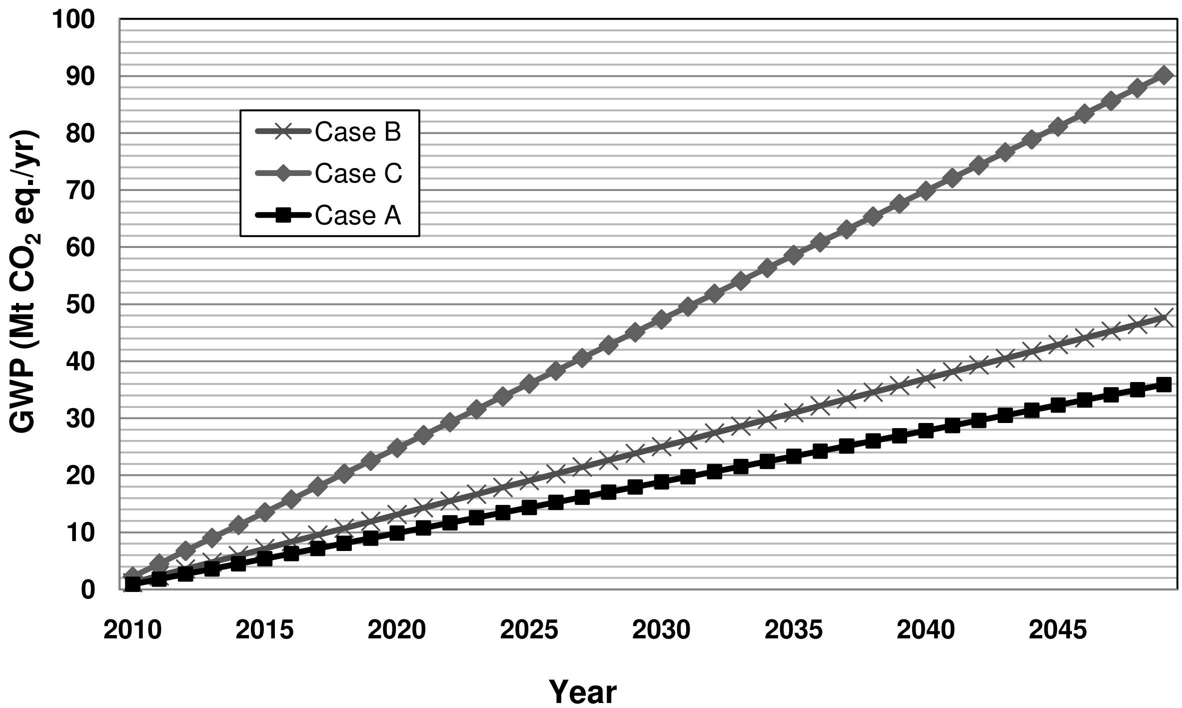


Figure 6.27: Building Stock Material/Fuel Use Embodied GWP Sensitivity

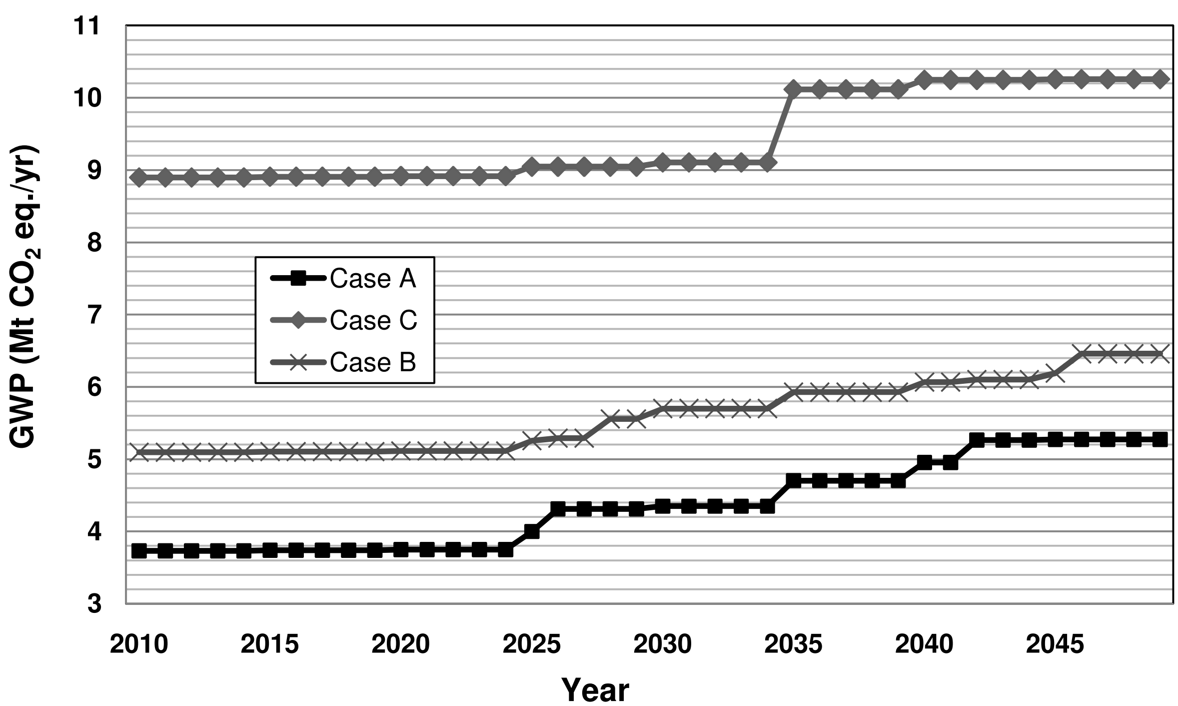


Figure 6.28 presents 40-year impacts for the three material/fuel cases, normalized to the Baseline. It should be noted that for other impact and resource use indicators the sensitivity does not represent best- and worst-cases, but the changes in effects due to the best and worst GWP mixes of materials and fuels. While many of the best/worst mixes may be the same, GWP sensitivity is the largest relative change among indicators, suggesting additional analysis is required to determine the best- and worst-case material/fuel combinations for other indicators. With the exception of eutrophication and ozone depletion, all impact results are higher (25-85%) for Case C and lower for Case A (7-24%); again, the Baseline results are closer to Case A than Case C. Higher ozone depletion for Case A is the result of increased heat pump usage.

The effect of material and fuel choice on energy resource use is shown in Figure 6.29. Annual TPE consumption in 2049 is 1,189 PJ for Case A and 1,641 PJ for Case C. The extent of sensitivity for the Baseline in 2049 is therefore 452 PJ, representing a range of 9% to 13% of Canada's TPE consumption in 2007. After 40 years, accumulated TPE is 25,434 PJ and 36,228 PJ for Cases A and C, an 8% decrease and 32% increase relative to the Baseline, respectively. Case C favors high GWP emission fuels such as coal and crude oils, whereas Case A favors low GWP emission fuels such as uranium and RPE. One exception to this is a small increase in coal use for Case A relative to the Baseline. This is a result of the choice of electric SH and DHW systems in Ontario and Manitoba where coal is included in their electricity generation mixes. This increase is greater than coal use reductions in Alberta, Saskatchewan, New Brunswick, and Nova Scotia from switching to exclusively natural gas SH and DHW systems. Natural gas use is lower for Case A than the Baseline as a result of (i) the choice of electric systems in British Columbia, Manitoba, and Ontario - provinces that typically use a lot of natural gas, and (ii) the provinces that use exclusively natural gas systems in Case A either already use significant gas (i.e. Alberta, Saskatchewan Baseline), or (iii) are provinces with low levels of construction (i.e. New Brunswick, Nova Scotia, Prince Edward Island).

Figure 6.28: Building Stock Material/Fuel Use Case Impacts (2010-2049)

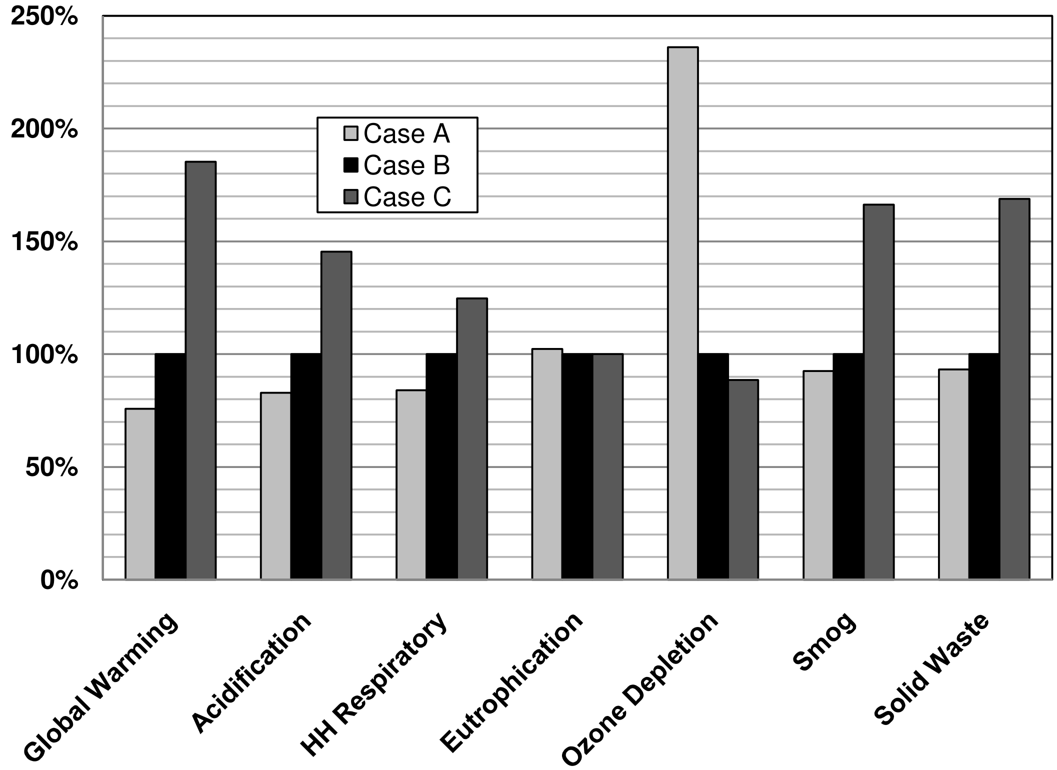
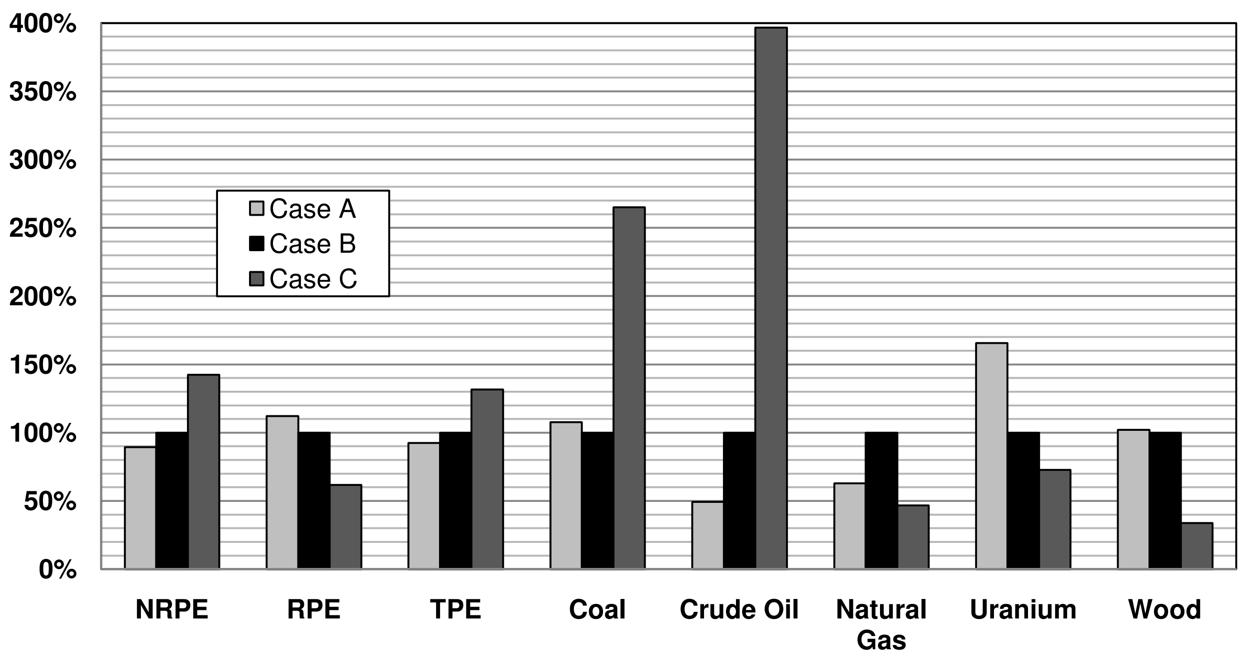


Figure 6.29: Building Stock Material/Fuel Use Case Resource Use (2010-2049)



6.4 Sensitivity to Energy Efficiency Measures

This section provides results for dwellings and building stocks with improved SE performance in accordance with the methodology outlined Section 4.4. All results consider only material/fuel Case B; again, the Baseline herein refers to all dwellings or building stocks of material/fuel Case B and energy Design 1.

6.4.1 Dwelling Scale

Figure 6.30 presents annual SE results for Design 6 dwellings, by dwelling type. Reductions with respect to Design 1 are 38-65 GJ/yr (53-70% reduction) for row, 49-86 GJ/yr (60-71% reduction) for semi-detached, and 68-128 GJ/yr (65-75% reduction) for detached units. SH is responsible for the majority of energy reduction (65-91%), followed by DHW (8-34%), and AL (0-1%). SC energy use increases between Design 1 and 6, but remains less than 13% of SE for any city. Results by end-use are given for detached dwellings in Figure 6.31; this serves to illustrate the more even balance of household consumption among SH, DHW, and AL. Detached dwelling SE by fuel type follows in Figure 6.32. Electricity is the dominant fuel used in the household mixes, accounting for 45-94% of SE. Relative to the Baseline dwellings, Designs 2 through 6 require ever greater material inputs via envelope improvement for increased energy efficiency. The BOM for these additional inputs is given in Table B9.

Figure 6.30: Detached Dwelling Design 6 Annual SE, by dwelling type

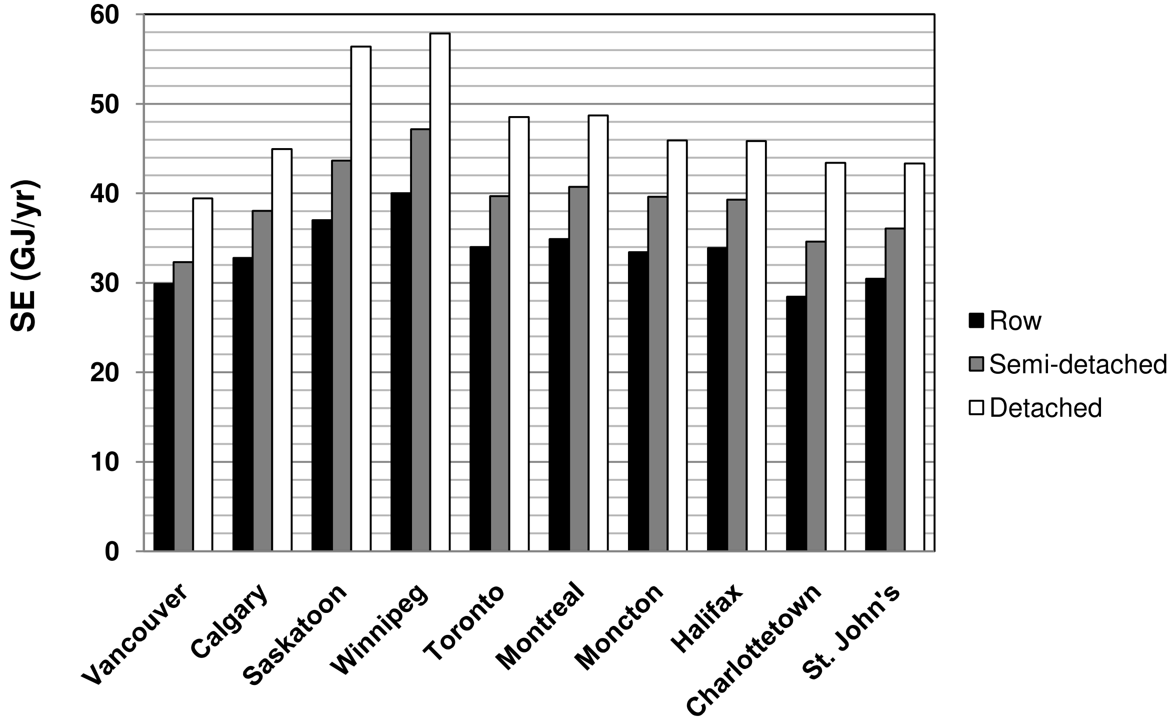


Figure 6.31: Detached Dwelling Design 6 Annual SE, by end-use

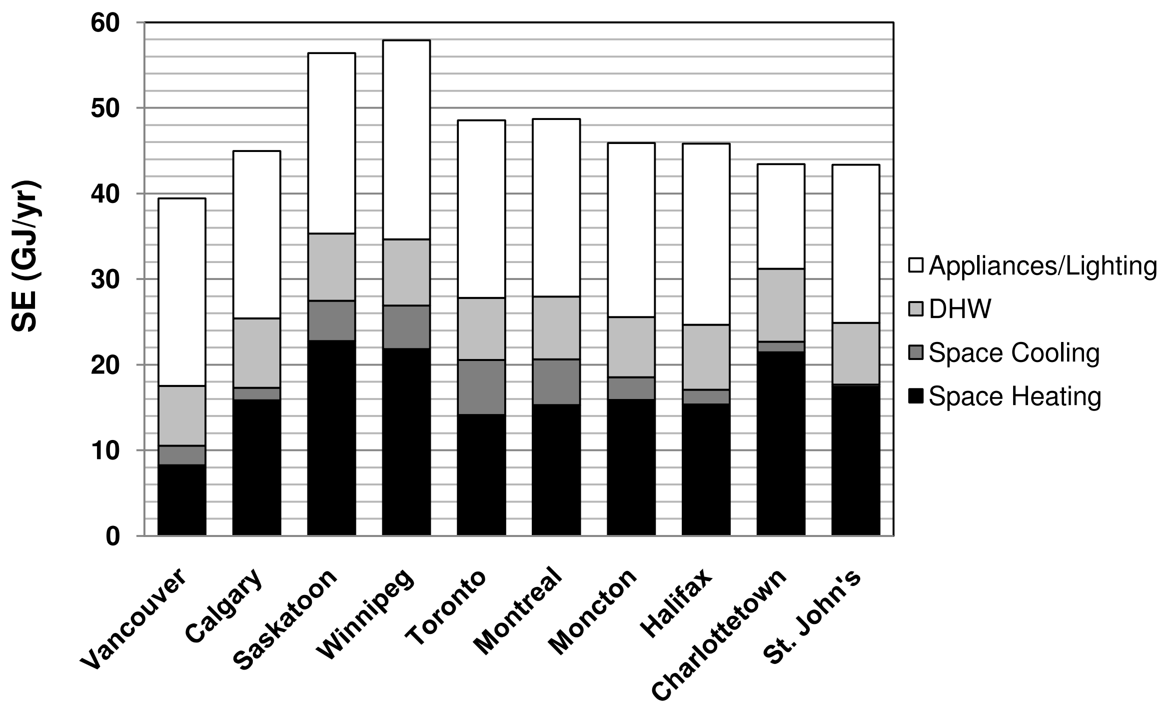


Figure 6.32: Detached Dwelling Design 6 Annual SE, by fuel

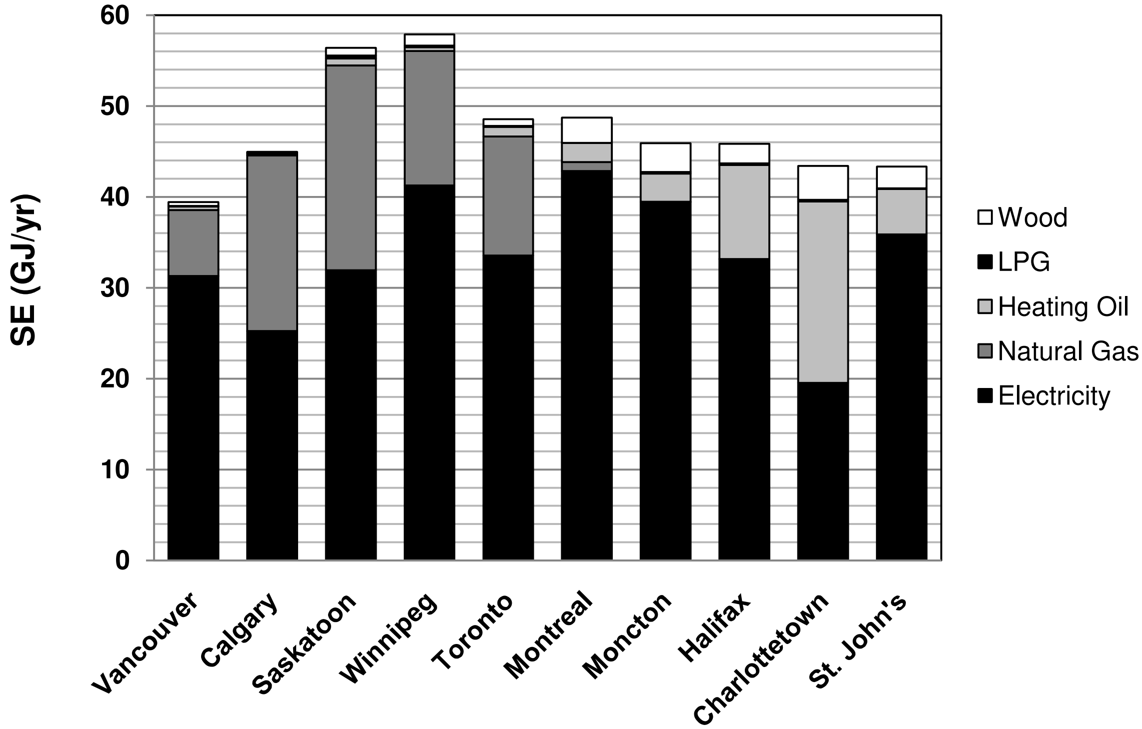


Figure 6.33 shows life cycle GWP for Design 6 dwellings for row, semi-detached, and detached housing and Figures 6.34 and 6.35 provide further details for detached units.

Observed Trends – Design 6 Dwelling GWP

- Row and semi-detached designs emit 63-81% and 73-87% that of detached housing, respectively. Dwelling type influences GWP less for Design 6 than Design 1 dwellings.
- The percent SH emissions is 3-23% for row, 8-31% for semi-detached, and 11-32% for detached housing. SH contribution to total emissions is reduced for Design 6 dwellings.
- SC is responsible for less than 11% of emissions for all dwelling types.
- Total emissions across cities varies 52-524 tonnes for row, 62-571 tonnes for semi-detached and 80-657 tonnes for detached housing.
- The percent embodied emissions is 9-82% for row, 10-78% for semi-detached, and 11-78% for detached housing.

- Pre-combustion (OE_2) of detached dwellings is 14-20% of operating energy stage GWP.
- EE and OE_2 together are responsible for 24-81% of detached emissions. LCA analysis therefore accounts for 1.3 to 5.3 times the impact as typical analysis.
- Between Design 1 and Design 6 detached dwellings there is a 72 to 683 tonnes CO_2 eq. decrease in GWP, or 43% to 66% reduction. This is the result of a decrease in operating energy GWP of 85-696 tonnes and increase in embodied GWP of 11-14 tonnes CO_2 eq.
- The additional detached dwelling embodied GWP is equivalent to 1.1 year in Halifax to 9.5 years in Montreal of annual operational GWP savings. This variation is influenced by the significance of operating energy to total GWP for each dwelling.
- GWP reduction generally diminishes for each successive energy Design.

Figure 6.33: Dwelling Design 6 GWP, by dwelling type

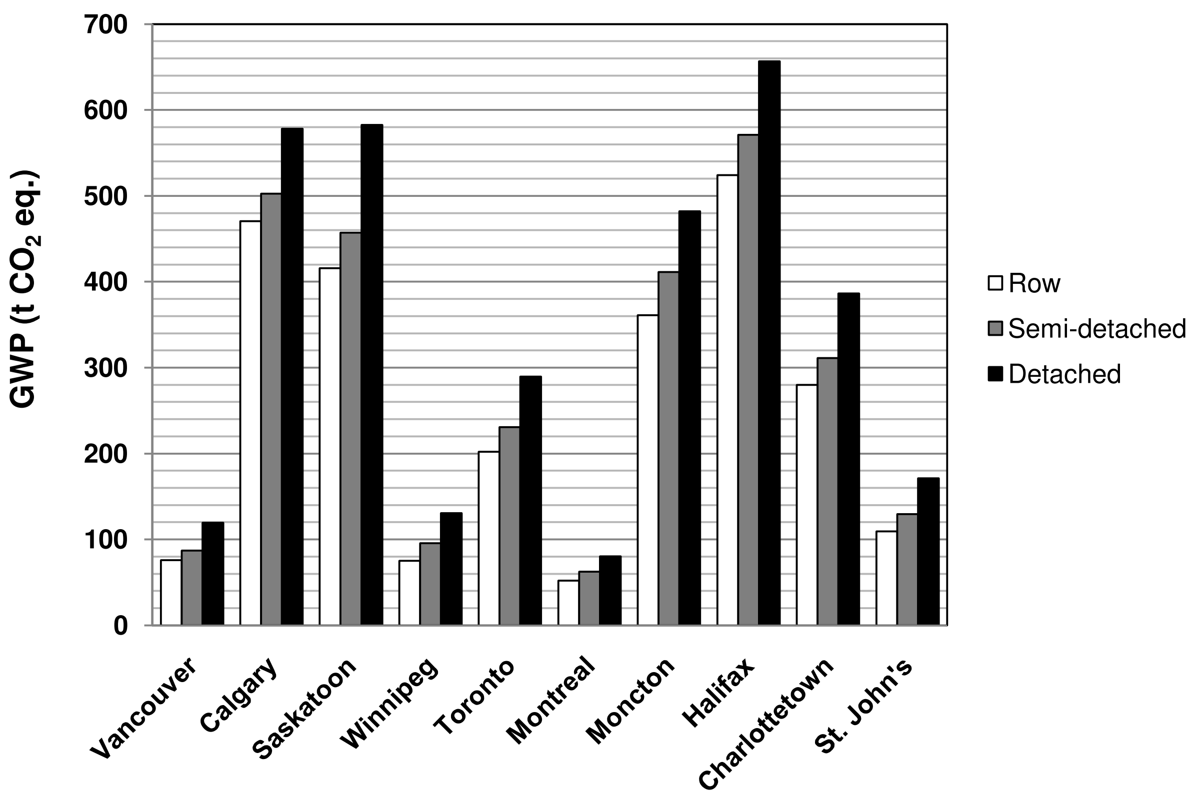


Figure 6.34: Detached Dwelling Design 6 GWP, by component

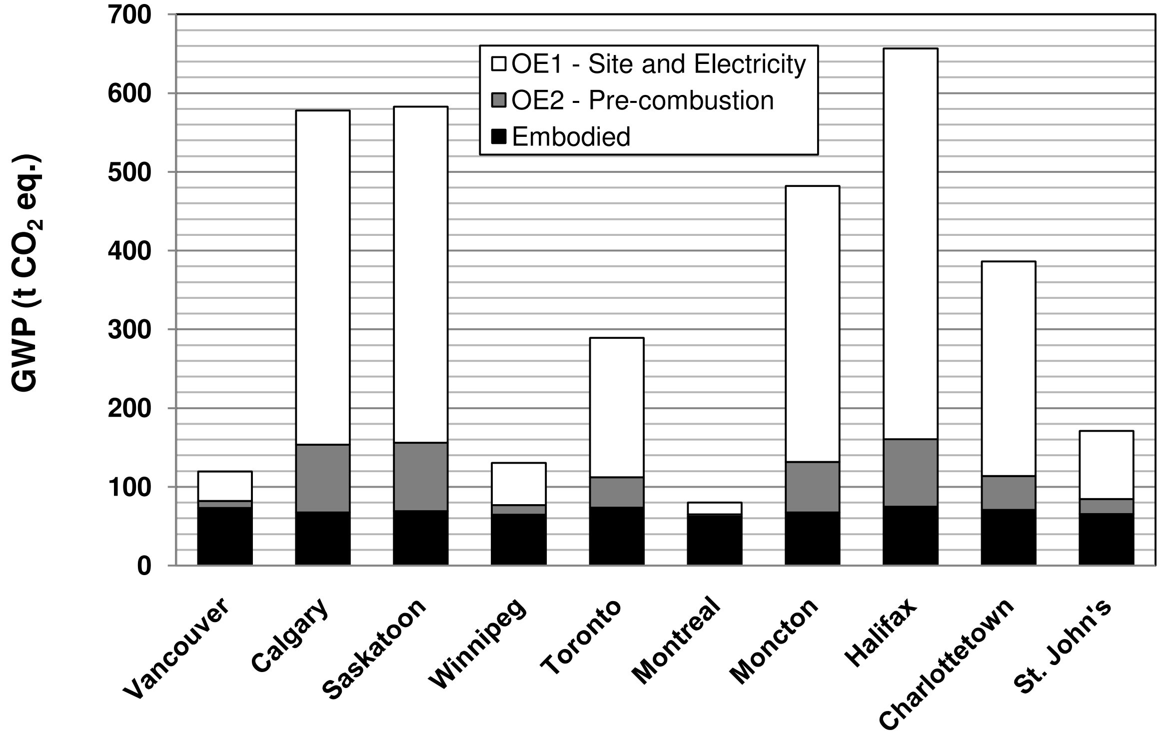
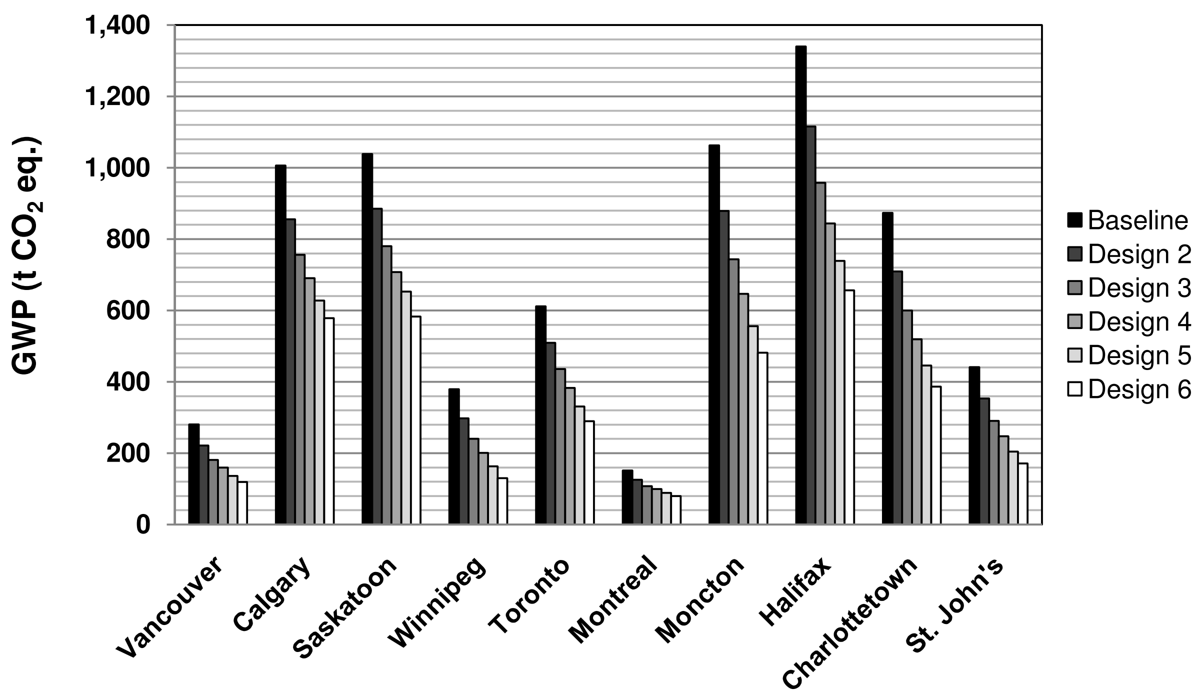


Figure 6.35: Detached Dwelling GWP for Designs 1 through 6



6.4.2 Building Stock Scale

The four building stock scenarios considered are labeled “Baseline”, “7 Years”, “4 Years”, and “0 Years”. The number of years refers to the period dwellings are constructed with a particular Design. For example, the 7 Years scenario considers Design 1 dwellings built in 2010-2016, Design 2 dwellings built in 2017-2023, Design 3 dwellings in 2024-2030, etc. The 0 Years scenario considers Design 6 dwellings built starting in 2010, and therefore represents a best case. Years in which Designs are introduced in the scenarios is presented in Table 6.1.

Table B12 of Appendix B shows the additional material inputs relative to the Baseline required over the 40-year period for each of three scenarios and 40-year SE is presented in Table B7. The next three Figures (6.36-6.39) are annual GWP emissions for the building stock scenarios, starting with total GWP, and then breakdowns of operating energy and embodied stage GWP. In addition, accumulative total GWP is given in Figure A6.

Table 6.1: Energy Efficiency Building Stock Scenarios

Scenario	Year of Introduction in Stock					
	Design 1	**Design 2**	**Design3**	**Design 4**	**Design 5**	**Design 6**
Baseline	2010	-	-	-	-	-
7 Years	2010	2017	2024	2031	2038	2045
4 Years	2010	2014	2018	2022	2026	2030
0 Years	-	-	-	-	-	2010

Observed Trends - Building Stock Energy Efficiency Scenario GWP

- In 2049, annual GWP is reduced by 13.8, 18.9, and 25.5 Mt CO_2 eq./yr (percent reductions of 26%, 35%, and 47%) relative to the Baseline for scenarios 7 Years, 4 Years, and 0 Years, respectively.
- Percent annual GWP reductions are less than 10% until the years 2028, 2021, and 2012, for 7 Years, 4 Years, and 0 Years scenarios, respectively. In other

words, it takes 12, 8, and 3 years after the first improvement to dwellings constructed to see noticeable reduction in GWP.

- The payback in terms of accumulated GWP is longer. Relative to the Baseline, percent accumulative GWP reductions are less than 10% until the years 2038, 2029, and 2014, for 7 Years, 4 Years, and 0 Years scenarios, respectively.
- After 40 years total GWP reductions are 186, 289 and 505 Mt CO_2 eq. (15%, 24%, and 42%) for scenarios 7 Years, 4 Years, and 0 Years, respectively.
- The percent GWP reduction of the 0 Years scenario with respect to the Baseline (42%) is lower than the range of percent reduction noted for Design 6 dwellings with respect to Design 1 dwellings (43% to 66%) in Section 6.3.1. This is caused by the reduced influence of the operating energy stage relative to embodied effects in dynamic analysis of a growing building stock.
- For the Baseline and 0 Years scenarios, the operational GWP rises at a linear rate due to the constant annual dwelling construction rate. Scenarios 7 Years and 4 Years show increasing operational emissions at a decreasing rate, a consequence of improvements to the dwellings constructed over time.
- Over 40 years the maintenance stage increases embodied GWP by a factor of about 1.3, whereas the change in dwelling design alters embodied GWP by a factor of 1.2.
- The percent embodied emissions in 2049 are 24%, 28%, and 39% for scenarios 7 Years, 4 Years, and 0 Years. This increase relative to the Baseline is due to the emergence of more energy efficient (i.e. more material intensive) dwellings.
- After 40 years the GWP payback in terms of additional embodied emissions is 4.3 to 3.5 years, with lower paybacks for more aggressive efficiency measures (i.e. Years 0 scenario).

Figure 6.36: Building Stock Energy Efficiency Scenario GWP

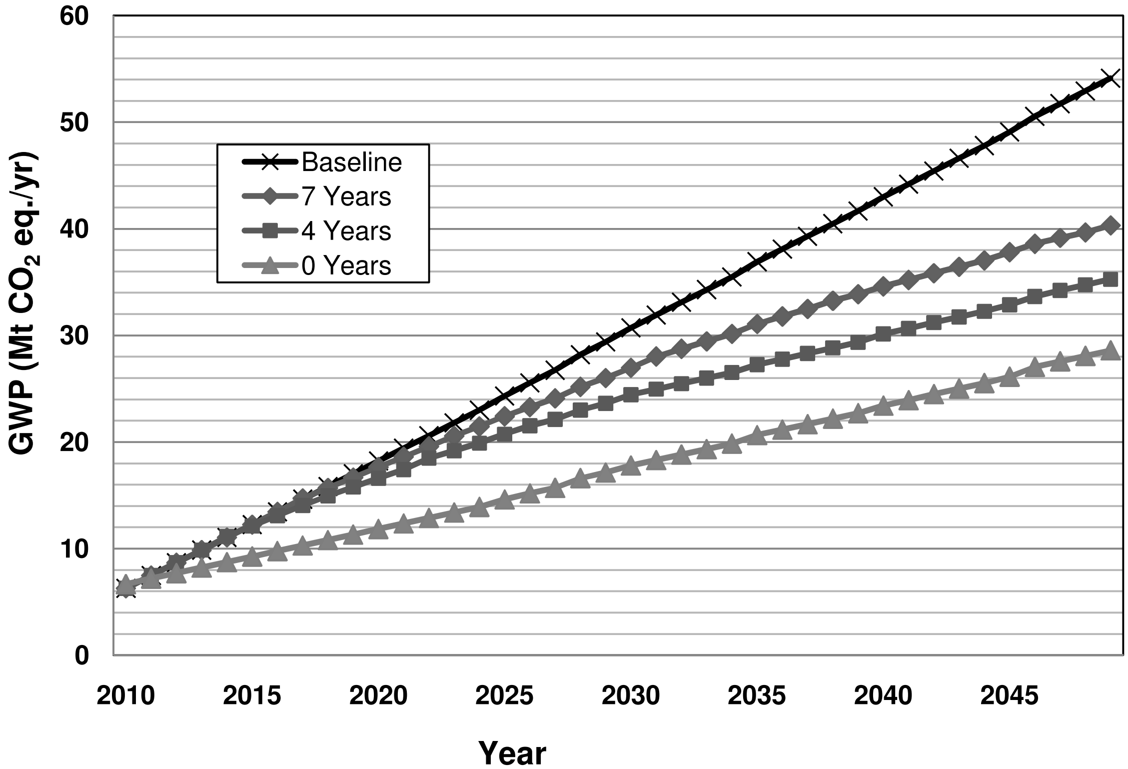


Figure 6.37: Building Stock Energy Efficiency Scenario Operating Energy GWP

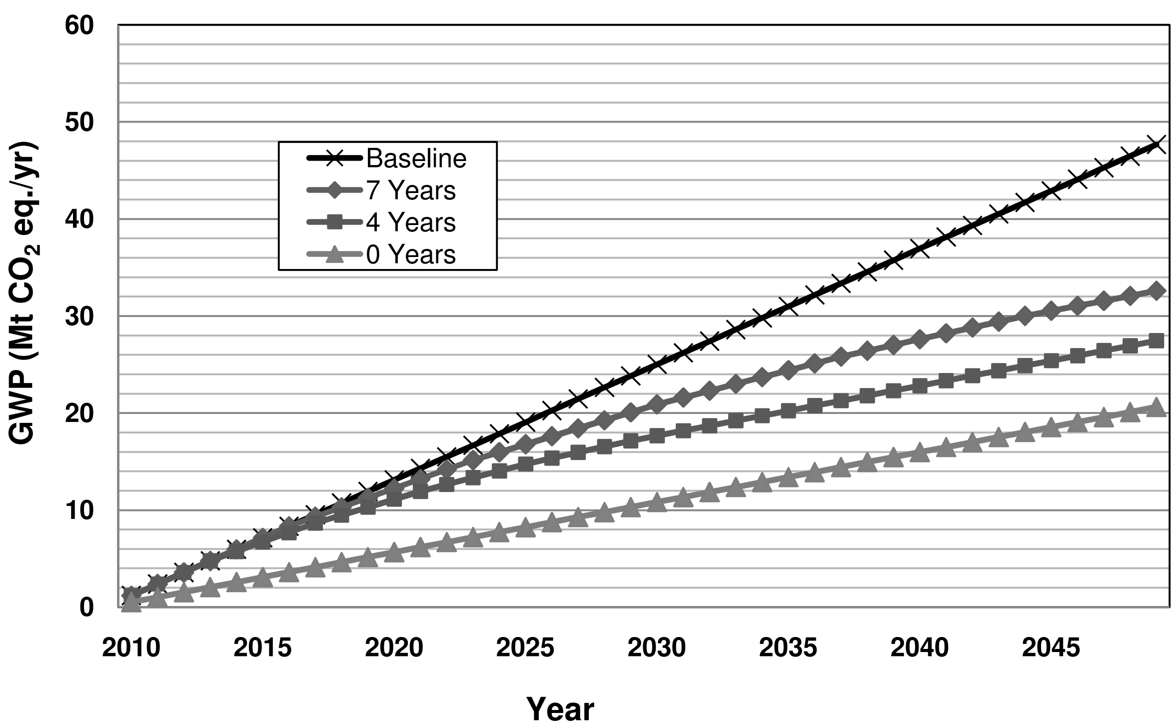


Figure 6.38: Building Stock Energy Efficiency Scenario Embodied GWP

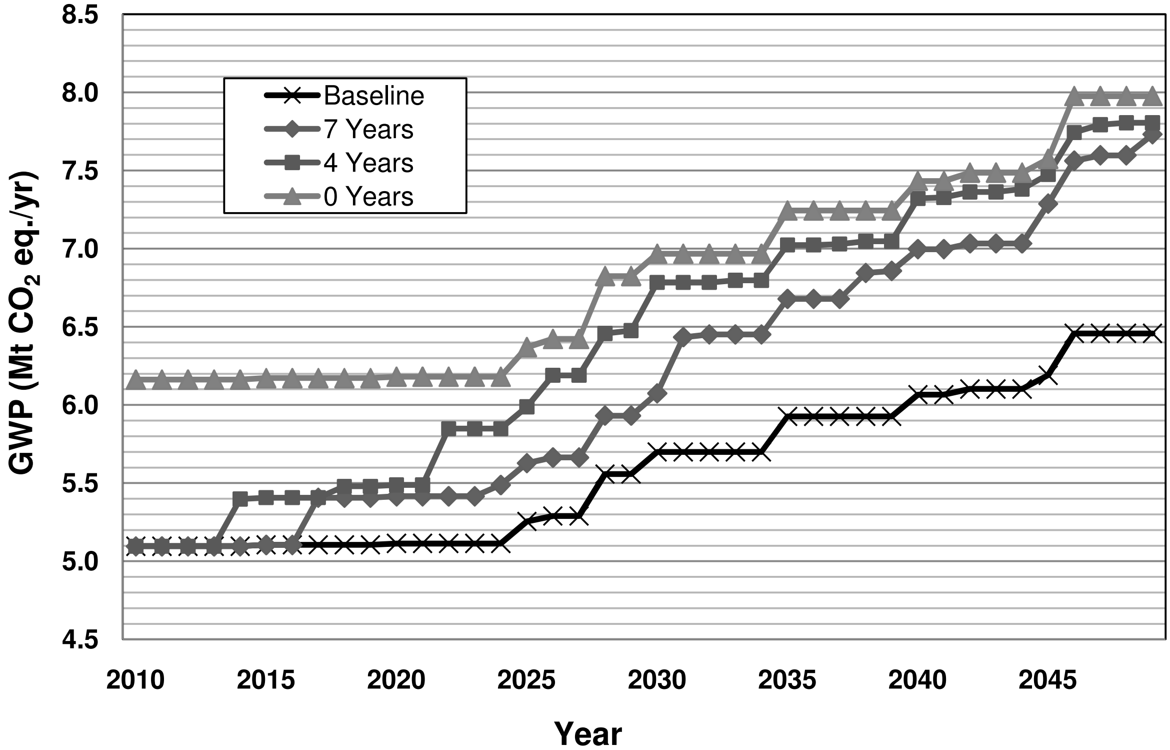
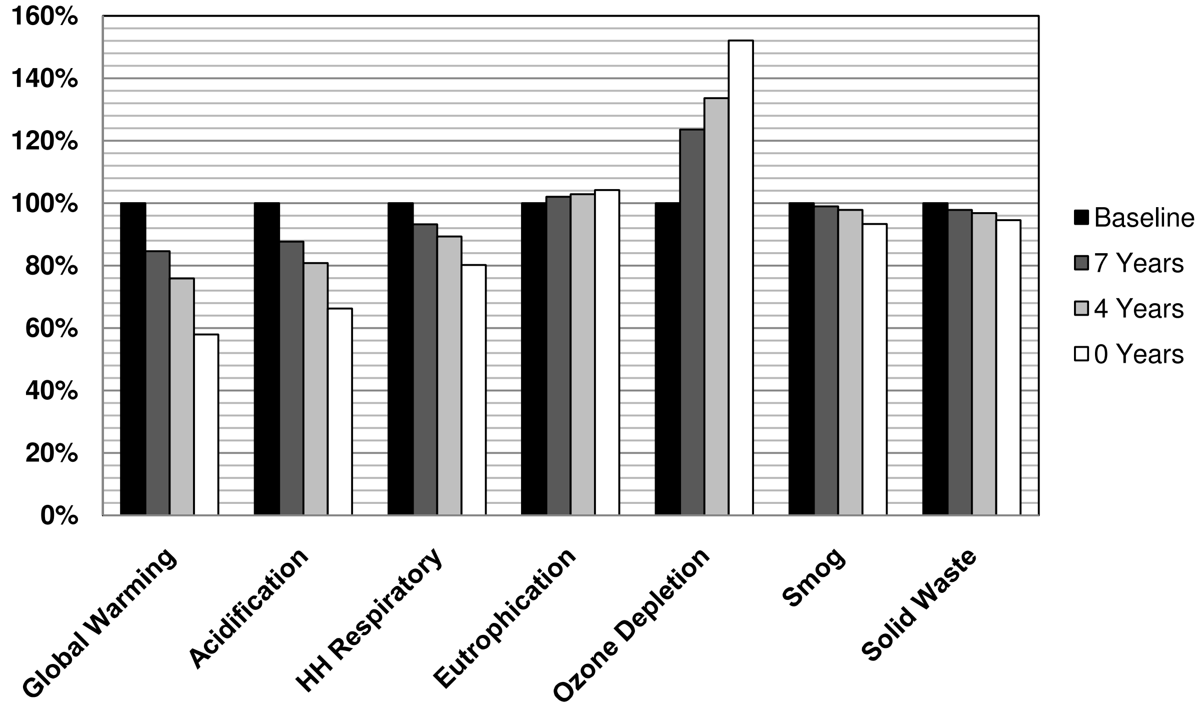


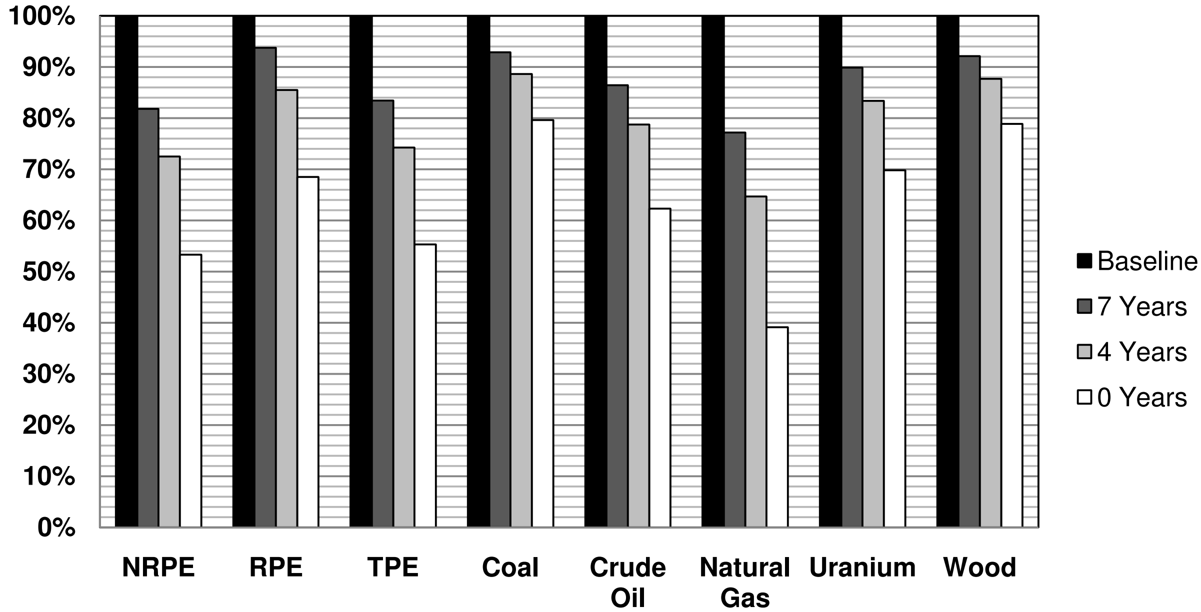
Figure 6.39 presents impact indicator results for the three energy efficiency scenarios relative to the Baseline. Reductions are noted across the three scenarios for all other impacts with the exception of eutrophication and ozone depletion. The increase in ozone depletion can be explained by the greater share of air-conditioning use for Designs 2 though 6. The degree of impact reduction for the various indicators and scenarios is dependent on (i) the significance of the operating energy stage to total impact and (ii) the influence of additional material inputs for energy efficiency. With the exception of ozone depletion, percent reduction for scenario 0 Years varies from 42% for GWP to 5% for solid waste. Across the four scenarios the embodied emissions account for 19-39%, 25-48%, 96-98%, and 100% of GWP, acidification, eutrophication, and ozone depletion, respectively, and in the range of 44-77% for HH respiratory effects, photochemical smog, and solid waste. Again, the percent embodied emissions increase with increased energy efficiency.

Figure 6.39: Building Stock Energy Efficiency Scenario Impacts (2010-2049)



As shown in Figure 6.40, reductions in SE use for scenarios 7 Years, 4 Years, and 0 Years reduces energy resource use in all cases. In 2049, scenarios 7 Years, 4 Years, and 0 Years are predicted to consume 937 PJ, 818 PJ, and 661 PJ TPE, respectively. Including the Baseline, the four scenarios represent 10%, 7%, 6% and 5% of total Canadian energy use in 2007. 40 year primary energy consumption is 23,024 PJ, 20,504 PJ, and 15,309 PJ, amounting to reductions of 16%, 25%, and 44% relative to the Baseline. The degree of reduction is influenced by what each respective fuel is typically used for. Since SE reduction comes from SH and DHW use, fuels used for these purposes are reduced the most. For example, there is up to a 38%, 61% and 32% reduction relative to the Baseline for crude oil, natural gas and RPE, respectively. In the case of RPE, provinces that generate a lot of electricity this way typically have a higher percentage of electric space and water heaters. Lesser reductions are noted for fuels exclusively used for electricity generation such as coal and uranium.

Figure 6.40: Building Stock Energy Efficiency Scenario Resource Use (2010-2049)

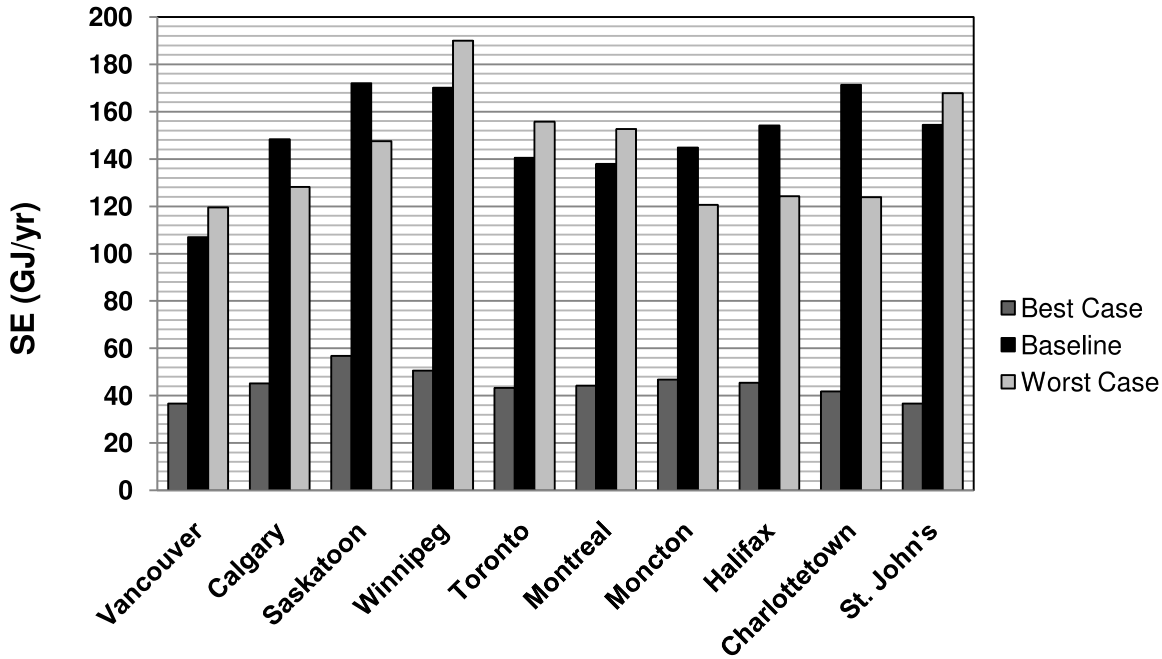


6.5. Total Housing GWP Sensitivity

GWP within the research scope varies between Case A Design 6 (Best Case, or BC) and Case C Design1 (Worst Case, or WC). Total GWP sensitivity is not the sum of the two types (material/fuel + energy performance) since better fuel choice reduces the reduction potential of energy efficiency (and vice versa).

The effect of GWP sensitivity on annual SE is shown in Figure 6.41. By comparing these results to those of Figure 6.20 (Section 6.3) it can be concluded that BC annual SE is more a function of energy Design than material/fuel Case. Table B6 (Appendix B) shows corresponding static SE results at the building stock scale and BOMs for Toronto detached dwellings and building stocks are presented in Tables B10 and B11. Figure 6.42 shows the combined results of Figures 6.23 (Section 6.3) and 6.35 (Section 6.4) to illustrate the relative effects of material/fuel use choice and energy efficiency measures. Total Dwelling GWP sensitivity for each dwelling type is then presented relative to the Baseline in Figure 6.42. Finally, the BC, WC and Baseline building stocks are shown in Figure 6.44.

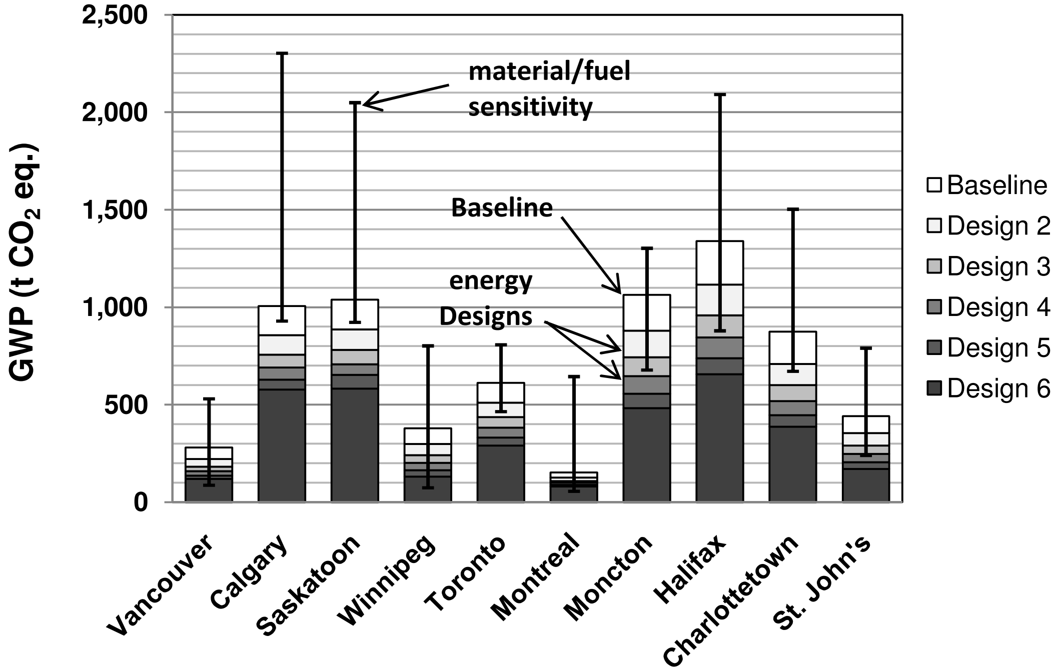
Figure 6.41: Detached Dwelling Annual SE of Total GWP Sensitivity



Observed Trends - Total Housing GWP Sensitivity

- The relative influence between material/fuel choice and energy efficiency is different across cities.
- The extent of dwelling sensitivity is 237-933 for row, 325-1,306 for semi-detached and 450-1,754 for detached housing, or 75-399%, 83-414%, and 86-387% of the Baseline, respectively.
- Montreal is the best performing detached dwelling at 56 tonnes and Calgary is the poorest performing at 2,303 tonnes.
- By 2049, BC annual building stock GWP is 25 Mt CO_2/yr, a 54% reduction relative to the Baseline emissions (54 Mt). In contrast, WC is 100Mt, an increase of 86%.
- The total sensitivity of annual building stock GWP in 2049 is 75 Mt and building stock results vary by a factor of over 4 between best and worst cases.
- In 2049 the total range in annual emissions represents 3% to 13% of 2007 National emissions.

Figure 6.42: Detached Dwelling GWP Sensitivity, by type[1]



[1] bars show superimposed results of each energy Design, not accumulative results

Figure 6.43: Dwelling Total GWP Sensitivity, by dwelling type

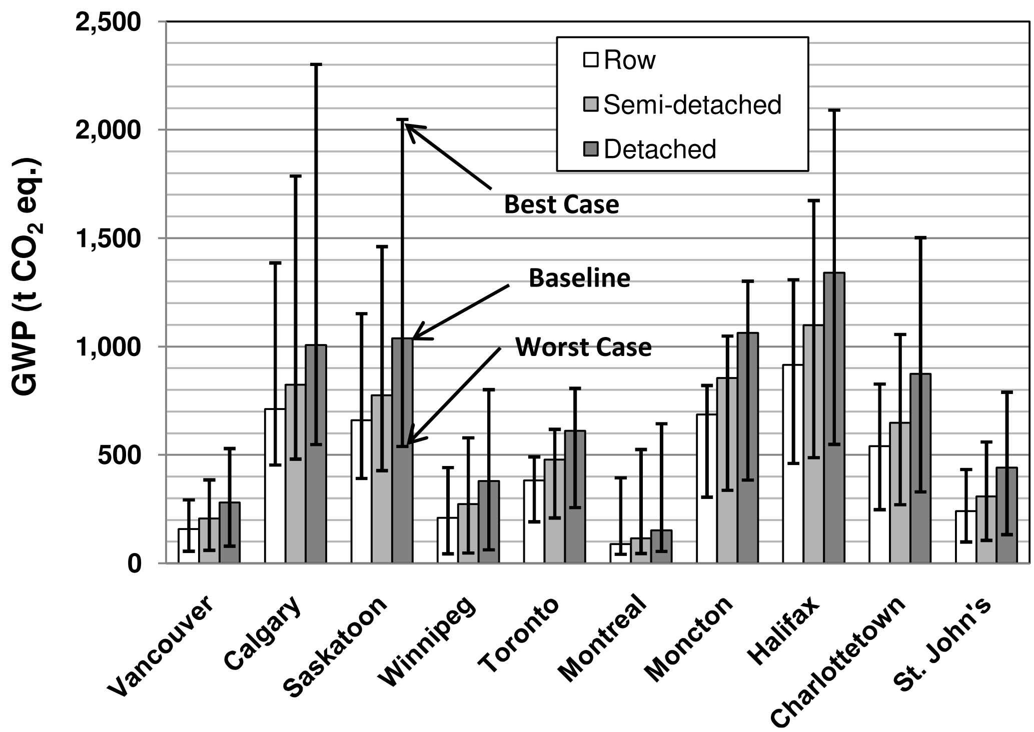
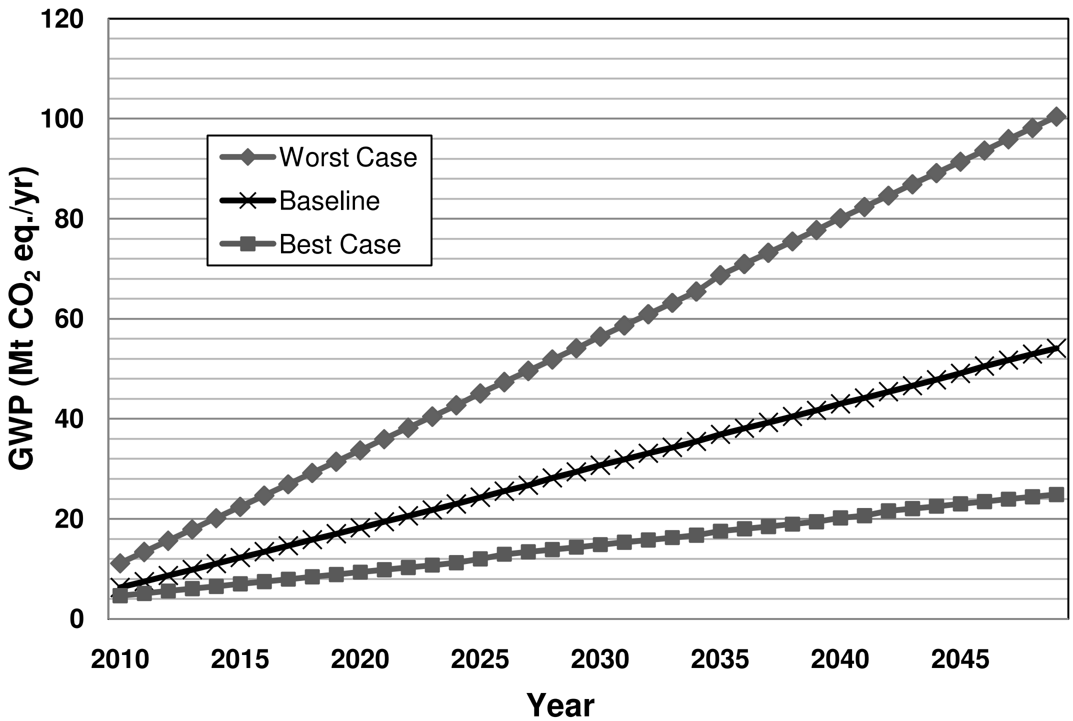


Figure 6.44: Building Stock Total GWP Sensitivity



7.0 DISCUSSION

7.1 Commentary

The R2000 standard and EnerGuide rating system evaluate dwellings in terms of SE use. Similarly, the green building rating system LEED for Homes currently evaluates energy and material aspects of environmental performance based on SE reduction and prescriptive requirements for materials. These techniques aim to reduce environmental impact by proxy since no analysis of emissions or resource use take place. In contrast, LCA of housing is widely recognized as an effective methodology for quantifying performance because it tracks actual flows to and from nature based on scientific principles and according to an international standard. The integration of LCA into regulation would not only allow buildings to be rated based on measurable performance indicators, but also would provide new tools (e.g. material and fuel choice) to designers to reduce impact. Benchmarking residential dwelling construction via batch assessment is an important first step for integration of LCA as it provides a basis for the determination of what acceptable environmental performance is, and in the case of green building rating systems, whether a proposed design is an acceptable improvement to conventional construction.

The system boundary of typical energy end-use modeling encompasses site energy use and extends to electricity generation effects for GWP. Analysis therefore considers materials as externalities and doesn't include energy consumption by other sectors to produce and transport energy (i.e. pre-combustion). Similarly, the most common method of reporting environmental emissions and energy use in Canada is to allot various sectors the emissions they are directly responsible for. Examples of this approach include how Environment Canada inventories GWP, and how NRCan inventories SE use. This is a perfectly appropriate approach to inventorying effects as it is based on aggregating data from emitters/energy consumers in each sector. The question that arises is whether policy is best served by analysis of inventory data or energy end-use modeling. What lacks in these models are the inherent relationships that exist between emitters; a policy designed to reduce emissions from one emitter does not consider its influence on the industrial system as a whole. The implicit risk in this disconnect is that analysis can either underestimate or overestimate the potential for emissions reductions. The LCA approach outlined herein accounts for the holistic nature of building design and the intertwined consequences initiated by their end-uses, thereby ensuring that trade-offs and the degree of impact reduction is acceptable.

A significant step for LCA integration into LEED and other initiatives such as R2000 would be the inclusion of material takeoff and LCA calculations into an energy simulation program. This would provide designers with the means to evaluate housing and compare results with the requirements of such standards without needing expertise in LCA. HOT2000 is an ideal choice as it has a long history of validation, is used extensively by the industry, and is the software used for the R2000 standard and EnerGuide rating system (an optional path to LEED for Homes credit and OBC compliance). Building stock modeling would benefit from this integration as well. Material calculation adds significant work to modeling and would be greatly simplified if the simulation engine did this automatically.

While LCA is a much improved methodology for assessing and potentially regulating the environmental implications of housing it does have its limitations and should not necessarily be the sole metric for compliance. For example, at present LCA does not readily handle local site specific effects from resource extraction or indoor air quality [97]. Many other building aspects can be dealt with by LCA in theory but may not be practical in the short term. For example, LEED for Homes encourages the use of roof assemblies that reduce urban heat island effect; without more research on the incremental benefit of heat island effect reduction, use of these assemblies may not be encouraged by LCA analysis alone. Besides the need for benchmark building data, implementation of whole building LCA in regulation requires a consistent, reputable, and publically available LCI database. This work has begun with the development of the US LCI database administered by the US National Renewable Energy Lab (NREL). It is expected that over time the US LCI database will be of sufficient breath and quality for this purpose.

Past research on the life cycle effects of housing has typically been case study oriented and of limited scope. The most significant contribution of this research work is a framework to conduct whole building assessment on a much larger scale. A software platform such as Res-BEAT that stores dwelling design inputs and conducts batch assessment has two important benefits:

1) It facilitates benchmarking and stock modeling, tools for developing and validating the use of LCA in building regulation.
2) It facilitates a more vigorous analysis of the environmental performance of housing and the effects of design decisions.

The analysis presented builds on the assessment of new detached and attached housing detailed in the CMHC report *Life Cycle Environmental Impacts of the Canadian Residential Sector* [48]. Improvements to the model include:

- Dwelling space heating and cooling energy use varies by municipality (HOT2000 simulation) rather than by province;
- Archetype size varies by province rather than a national average;
- Electricity generation and building material environmental profiles vary by province rather than a national average;
- The dependant relationship between building material and secondary energy use (i.e. embodied and operating energy effects) is accounted for;
- The building material mix characterizes average usage rates rather than a single dwelling design;
- Inclusion of more embodied effects associated with building products (e.g. building service systems);
- Dynamic analysis of model inputs and outputs.

7.2 Model Limitations and Future Work

The intent of this research is not to produce a set of validated benchmarks for use in regulation. The objective of this work is to illustrate that given the relative uniformity and simplicity of detached and attached construction (in contrast to multi-unit residential, commercial and institutional buildings), statistical and building code analysis, energy simulation, and subsequent LCA may be sufficient for producing such benchmarks. Any set of benchmarks produced in this manner would have to be reviewed by building stakeholders and validated by industry experts.

In terms of characterizing construction, the following items were left out of the research scope and should be addressed in future work:

- Other building archetypes (e.g. 3-storey, bungalow, etc.), including those with slab on grade and flat roof construction.
- Other assemblies common to residential construction such as SIP and concrete block walls, open web wood joists, etc.
- Other operating systems such as radiant floor heating and instantaneous water heaters, etc.
- Analysis of provincial building codes and local construction practices.

The following have been identified as some of the current issues with using statistics to produce housing benchmarks:

- There are no residential building material use rate statistics; ideally they should be at a provincial or municipal scale.
- There are no statistics on the rates of landfilling, reuse, and recycling of building materials at the municipal level.
- There is generally no separation of energy use statistics between new and existing dwellings, making it difficult to gauge use rates for SH, SC, DHW, and AL systems at present.

While the system boundary of benchmarks to be used in regulation is a highly debatable topic, the research model currently has elements where not all life cycle stages are included:

- Electricity and natural gas use for AL are considered but the embodied effects of producing and replacing these products are not.

- Hot water energy consumption is included but the upstream and downstream effects of municipal water use are not.

The building stock models presented are not intended to be legitimate forecasts of future emissions associated with residential housing. Instead, the analysis serves to identify general building stock performance characteristics and investigate the degree to which designers can influence performance by way of sensitivity analysis. Other than the issues discussed above, the stock models are limited in their ability to provide realistic forecasts due to the assumptions that manufacturing practice, electricity generation, building material and service systems use, and construction demand remain constant over the study period.

There are many ways in which the system boundary of the stock model can be expanded to improve analysis and provide further insight about the residential sector. These include:

- **Renewable energy production and energy efficient systems:** use of these systems is expected to rise and is therefore an important consideration for models of future construction.
- **The existing residential stock:** due the volume of housing, energy reduction potential, and retrofitting activities of the existing stock it could greatly benefit from a life cycle analysis perspective.
- **Apartment buildings:** these dwellings currently represent approximately one quarter of residential dwelling units and should be included in the system to account for their impact and changes in dwelling type use.
- **Infrastructure and transportation:** expansion of scope to include these items would provide a more thorough analysis since housing, infrastructure, and transportation are interdependent facets of the residential sector.
- **Life cycle costing/social impacts:** the integration of the triple bottom line for sustainability would greatly improve decision making.

8.0 CONCLUSIONS

At current construction and demolition rates, dwellings constructed in the next 40 years could account for approximately 45% of housing in 2050. This presents an opportunity to drastically reduce the sector's energy consumption and environmental footprint. The LCA batch dwelling analysis and building stock modeling frameworks presented require significant statistical analysis, material and energy quantification, LCA data, and a means to calculate and present results. This research work shows that higher level analysis of the residential sector according to LCA is an achievable and appropriate improvement to current environmental performance measurement metrics. LCA provides a more robust and holistic assessment by capturing a greater share of effects and relaying more information to the practitioner. Furthermore, the analysis framework presented is also a critical step for future analysis that also considers life cycle costing and social life cycle assessment. Benchmarking Canadian construction via batch assessment is an important step for the implementation of LCA in construction regulation as it allows the establishment of minimum performance standards. Building stock LCA compliments and enhances energy end-use modeling approaches, and provides the basis to analyze the implications of proposed regulation.

An Excel based program named Res-BEAT was developed for the purpose of conducting LCA batch dwelling and building stock analysis. Res-BEAT calculates impact results, resource use, bills of materials, and annual operating energy use. The program currently contains a database of over 18,000 dwelling designs that can be individually analysed or combined to form a building stock. The designs are categorized based on 36 Canadian locations, 29 dwelling archetypes, 3 material/fuel "Cases", and 6 energy performance "Designs". Building material takeoffs were calculated with a spreadsheet program developed for the research work named the Residential Archetype Materials Calculator (RAMC). The program allows the user to select any combination of common building assemblies; the resulting takeoffs are then input in Res-BEAT. Annual operating fuel use data was calculated with the energy modeling program HOT2000. Res-BEAT relies primarily on the Athena Institute's Impact Estimator database for LCA data.

The research work expanded the scope of typical residential assessment by estimating life cycle effects for the following elements currently not included in the Athena database:

- 6 building envelope materials/assemblies;
- 10 types of electrical wire, electrical boxes;
- 7 types of plumbing pipe, DHW tank;
- HVAC components: furnace, boiler, heat pump, air-conditioner, radiators, electric baseboard heaters, HRV, ductwork;
- wood combustion.

Benchmarking dwelling performance via batch assessment provides considerable insight into current Canadian construction practice and allows for rigorous sensitivity analysis. The following are some pertinent findings regarding dwelling life cycle GWP for the 10 cities considered across Canada.

- Row and semi-detached designs emit 54-71% and 70-81% that of detached dwellings, respectively.
- SH contributes most to GWP, 36-60% for row, 45-68% for semi-detached, and 50-71% for detached.
- Total emissions across cities vary considerably, 88-915 tonnes for row, 116-1,098 tonnes for semi-detached and 152-1,340 tonnes for detached housing.
- The extent of material/fuel use dwelling sensitivity is 179-713 tonnes for row, 246-1,013 tonnes for semi-detached and 344-1,373 tonnes for detached housing. Baseline emissions are closer to the best case.
- Between Design 1 and Design 6 detached dwellings there is a 72 to 683 tonnes CO_2 eq. decrease in GWP, or 43% to 66% reduction. This is the result of a decrease in operating energy GWP of 85-696 tonnes and increase in embodied GWP of 11-14 tonnes CO_2 eq.
- Within research scope, Montreal is the best performing detached dwelling at 56 tonnes and Calgary is the poorest performing at 2,303 tonnes.

- Percent embodied GWP is 5-35% for row, 5-31% for semi-detached, and 4-29% for detached housing. This changes to 9-82%, 10-78%, and 11-78% for Design 6 dwellings.
- Baseline embodied and pre-combustion effects are 17-47% of detached emissions. In other words, LCA analysis accounts for 1.2 to 1.9 times the impact as typical analysis.

The Baseline building stock model estimates that dwellings constructed during the period 2010-2049 will account for life cycle emissions of 54.1 Mt CO_2 eq. in 2049. This represents 7% of GWP emitted by Canada in 2007. Similarly, the Baseline building stock is predicted to consume 1,270 PJ TPE in 2049, representing 10% of 2007 national consumption. The degree of impact associated with housing built in the next 40 years is therefore likely a significant contributor at the national scale.

Much of the emissions captured by the model are from sources typically not attributed to the residential sector, including mining, transportation, manufacturing, etc. Analysis at the national scale shows that the research system boundary incorporates significant additional effects (1.5 times) associated with housing compared to typical energy end-use modeling. In the future, the proportion of embodied effects is expected to rise and its exclusion from the system boundary of stock modeling will become harder to justify. For example, the energy efficiency scenarios presented show that the embodied percent contribution to impact indicators can increase by as much as 20% over the study period.

The sensitivity analysis performed aims to answer questions about the degree to which designers and policy makers can influence the performance of the stock. The range of results for material and fuel choice in 2049 is 41-100 Mt CO_2 GWP and 1,189-1,641 PJ TPE, or 6-13% and 9-13% of 2007 Canadian effects, respectively. In 2049, the three energy efficiency building stock scenarios presented account for GWP emissions of 29-40 Mt CO_2 and 616-937 PJ TPE or 4-5% and 5-7% of 2007 national effects. While the degree of energy performance improvement is the primary driving force for impact reduction, the analysis shows that another important factor is when those improvements are implemented in the stock.

Adding the effect of both sensitivity cases, the best overall building stock results in 2049 are 25 Mt CO_2 GWP and 598 PJ TPE, 54% and 53% reductions relative to the Baseline, respectively. While the building stock results are quite sensitive with respect to material/fuel choice and energy performance, attaining the best case performance is unlikely as it would require drastic shifts in construction practice in the short term. Two important mechanisms by which future life cycle effects could be further reduced are the increased use of renewable energy systems and changes to electricity generation fuel mixes.

The research analysis shows that improved envelopes and equipment efficiencies are effective ways to lower emissions. Envelope improvements in particular require additional material inputs but the payback in terms of GWP and TPE is good for all cases considered in the research. Other than SE, the extent of reduction is influenced by how emission intensive the fuel mix being drawn on is. Analysis of changes to fuel use mix reveals that the best and worst case mixes for GWP have a similar influence on other impact indicators. The degree of fuel use GWP sensitivity for housing is very dependent on location, namely the provincial electricity generation mix. The influence of energy efficiency and material/fuel use on GWP are of similar order of magnitude generally; this begs the question as to which approach (or combination of) is a more economical strategy across Canada.

Appendix A: Additional Results Graphs

Figure A1: Baseline Montreal Detached Dwelling Impacts, by stage

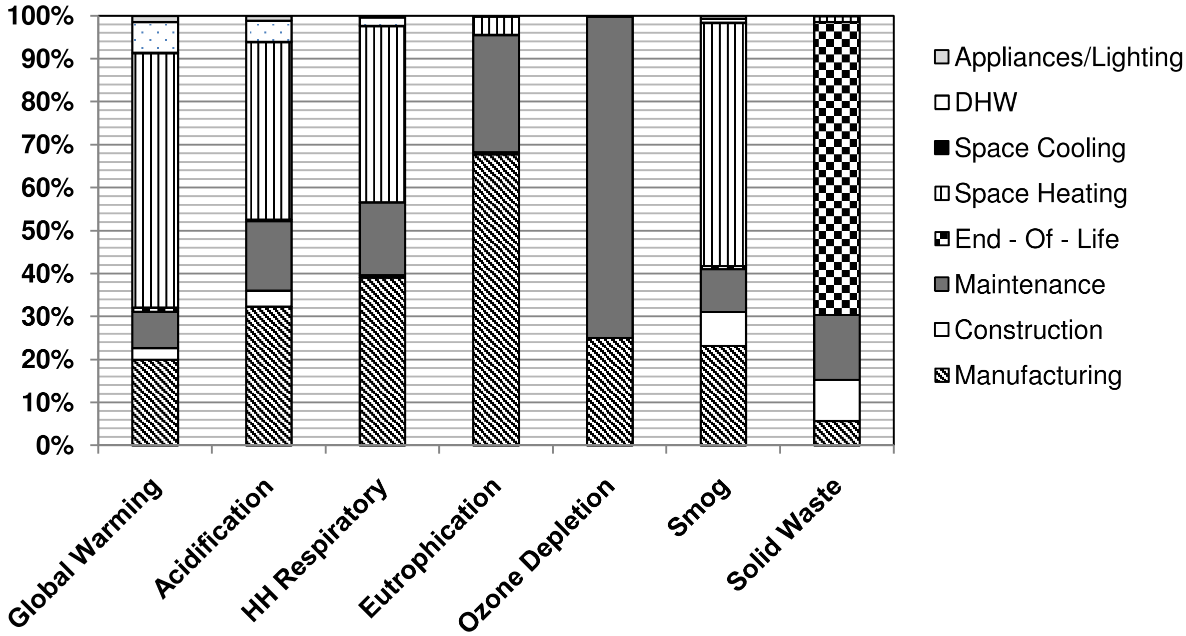


Figure A2: Baseline Calgary Detached Dwelling Impacts, by stage

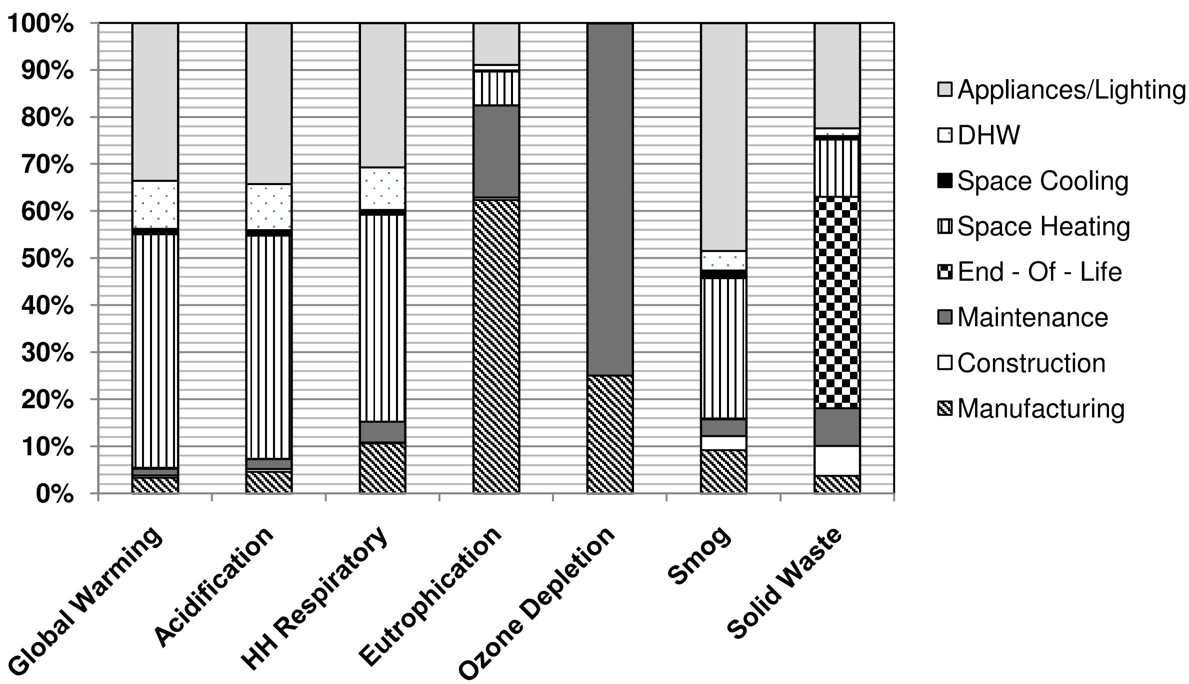


Figure A3: Baseline Montreal Detached Dwelling Resource Use, by stage

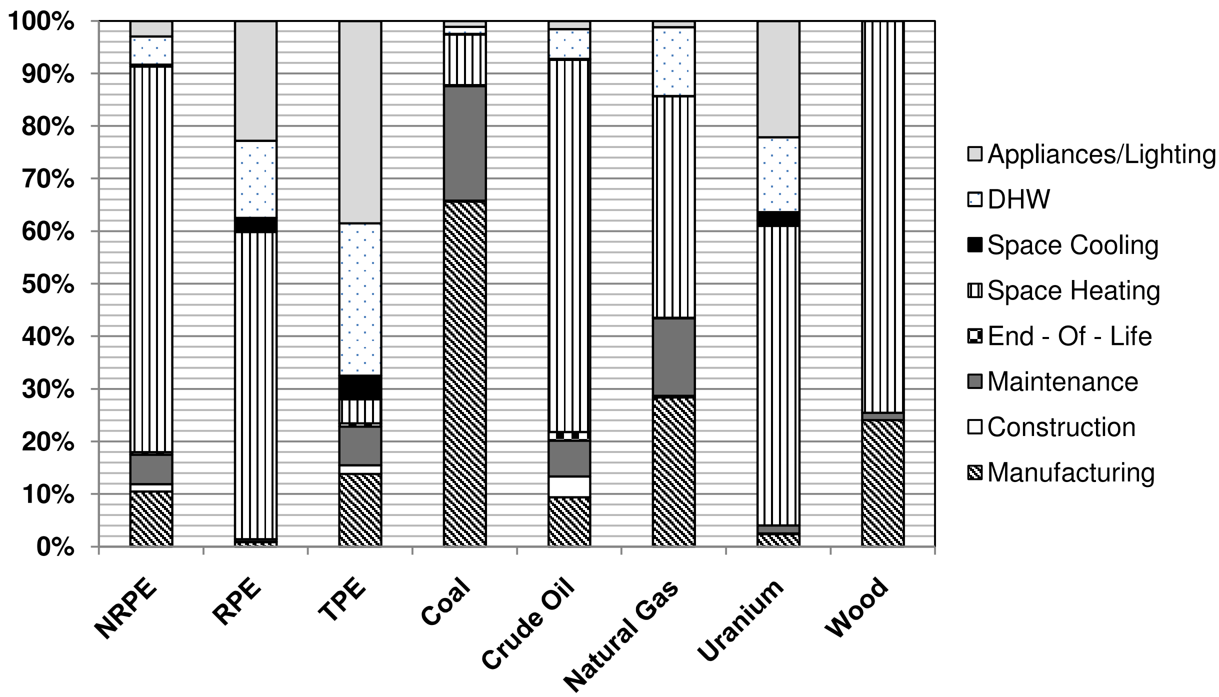


Figure A4: Baseline Calgary Detached Dwelling Resource Use, by stage

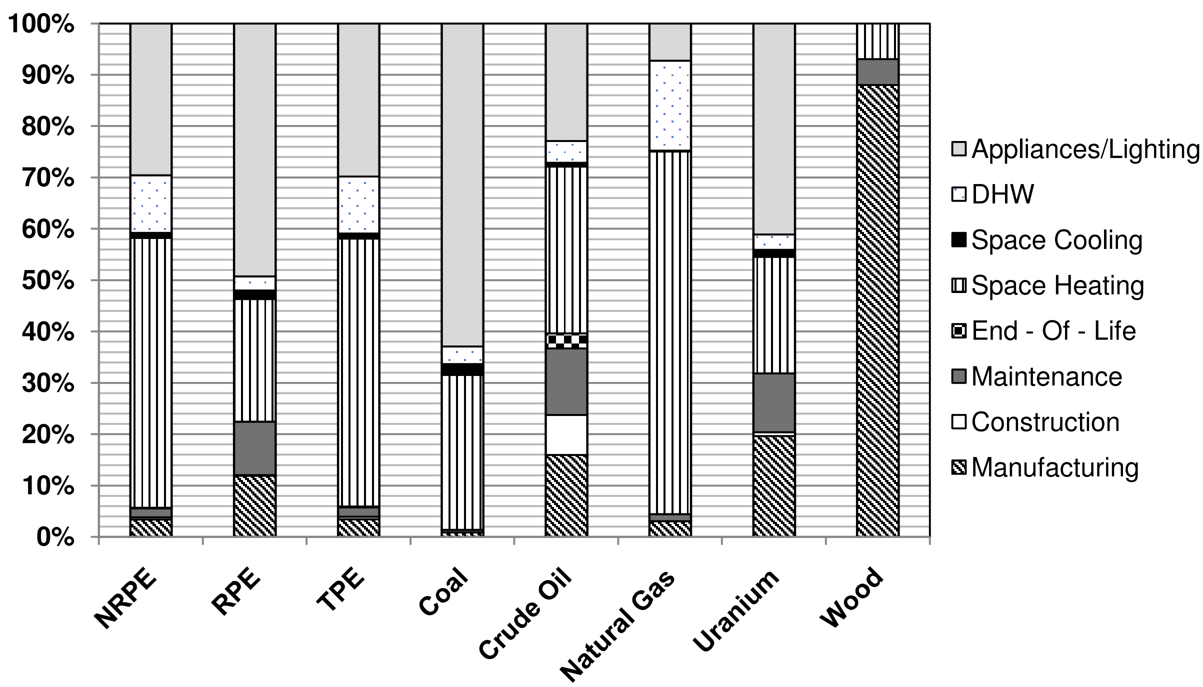


Figure A5: Building Stock Material/Fuel Use Sensitivity - Accumulated GWP

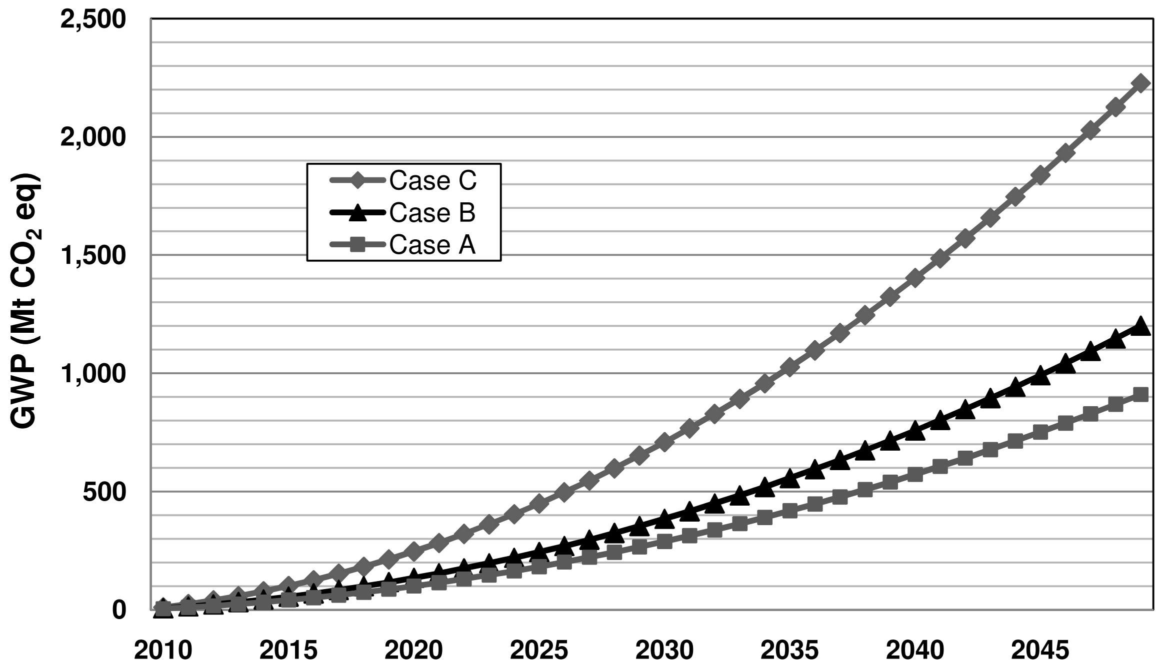


Figure A6: Building Stock Energy Efficiency Scenarios - Accumulated GWP

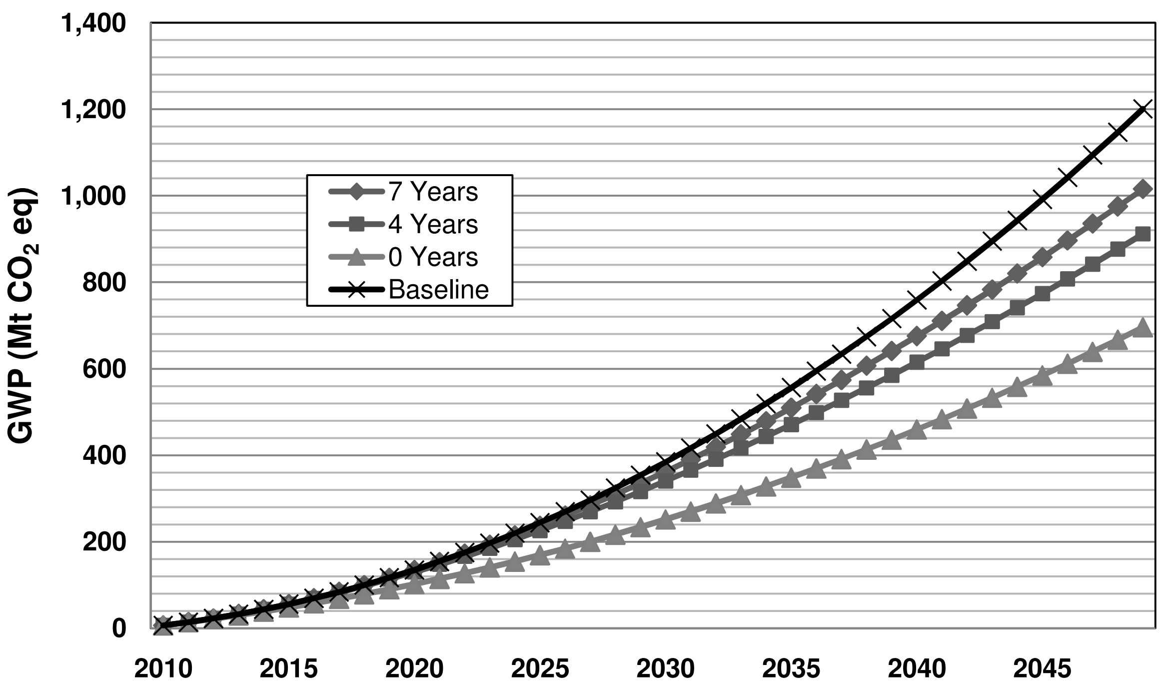


Figure A7: Baseline Dwelling TPE, by dwelling type

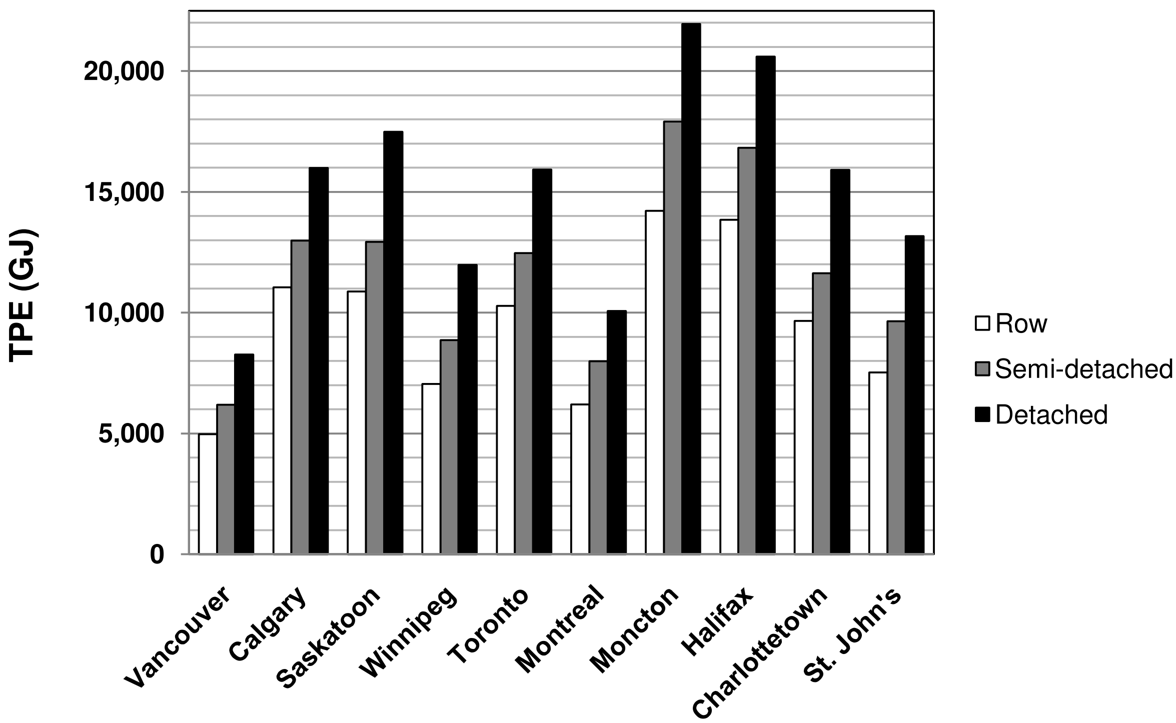


Figure A8: Baseline Detached Dwelling TPE, by component

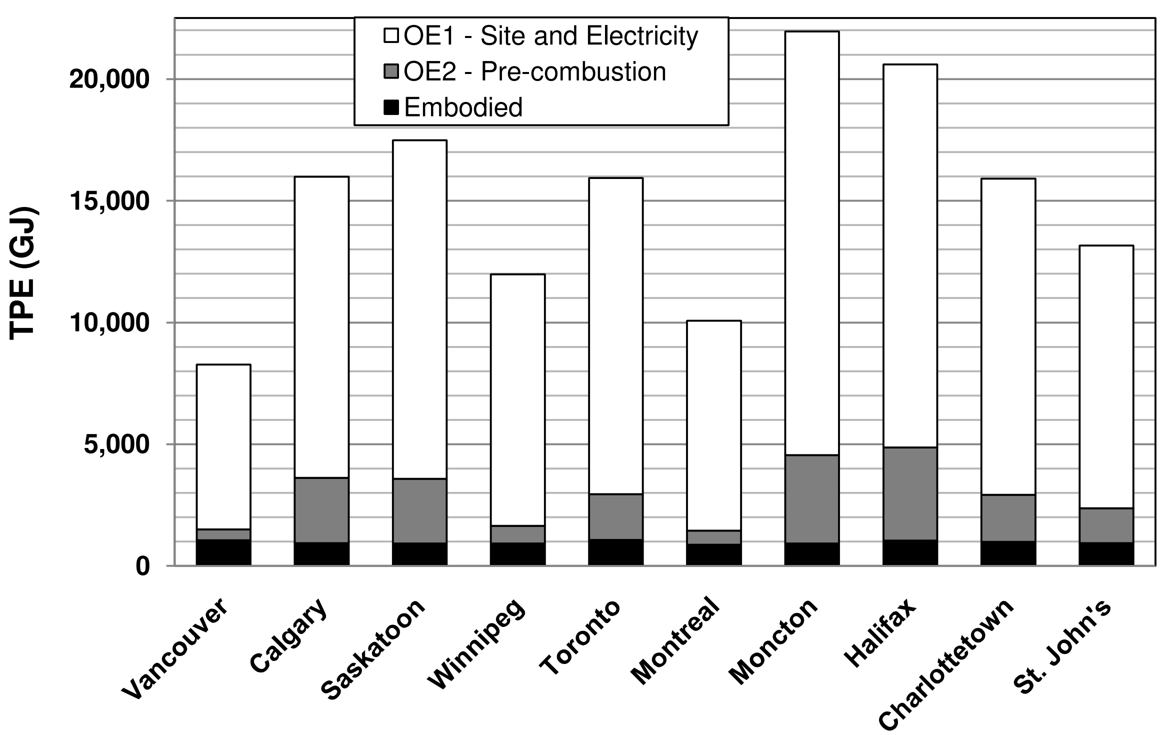


Figure A9: Baseline Detached Dwelling Operating Energy TPE, by end-use

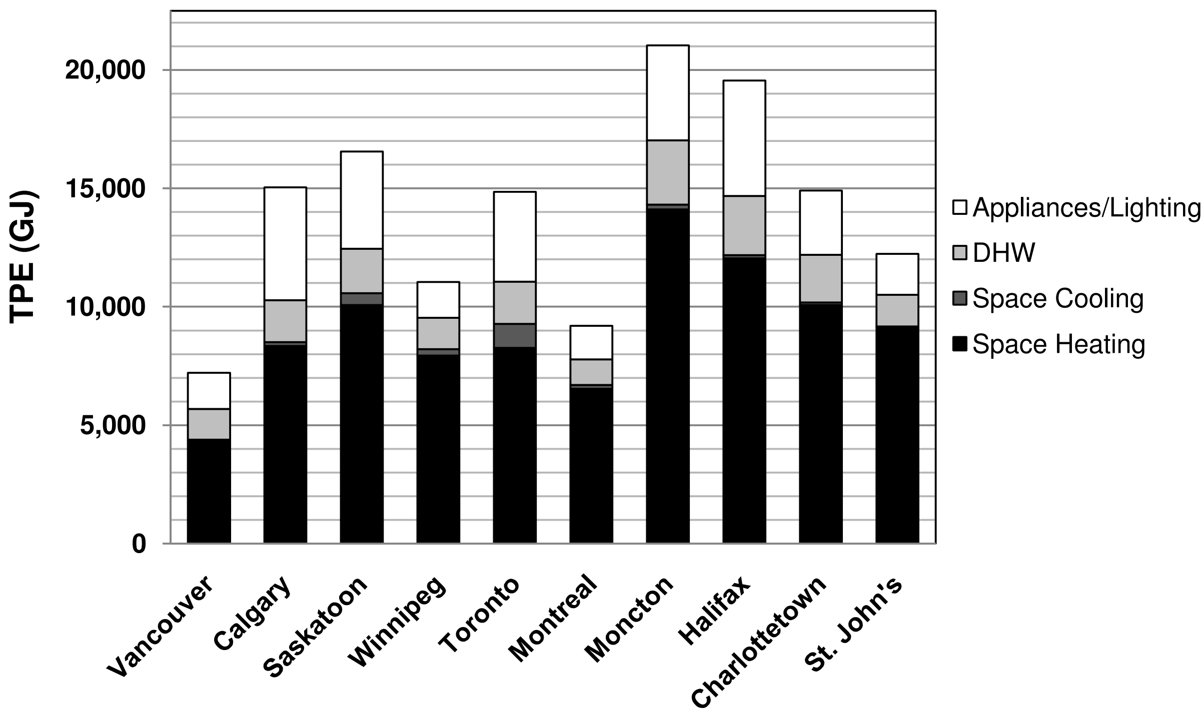


Figure A10: Baseline Detached Dwelling Embodied TPE, by stage

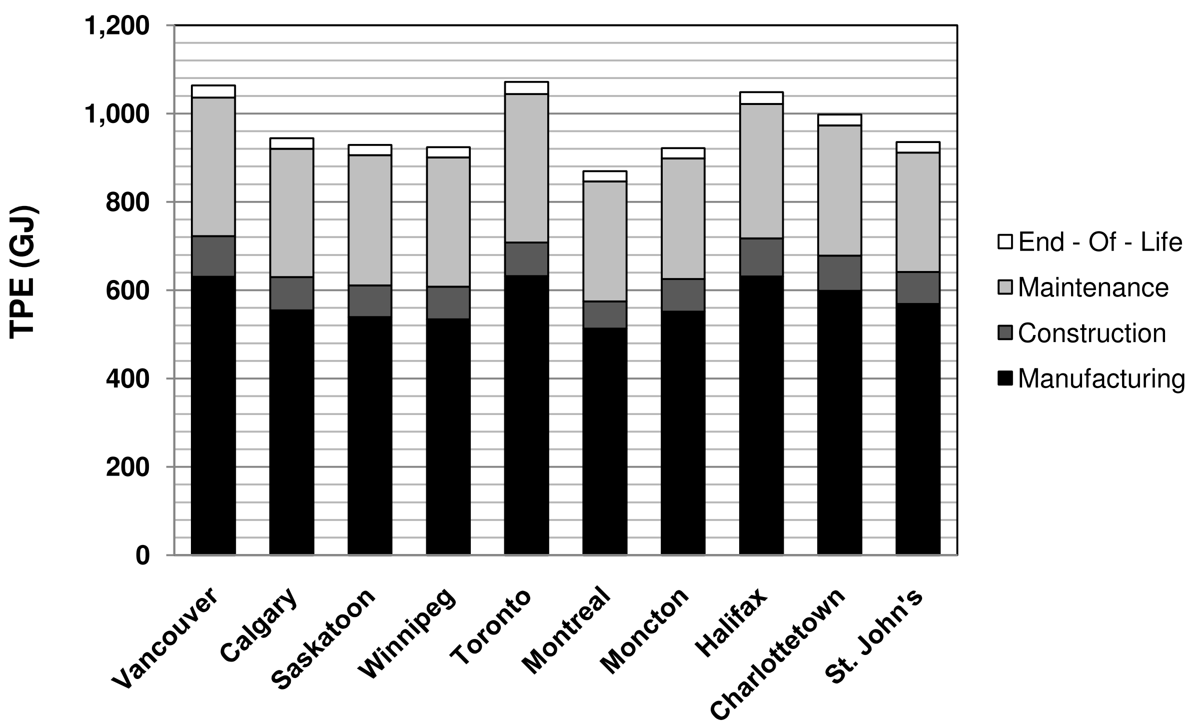


Figure A11: Baseline Stock TPE

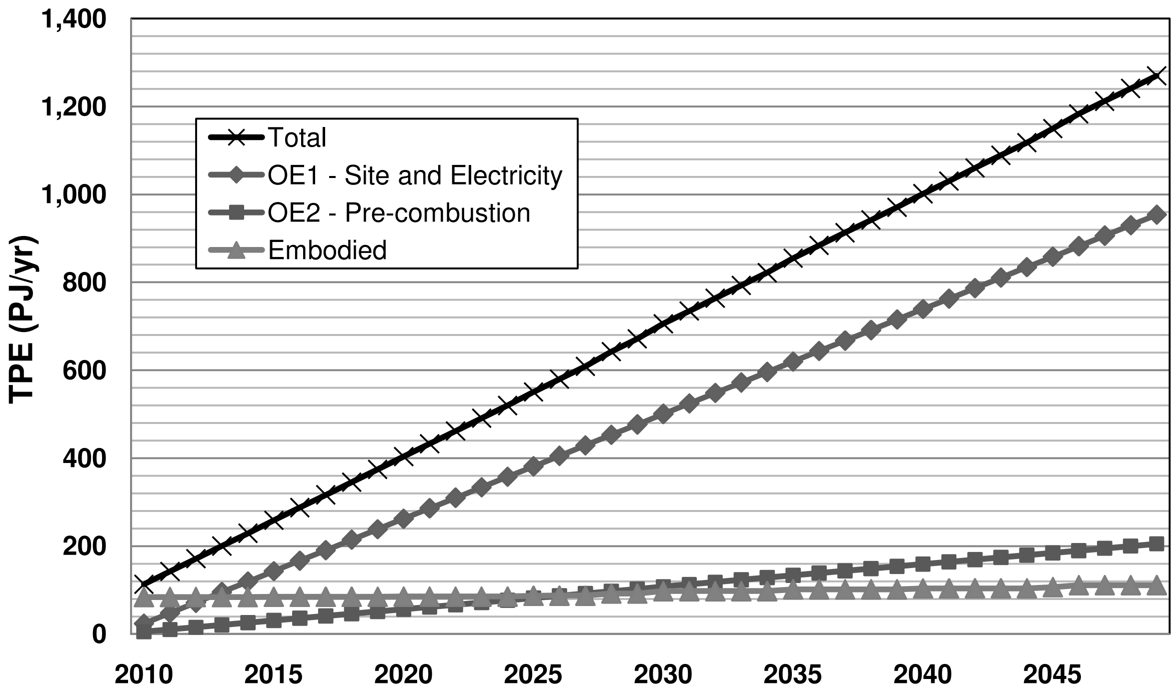


Figure A12: Baseline Stock TPE (2010-2049), by province

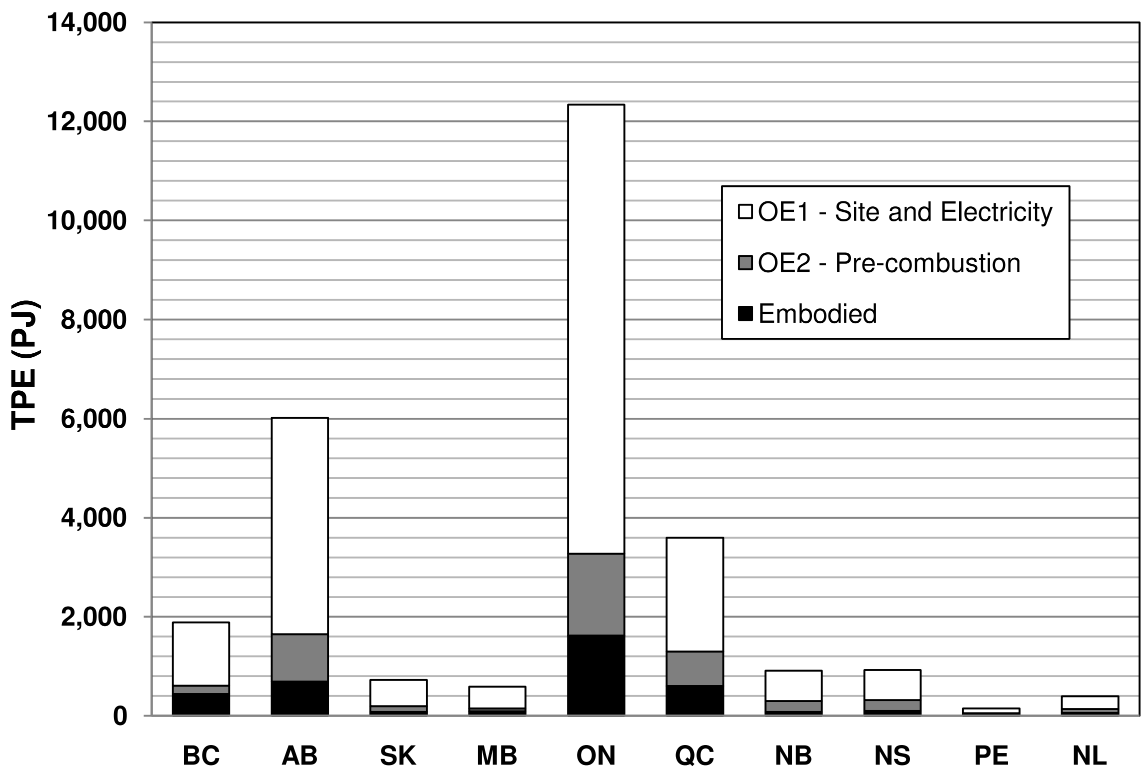
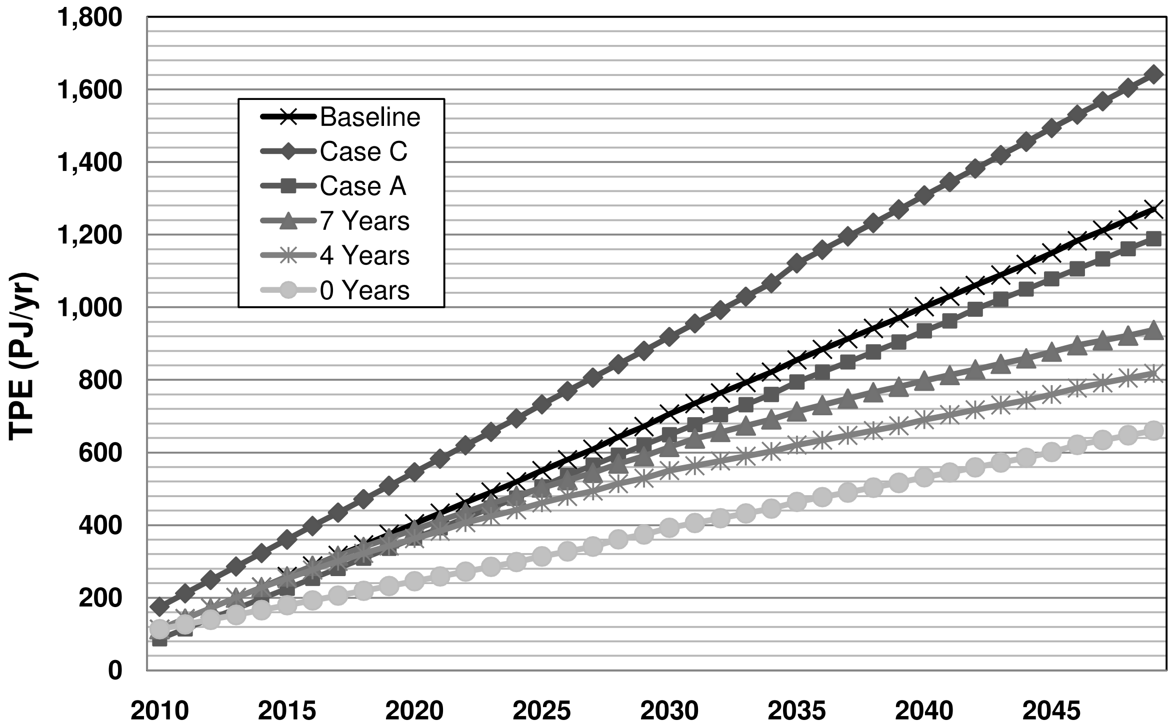


Figure A13: Building Stock TPE Sensitivity



Appendix B: Results Tables

Table B1: 60-Year Case B Design 1 (Baseline) Dwelling Annual SE

Housing Type	Location	HDD	Total (GJ/yr)	By Fuel (GJ/yr) Electricity	Natural Gas	Heating Oil	LPG	Wood	By End-Use (GJ/yr) Space Heating	Space Cooling	DHW	Appliances /Lighting
Detached	**Vancouver**	2925	107.0	48.8	47.1	3.9	1.0	6.3	65.2	0.7	19.5	21.7
	Calgary	5200	148.4	30.0	115.3	1.1	1.3	0.7	103.3	0.7	24.5	20.0
	Saskatoon	5950	172.0	38.7	119.3	5.1	2.0	7.0	126.4	2.4	22.8	20.4
	Winnipeg	5900	170.2	75.7	80.0	2.9	1.1	10.5	122.5	4.1	20.3	23.2
	Toronto	3650	140.5	48.0	76.7	7.6	1.0	7.2	93.1	5.5	21.0	21.0
	Montreal	4250	138.0	90.5	5.3	15.2	0.1	26.9	98.7	2.5	15.8	21.0
	Moncton	4750	144.8	88.2	0.2	22.7	1.4	32.3	108.4	1.0	15.1	20.3
	Halifax	4100	154.2	58.8	0.0	70.4	1.9	23.1	112.5	0.6	19.7	21.4
	Charlottetown	4600	171.3	26.0	0.0	111.5	1.2	32.5	133.5	0.5	24.6	12.8
	St. John's	4800	154.5	92.9	0.0	36.8	0.6	24.2	119.1	0.1	16.0	19.3
Semi-detached	**Vancouver**	2925	80.9	38.5	35.6	2.2	0.7	4.0	43.4	0.4	18.0	19.1
	Calgary	5200	116.6	26.2	88.2	0.8	0.9	0.5	76.4	0.4	21.1	18.7
	Saskatoon	5950	124.0	30.5	85.1	3.1	1.3	3.9	84.6	1.6	19.5	18.3
	Winnipeg	5900	126.6	60.5	58.1	1.7	0.7	5.6	84.7	2.9	17.7	21.3
	Toronto	3650	108.7	38.8	60.3	5.2	0.7	3.8	66.9	3.7	19.4	18.8
	Montreal	4250	109.1	80.9	4.9	10.8	0.1	12.4	75.0	1.8	13.9	18.3
	Moncton	4750	118.6	72.1	0.2	16.0	1.1	29.2	85.2	0.7	13.5	19.2
	Halifax	4100	123.7	49.3	0.0	54.7	1.4	18.3	85.2	0.4	17.8	20.2
	Charlottetown	4600	120.9	21.4	0.0	78.7	0.8	20.1	87.1	0.3	21.7	11.8
	St. John's	4800	114.2	67.9	0.0	24.4	0.4	21.5	81.7	0.1	14.9	17.5
Row	**Vancouver**	2925	63.6	33.6	26.0	1.4	0.4	2.3	26.2	0.3	18.0	19.1
	Calgary	5200	90.9	25.1	64.3	0.6	0.6	0.3	50.7	0.4	21.1	18.7
	Saskatoon	5950	97.7	28.6	63.3	2.2	0.9	2.7	58.6	1.3	19.5	18.2
	Winnipeg	5900	99.7	51.1	43.0	1.1	0.5	3.9	58.3	2.5	17.7	21.2
	Toronto	3650	84.5	34.3	43.8	3.5	0.5	2.4	43.3	3.1	19.4	18.7
	Montreal	4250	83.3	64.2	3.6	7.2	0.1	8.2	49.7	1.5	13.9	18.2
	Moncton	4750	90.6	58.4	0.1	11.3	0.7	20.1	58.6	0.6	13.5	17.8
	Halifax	4100	95.4	42.8	0.0	39.5	0.9	12.2	57.0	0.4	17.8	20.2
	Charlottetown	4600	93.8	20.3	0.0	59.2	0.5	13.8	60.1	0.3	21.7	11.8
	St. John's	4800	87.0	55.6	0.0	16.8	0.2	14.3	54.6	0.0	14.9	17.5

Table B2: 60-Year Case A Design 1 Dwelling Annual SE

Housing Type	Location	HDD	Total (GJ/yr)	By Fuel (GJ/yr)					By End-Use (GJ/yr)			
				Electricity	Natural Gas	Heating Oil	LPG	Wood	Space Heating	Space Cooling	DHW	Appliances /Lighting
Detached	Vancouver	2925	67.3	60.4	0.5	0.0	0.0	6.3	31.2	0.7	13.7	21.7
	Calgary	5200	148.8	25.3	122.7	0.0	0.0	0.7	103.1	0.7	25.1	20.0
	Saskatoon	5950	173.7	28.0	138.7	0.0	0.0	7.0	126.3	2.4	24.5	20.4
	Winnipeg	5900	128.3	117.5	0.3	0.0	0.0	10.5	85.8	4.1	15.2	23.2
	Toronto	3650	91.9	84.0	0.7	0.0	0.0	7.2	51.4	5.5	14.1	21.0
	Montreal	4250	109.7	82.7	0.0	0.0	0.0	26.9	71.4	2.5	14.8	21.0
	Moncton	4750	157.9	26.5	99.0	0.0	0.0	32.3	113.2	1.0	23.4	20.3
	Halifax	4100	156.4	27.4	106.0	0.0	0.0	23.1	111.3	0.6	23.1	21.4
	Charlottetown	4600	162.5	18.8	111.2	0.0	0.0	32.5	125.4	0.5	23.9	12.8
	St. John's	4800	105.8	81.6	0.0	0.0	0.0	24.2	72.0	0.1	14.5	19.3
Semi-detached	Vancouver	2925	53.3	48.8	0.5	0.0	0.0	4.0	21.2	0.4	12.6	19.1
	Calgary	5200	116.3	23.4	92.5	0.0	0.0	0.5	75.6	0.4	21.7	18.7
	Saskatoon	5950	124.7	24.4	96.4	0.0	0.0	3.9	83.7	1.6	21.1	18.3
	Winnipeg	5900	97.5	91.6	0.3	0.0	0.0	5.6	60.3	2.9	13.0	21.3
	Toronto	3650	72.5	68.1	0.7	0.0	0.0	3.8	37.2	3.7	12.8	18.8
	Montreal	4250	84.3	71.8	0.0	0.0	0.0	12.4	51.1	1.8	13.0	18.3
	Moncton	4750	130.1	24.8	76.0	0.0	0.0	29.2	88.9	0.7	21.3	19.2
	Halifax	4100	125.9	25.6	82.0	0.0	0.0	18.3	84.3	0.4	21.0	20.2
	Charlottetown	4600	114.4	17.0	77.3	0.0	0.0	20.1	81.2	0.3	21.0	11.8
	St. John's	4800	84.0	62.5	0.0	0.0	0.0	21.5	53.1	0.1	13.4	17.5
Row	Vancouver	2925	45.8	42.9	0.5	0.0	0.0	2.3	13.7	0.3	12.6	19.1
	Calgary	5200	90.9	22.9	67.7	0.0	0.0	0.3	50.2	0.4	21.7	18.7
	Saskatoon	5950	98.6	23.6	72.3	0.0	0.0	2.7	58.0	1.3	21.1	18.2
	Winnipeg	5900	79.4	75.2	0.3	0.0	0.0	3.9	42.7	2.5	13.0	21.2
	Toronto	3650	59.3	56.2	0.7	0.0	0.0	2.4	24.7	3.1	12.8	18.7
	Montreal	4250	67.5	59.3	0.0	0.0	0.0	8.2	34.8	1.5	13.0	18.2
	Moncton	4750	100.8	23.0	57.7	0.0	0.0	20.1	61.0	0.6	21.3	17.8
	Halifax	4100	97.8	25.1	60.5	0.0	0.0	12.2	56.2	0.4	21.0	20.2
	Charlottetown	4600	89.1	16.6	58.7	0.0	0.0	13.8	56.1	0.3	21.0	11.8
	St. John's	4800	67.5	53.1	0.0	0.0	0.0	14.3	36.5	0.0	13.4	17.5

Table B3: 60-Year Case C Design 1 (Worst-Case) Dwelling Annual SE

Housing Type	Location	HDD	Total (GJ/yr)	By Fuel (GJ/yr)					By End-Use (GJ/yr)			
				Electricity	Natural Gas	Heating Oil	LPG	Wood	Space Heating	Space Cooling	DHW	Appliances /Lighting
Detached	Vancouver	2925	119.6	26.7	0.5	92.4	0.0	0.0	71.4	0.7	25.8	21.7
	Calgary	5200	128.2	127.4	0.7	0.0	0.0	0.0	92.2	0.7	15.4	20.0
	Saskatoon	5950	147.6	147.0	0.5	0.0	0.0	0.0	109.7	2.4	15.0	20.4
	Winnipeg	5900	190.0	32.6	0.3	157.1	0.0	0.0	134.8	4.1	27.8	23.2
	Toronto	3650	155.8	30.7	0.7	124.3	0.0	0.0	103.1	5.5	26.3	21.0
	Montreal	4250	152.7	28.3	0.0	124.3	0.0	0.0	101.9	2.5	27.4	21.0
	Moncton	4750	120.6	120.6	0.0	0.0	0.0	0.0	85.2	1.0	14.2	20.3
	Halifax	4100	124.3	124.3	0.0	0.0	0.0	0.0	88.3	0.6	14.0	21.4
	Charlottetown	4600	123.8	123.8	0.0	0.0	0.0	0.0	96.1	0.5	14.6	12.8
	St. John's	4800	167.8	25.0	0.0	142.8	0.0	0.0	121.5	0.1	26.9	19.3
Semi-detached	Vancouver	2925	90.6	23.4	0.5	66.7	0.0	0.0	47.1	0.4	24.1	19.1
	Calgary	5200	99.8	99.0	0.7	0.0	0.0	0.0	67.7	0.4	13.0	18.7
	Saskatoon	5950	105.7	105.1	0.5	0.0	0.0	0.0	73.2	1.6	12.5	18.3
	Winnipeg	5900	142.5	28.8	0.3	113.4	0.0	0.0	93.6	2.9	24.7	21.3
	Toronto	3650	119.7	26.3	0.7	92.7	0.0	0.0	72.7	3.7	24.4	18.8
	Montreal	4250	126.3	24.8	0.0	101.5	0.0	0.0	81.5	1.8	24.6	18.3
	Moncton	4750	97.5	97.5	0.0	0.0	0.0	0.0	64.9	0.7	12.7	19.2
	Halifax	4100	99.6	99.6	0.0	0.0	0.0	0.0	66.5	0.4	12.5	20.2
	Charlottetown	4600	87.4	87.4	0.0	0.0	0.0	0.0	62.8	0.3	12.5	11.8
	St. John's	4800	122.0	22.6	0.0	99.4	0.0	0.0	79.1	0.1	25.3	17.5
Row	Vancouver	2925	71.6	23.1	0.5	48.0	0.0	0.0	28.2	0.3	24.0	19.1
	Calgary	5200	77.1	76.4	0.7	0.0	0.0	0.0	45.1	0.4	13.0	18.7
	Saskatoon	5950	82.9	82.4	0.5	0.0	0.0	0.0	50.8	1.3	12.5	18.2
	Winnipeg	5900	112.5	27.8	0.3	84.4	0.0	0.0	64.2	2.5	24.7	21.2
	Toronto	3650	93.2	25.2	0.7	67.3	0.0	0.0	47.0	3.1	24.4	18.7
	Montreal	4250	98.0	24.0	0.0	74.0	0.0	0.0	53.6	1.5	24.6	18.2
	Moncton	4750	75.6	75.6	0.0	0.0	0.0	0.0	44.5	0.6	12.7	17.8
	Halifax	4100	77.4	77.4	0.0	0.0	0.0	0.0	44.4	0.4	12.5	20.2
	Charlottetown	4600	67.9	67.9	0.0	0.0	0.0	0.0	43.3	0.3	12.5	11.8
	St. John's	4800	95.2	22.2	0.0	73.0	0.0	0.0	52.4	0.0	25.3	17.5

Table B4: 60-Year Case B Design 6 Dwelling Annual SE

Housing Type	Location	HDD	Total (GJ/yr)	% Reduction[1]	By Fuel (GJ/yr)					By End-Use (GJ/yr)			
					Electricity	Natural Gas	Heating Oil	LPG	Wood	Space Heating	Space Cooling	DHW	Appliances /Lighting
Detached	**Vancouver**	2925	39.4	63.2%	31.3	7.3	0.4	0.1	0.4	8.2	2.3	7.0	21.9
	Calgary	5200	45.0	69.7%	25.2	19.3	0.2	0.2	0.1	15.8	1.5	8.1	19.5
	Saskatoon	5950	56.4	67.2%	31.9	22.5	0.8	0.3	0.9	22.8	4.7	7.9	21.1
	Winnipeg	5900	57.9	66.0%	41.3	14.8	0.4	0.2	1.2	21.8	5.1	7.7	23.2
	Toronto	3650	48.5	65.5%	33.5	13.1	1.0	0.1	0.7	14.1	6.4	7.3	20.7
	Montreal	4250	48.7	64.7%	42.9	1.0	2.1	0.0	2.8	15.3	5.3	7.3	20.8
	Moncton	4750	45.9	68.3%	39.4	0.0	3.1	0.2	3.2	15.9	2.6	7.0	20.3
	Halifax	4100	45.8	70.3%	33.2	0.0	10.3	0.2	2.1	15.3	1.7	7.6	21.2
	Charlottetown	4600	43.4	74.7%	19.5	0.0	20.0	0.2	3.7	21.4	1.2	8.5	12.2
	St. John's	4800	43.3	71.9%	35.9	0.0	5.0	0.1	2.4	17.4	0.3	7.2	18.4
Semi-detached	**Vancouver**	2925	32.3	60.1%	26.2	5.7	0.2	0.0	0.2	5.8	1.1	6.4	19.0
	Calgary	5200	38.0	67.4%	22.9	14.9	0.1	0.1	0.0	12.2	0.8	6.8	18.2
	Saskatoon	5950	43.7	64.8%	25.9	16.5	0.5	0.2	0.5	16.4	2.5	6.5	18.3
	Winnipeg	5900	47.2	62.7%	34.9	11.2	0.3	0.1	0.7	16.4	3.2	6.6	20.9
	Toronto	3650	39.7	63.5%	28.1	10.5	0.7	0.1	0.4	10.5	3.9	6.6	18.6
	Montreal	4250	40.7	62.7%	37.1	0.9	1.5	0.0	1.3	12.3	3.7	6.3	18.3
	Moncton	4750	39.6	66.6%	34.6	0.0	2.1	0.1	2.8	12.4	1.7	6.2	19.3
	Halifax	4100	39.3	68.2%	29.7	0.0	7.8	0.1	1.6	11.7	1.0	6.7	19.9
	Charlottetown	4600	34.6	71.4%	17.2	0.0	14.8	0.1	2.5	15.6	0.6	7.2	11.1
	St. John's	4800	36.1	68.4%	30.5	0.0	3.3	0.0	2.2	12.5	0.1	6.7	16.7
Row	**Vancouver**	2925	29.9	53.0%	25.1	4.6	0.1	0.0	0.0	4.0	0.8	6.4	18.8
	Calgary	5200	32.8	63.9%	22.4	10.2	0.1	0.0	0.0	7.2	0.6	6.8	18.1
	Saskatoon	5950	37.0	62.1%	24.7	11.6	0.3	0.1	0.3	10.6	2.0	6.5	18.0
	Winnipeg	5900	40.0	59.8%	31.9	7.5	0.1	0.1	0.4	10.0	2.7	6.6	20.8
	Toronto	3650	34.0	59.7%	26.1	7.3	0.4	0.0	0.2	6.1	3.2	6.6	18.1
	Montreal	4250	34.9	58.1%	32.8	0.6	0.8	0.0	0.7	7.4	3.0	6.3	18.1
	Moncton	4750	33.4	63.1%	30.7	0.0	1.2	0.0	1.5	7.6	1.4	6.2	18.2
	Halifax	4100	33.9	64.5%	28.1	0.0	5.0	0.0	0.7	6.6	0.8	6.7	19.7
	Charlottetown	4600	28.4	69.7%	16.8	0.0	10.1	0.1	1.4	9.5	0.5	7.2	11.2
	St. John's	4800	30.5	65.0%	27.6	0.0	1.8	0.0	1.0	6.9	0.1	6.7	16.7

[1]Energy use percent reduction relative to Design 1 (Baseline)

Table B5: 60-Year Case A Design 6 (Best-Case) Dwelling Annual SE

Housing Type	Location	HDD	Total (GJ/yr)	By Fuel (GJ/yr)					By End-Use (GJ/yr)			
				Electricity	Natural Gas	Heating Oil	LPG	Wood	Space Heating	Space Cooling	DHW	Appliances /Lighting
Detached	**Vancouver**	2925	36.6	35.7	0.5	0.0	0.0	0.4	5.9	2.3	6.6	21.9
	Calgary	5200	45.1	24.3	20.8	0.0	0.0	0.1	16.0	1.5	8.2	19.5
	Saskatoon	5950	56.8	29.3	26.7	0.0	0.0	0.9	23.0	4.7	8.0	21.1
	Winnipeg	5900	50.6	49.1	0.3	0.0	0.0	1.2	14.9	5.1	7.3	23.2
	Toronto	3650	43.3	34.5	8.1	0.0	0.0	0.7	8.8	6.4	7.4	20.7
	Montreal	4250	44.3	41.5	0.0	0.0	0.0	2.8	11.0	5.3	7.2	20.8
	Moncton	4750	46.8	26.9	16.7	0.0	0.0	3.2	16.2	2.6	7.6	20.3
	Halifax	4100	45.5	26.8	16.5	0.0	0.0	2.1	15.1	1.7	7.4	21.2
	Charlottetown	4600	41.9	17.5	20.6	0.0	0.0	3.7	20.7	1.2	7.7	12.2
	St. John's	4800	36.7	34.2	0.0	0.0	0.0	2.4	10.9	0.3	7.0	18.4
Semi-detached	**Vancouver**	2925	30.9	30.2	0.5	0.0	0.0	0.2	4.8	1.1	6.0	19.0
	Calgary	5200	38.1	22.2	15.8	0.0	0.0	0.0	12.2	0.8	6.8	18.2
	Saskatoon	5950	43.8	24.2	19.1	0.0	0.0	0.5	16.4	2.5	6.6	18.3
	Winnipeg	5900	42.3	41.3	0.3	0.0	0.0	0.7	11.9	3.2	6.3	20.9
	Toronto	3650	36.2	28.4	7.4	0.0	0.0	0.4	6.9	3.9	6.7	18.6
	Montreal	4250	37.0	35.7	0.0	0.0	0.0	1.3	8.7	3.7	6.2	18.3
	Moncton	4750	40.3	24.8	12.7	0.0	0.0	2.8	12.7	1.7	6.7	19.3
	Halifax	4100	39.0	24.8	12.7	0.0	0.0	1.6	11.6	1.0	6.6	19.9
	Charlottetown	4600	33.3	15.7	15.1	0.0	0.0	2.5	15.0	0.6	6.5	11.1
	St. John's	4800	32.2	30.0	0.0	0.0	0.0	2.2	8.9	0.1	6.5	16.7
Row	**Vancouver**	2925	29.6	29.0	0.5	0.0	0.0	0.0	4.0	0.8	6.0	18.8
	Calgary	5200	32.8	21.9	10.9	0.0	0.0	0.0	7.2	0.6	6.8	18.1
	Saskatoon	5950	37.1	23.3	13.5	0.0	0.0	0.3	10.6	2.0	6.6	18.0
	Winnipeg	5900	37.7	36.9	0.3	0.0	0.0	0.4	7.9	2.7	6.3	20.8
	Toronto	3650	33.0	25.4	7.4	0.0	0.0	0.2	5.0	3.2	6.7	18.1
	Montreal	4250	33.4	32.7	0.0	0.0	0.0	0.7	6.0	3.0	6.2	18.1
	Moncton	4750	34.0	23.3	9.1	0.0	0.0	1.5	7.7	1.4	6.7	18.2
	Halifax	4100	33.6	24.3	8.6	0.0	0.0	0.7	6.5	0.8	6.6	19.7
	Charlottetown	4600	27.4	15.5	10.4	0.0	0.0	1.4	9.2	0.5	6.5	11.2
	St. John's	4800	29.3	28.3	0.0	0.0	0.0	1.0	6.0	0.1	6.5	16.7

Table B6: Building Stock SE (2010-2049)

Secondary Energy Use		Case A Design 6 (Best-Case)[1]	Case A Design 1	Case B Design 1 (Baseline)	Case C Design 1 (Worst-Case)
Space Heating	Electricity (kWh)	2.13E+11	1.01E+12	7.74E+11	8.64E+11
	Natural Gas (m^3)	9.59E+09	7.14E+10	1.39E+11	0.00E+00
	Diesel (L)	0.00E+00	0.00E+00	2.42E+10	1.91E+11
	LPG (L)	0.00E+00	0.00E+00	3.81E+09	0.00E+00
	Wood (tonnes)	7.15E+06	7.13E+07	7.13E+07	0.00E+00
Space Cooling	Electricity (kWh)	1.20E+11	8.33E+10	8.33E+10	8.33E+10
DHW	Natural Gas (m^3)	1.47E+10	1.83E+10	3.94E+10	0.00E+00
	Electricity (kWh)	6.96E+10	3.22E+11	1.68E+11	1.20E+11
	Diesel (L)	0.00E+00	0.00E+00	2.96E+09	5.60E+10
Appliances/ Lighting	Electricity (kWh)	6.11E+11	6.16E+11	6.16E+11	6.16E+11
	Natural Gas (m^3)	1.47E+09	1.47E+09	1.47E+09	1.47E+09

[1]denotes which dwellings design are added to stock annually

Table B7: Building Stock Energy Efficiency Scenario SE (2010-2049)

Secondary Energy Use		Baseline	7 years	4 Years	0 years
Space Heating	Electricity (kWh)	7.74E+11	5.61E+11	4.41E+11	1.96E+11
	Natural Gas (m^3)	1.39E+11	9.31E+10	6.79E+10	1.71E+10
	Diesel (L)	2.42E+10	1.62E+10	1.18E+10	2.88E+09
	LPG (L)	3.81E+09	2.55E+09	1.86E+09	4.55E+08
	Wood (tonnes)	7.13E+07	4.48E+07	3.21E+07	7.15E+06
Space Cooling	Electricity (kWh)	8.33E+10	9.73E+10	1.05E+11	1.20E+11
DHW	Natural Gas (m^3)	3.94E+10	2.86E+10	2.33E+10	1.26E+10
	Electricity (kWh)	1.68E+11	1.40E+11	1.22E+11	8.11E+10
	Diesel (L)	2.96E+09	2.11E+09	1.72E+09	9.65E+08
Appliances/ Lighting	Electricity (kWh)	6.16E+11	6.16E+11	6.15E+11	6.11E+11
	Natural Gas (m^3)	1.47E+09	1.47E+09	1.47E+09	1.47E+09

Table B8: 60-Year Toronto Detached Dwelling Design 1 BOM

Material/Assembly	Case B (Baseline)			Case A			Case C (Worst-Case)		
	Row	Semi-Detached	Detached	Row	Semi-Detached	Detached	Row	Semi-Detached	Detached
#15 Organic Felt (m2)	429	444	660	0	0	0	119	182	292
#30 Organic Felt (m2)	55	55	80	752	752	1,093	188	188	273
1/2" Regular Gypsum Board (m2)	582	633	815	777	844	1,200	0	0	0
5/8" Fire-Rated Type X Gypsum Board (m2)	150	75	0	150	75	0	150	75	0
5/8" Regular Gypsum Board (m2)	194	211	384	0	0	0	777	844	1,200
6 mil Polyethylene (m2)	268	331	427	279	341	446	279	341	446
Air Barrier (m2)	115	194	356	256	427	705	0	0	0
Aluminum (Tonnes)	0.30	0.39	0.56	0.38	0.49	0.72	1.40	1.88	2.84
Ballast (aggregate stone) (kg)	35,632	35,632	50,714	35,632	35,632	50,714	35,632	35,632	50,714
Batt. Fiberglass (m2 (25mm))	1,123	1,336	1,808	6	8	12	0	0	0
Batt. Rockwool (m2 (25mm))	415	416	488	0	0	0	513	256	0
Blown Cellulose (m2 (25mm))	235	183	153	1,783	1,965	2,494	0	0	0
Cedar Shingles (m2)	23	23	33	363	363	527	0	0	0
Cedar Wood Bevel Siding (m2)	10	16	27	0	0	0	0	0	0
Clay Tile (m2)	2.6	2.6	3.8	0.0	0.0	0.0	176.5	176.5	256.4
Cold Rolled Sheet (Tonnes)	0.01	0.01	0.02	0.00	0.00	0.00	0.02	0.04	0.05
Concrete 20 MPa (flyash 35%) (m3)	0	0	0	32	35	47	0	0	0
Concrete 20 MPa (flyash av) (m3)	30	33	45	0	0	0	15	15	20
Concrete Blocks (Blocks)	255	301	429	0	0	0	1,742	2,149	2,935
Concrete Tile (m2)	2.118	2.118	3.076	0.000	0.000	0.000	0.000	0.000	0.000
Dimpled Waterproof Membrane (m2)	64	94	147	64	94	147	64	94	147
EPDM membrane (white, 60 mil) (kg)	89	122	186	104	142	216	67	91	138
Expanded Polystyrene (m2 (25mm))	0	0	0	0	0	0	0	0	0
Exterior Insulation and Finish System (EIFS) (m2)	14	23	39	0	0	0	0	0	0
Extruded Polystyrene (m2 (25mm))	0	0	0	0	0	0	144	218	212

Table B8: 60-Year Toronto Detached Dwelling Design 1 BOM (cont.)

Material/Assembly	Case B (Baseline)			Case A			Case C (Worst-Case)		
	Row	Semi-Detached	Detached	Row	Semi-Detached	Detached	Row	Semi-Detached	Detached
Fiber Cement (m2)	6	9	15	0	0	0	0	0	0
Fibreglass (kg)	15	20	31	0	0	0	0	0	0
Foam Polyisocyanurate (m2 (25mm))	45	58	84	0	0	0	1,064	1,400	2,014
Galvanized Sheet (Tonnes)	0.57	0.57	1.02	0.16	0.16	0.42	0.57	0.58	0.99
Galvanized Studs (Tonnes)	0.19	0.20	0.27	0.00	0.00	0.00	7.14	7.40	9.01
Glazing Panel (Tonnes)	0.10	0.10	0.12	0.10	0.10	0.12	0.10	0.10	0.12
Hollow Structural Steel (Tonnes)	0.05	0.05	0.22	0.00	0.00	0.25	0.17	0.17	0.45
Joint Compound (Tonnes)	0.9	0.9	1.2	0.9	0.9	1.2	0.9	0.9	1.2
Laminated Veneer Lumber (m3)	1.4	1.5	1.8	1.3	1.3	0.2	0.0	0.0	0.0
Large Dimension Softwood Lumber, kiln-dried (m3)	5	5	7	12	12	15	0	0	0
Low E Tin Glazing (m2)	62	83	150	75	101	182	48	65	116
Metric Modular (Modular) Brick (m2)	29	49	80	0	0	0	0	0	0
Mortar (m3)	1.6	2.3	3.7	0.0	0.0	0.0	6.4	8.1	11.2
Nails (Tonnes)	0.229	0.261	0.385	0.246	0.284	0.451	0.121	0.142	0.215
Natural Stone (m2)	4	7	12	0	0	0	0	0	0
Organic Felt shingles 25yr (m2)	357	357	519	0	0	0	0	0	0
Oriented Strand Board (m2 (9mm))	504	593	873	110	183	302	786	889	1,302
Paper Tape (Tonnes)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Parallel Strand Lumber (m3)	0.15	0.15	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Pine Wood Bevel Siding (m2)	10	16	27	0	0	0	0	0	0
PVC (kg)	792	1,076	1,643	0	0	0	0	0	0
Rebar, Rod, Light Sections (Tonnes)	0.47	0.51	0.69	0.00	0.00	0.03	0.43	0.40	0.53
Residential(30 ga.) Steel Cladding (m2)	6	9	16	0	0	0	0	0	0
Screws Nuts & Bolts (Tonnes)	0.02	0.02	0.04	0.01	0.01	0.02	0.19	0.20	0.28
Slate Roofing (m2)	2.2	2.2	3.1	0.0	0.0	0.0	0.0	0.0	0.0
Small Dimension Softwood Lumber, kiln-dried (m3)	14	16	20	12	14	20	1	1	2

Table B8: 60-Year Toronto Detached Dwelling Design 1 BOM (cont.)

Material/Assembly	Case B (Baseline)			Case A			Case C (Worst-Case)		
	Row	Semi-Detached	Detached	Row	Semi-Detached	Detached	Row	Semi-Detached	Detached
Softwood Plywood (m2 (9mm))	291	291	403	532	532	737	0	0	0
Solvent Based Alkyd Paint (L)	1.4	1.4	2.8	0.8	0.8	1.9	0.8	0.8	1.9
Solvent Based Varnish (L)	0.315	0.315	0.458	0.000	0.000	0.000	0.000	0.000	0.000
Spruce Wood Bevel Siding (m2)	10	16	27	276	460	761	0	0	0
Stucco over metal mesh (m2)	7	12	20	0	0	0	0	0	0
Vinyl Siding (m2)	65	108	178	0	0	0	0	0	0
Water Based Latex Paint (L)	1,242	1,305	1,819	1,285	1,374	1,924	1,227	1,281	1,781
Weeping Tile (m)	32	46	73	32	46	73	32	46	73
Welded Wire Mesh / Ladder Wire (Tonnes)	0.05	0.05	0.07	0.00	0.00	0.00	0.14	0.11	0.20
Wide Flange Sections (Tonnes)	0.13	0.15	0.47	0.00	0.00	0.44	0.87	0.95	1.48
14/2 NMD90 Wire (m)	567	567	710	567	567	710	567	567	710
12/2 NMD90 Wire (m)	94	94	95	71	71	73	71	71	73
10/3 NMD90 Wire (m)	21	21	22	21	21	22	21	21	22
8/3 NMD90 Wire (m)	21	21	22	21	21	22	21	21	22
3 AWG Bare Wire (m)	12	12	13	12	12	13	12	12	13
00 AWG R90 Insulated Conductor Wire (m)	34	34	34	34	34	34	34	34	34
Light Box (unit)	21	21	26	21	21	26	21	21	26
Switch or Receptacle Box (unit)	87	87	110	87	87	110	87	87	110
13mm Copper Pipe (m)	31	31	42	31	31	42	31	31	42
19mm Copper Pipe (m)	91	91	115	72	72	96	72	72	96
40mm ABS Pipe (m)	39	39	52	39	39	52	39	39	52
50mm ABS Pipe (m)	13	13	18	13	13	18	13	13	18
75mm ABS Pipe (m)	34	34	45	34	34	45	34	34	45
100mm ABS Pipe (m)	30	30	40	30	30	40	30	30	40

Table B8: 60-Year Toronto Detached Dwelling Design 1 BOM (cont.)

Material/Assembly	Case B (Baseline)			Case A			Case C (Worst-Case)		
	Row	Semi-Detached	Detached	Row	Semi-Detached	Detached	Row	Semi-Detached	Detached
41mm PVC Conduit (m)	8.429	8.429	8.429	8.429	8.429	8.429	8.429	8.429	8.429
Ductwork (kg)	559	559	766	732	732	976	732	732	976
Radiators (kg)	62	62	79	0	0	0	0	0	0
Natural Gas Furnace (unit)	1.9	1.9	1.7	0.0	0.0	0.0	0.0	0.0	0.0
Oil Furnace (unit)	0.17	0.17	0.18	0.00	0.00	0.00	3.00	3.00	3.00
Propane Furnace (unit)	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Wood Furnace (unit)	0.08	0.08	0.11	0.08	0.08	0.11	0.00	0.00	0.00
Natural Gas Boiler (unit)	0.28	0.28	0.26	0.00	0.00	0.00	0.00	0.00	0.00
Oil Boiler (unit)	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Propane Boiler (unit)	0.005	0.005	0.005	0.000	0.000	0.000	0.000	0.000	0.000
Electric Baseboard (W)	3,686	3,686	4,321	0	0	0	0	0	0
Heat Pump (unit)	0.13	0.13	0.32	3.89	3.89	3.85	0.00	0.00	0.00
Central Air Conditioner (unit)	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
HRV (unit)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Natural Gas Water Tank (unit)	2.9	2.9	2.9	0.0	0.0	0.0	0.0	0.0	0.0
Electric Water Tank (unit)	1.0	1.0	1.0	4.0	4.0	4.0	0.0	0.0	0.0
Oil Water Tank (unit)	0.11	0.11	0.11	0.00	0.00	0.00	4.00	4.00	4.00

Table B9: Changes to 60-Year Case B Toronto Detached Dwelling BOM[1] for Designs 2-6

Material/Assembly	Energy Design				
	B2	B3	B4	B5	B6
Aluminum (Tonnes)	0.00	0.00	0.25	0.25	0.25
Batt. Fiberglass (m2 (25mm))	937	1,125	1,313	1,754	2,195
Batt. Rockwool (m2 (25mm))	254	305	355	474	594
Blown Cellulose (m2 (25mm))	80	96	112	149	187
EPDM membrane (white, 60 mil) (kg)	0	0	93	93	93
Expanded Polystyrene (m2 (25mm))	38	76	113	151	189
Extruded Polystyrene (m2 (25mm))	91	183	274	365	457
Fibreglass (kg)	0.00	0.00	15.32	15.32	15.32
Foam Polyisocyanurate (m2 (25mm))	44	52	61	82	102
Galvanized Studs (Tonnes)	0.009	0.009	0.009	0.009	0.009
Laminated Veneer Lumber (m3)	0.056	0.056	0.056	0.056	0.056
Low E Tin Glazing (m2)	0	0	75	75	75
Nails (Tonnes)	0.004	0.004	0.087	0.087	0.087
PVC (kg)	0	0	821	821	821
Screws Nuts & Bolts (Tonnes)	0.002	0.002	0.002	0.002	0.002
Small Dimension Softwood Lumber, kiln-dried (m3)	1.4	1.4	2.9	2.9	2.9
Water Based Latex Paint (L)	0.00	0.00	0.85	0.85	0.85
Central Air Conditioner (unit)	0.60	0.93	0.93	0.93	0.93

[1]Changes relative to Baseline. Baseline materials not shown do not change.

Table B10: 60-Year Best and Worst Case Detached Dwelling BOM

Material/Assembly	Case A Design 6 (Best-Case)	Case B Design 1 (Baseline)	Case C Design 1 (Worst-Case)
#15 Organic Felt (m2)	0	660	292
#30 Organic Felt (m2)	1,093	80	273
1/2" Regular Gypsum Board (m2)	1,200	815	0
5/8" Regular Gypsum Board (m2)	0	384	1,200
6 mil Polyethylene (m2)	446	427	446
Air Barrier (m2)	705	356	0
Aluminum (Tonnes)	1.1	0.6	2.8
Ballast (aggregate stone) (kg)	50,714	50,714	50,714
Batt. Fiberglass (m2 (25mm))	17	1,808	0
Batt. Rockwool (m2 (25mm))	0	488	0
Blown Cellulose (m2 (25mm))	6,246	153	0
Cedar Shingles (m2)	527	33	0
Cedar Wood Bevel Siding (m2)	0	27	0
Clay Tile (m2)	0	4	256
Cold Rolled Sheet (Tonnes)	0.00	0.02	0.05
Concrete 20 MPa (flyash 35%) (m3)	47	0	0
Concrete 20 MPa (flyash av) (m3)	0	45	20
Concrete Blocks (Blocks)	0	429	2,935
Concrete Tile (m2)	0.0	3.1	0.0
Dimpled Waterproof Membrane (m2)	147	147	147
EPDM membrane (white, 60 mil) (kg)	324	186	138
Expanded Polystyrene (m2 (25mm))	756	0	0
Exterior Insulation and Finish System (EIFS) (m2)	0	39	0
Extruded Polystyrene (m2 (25mm))	0	0	212
Fiber Cement (m2)	0	15	0
Fibreglass (kg)	0	31	0
Foam Polyisocyanurate (m2 (25mm))	0	84	2,014
Galvanized Sheet (Tonnes)	0.4	1.0	1.0
Galvanized Studs (Tonnes)	0.0	0.3	9.0
Glazing Panel (Tonnes)	0.12	0.12	0.12
Hollow Structural Steel (Tonnes)	0.25	0.22	0.45

Table B10: Best and Worst Case Detached Dwelling BOM (cont.)

Material/Assembly	Case A Design 6 (Best-Case)	Case B Design 1 (Baseline)	Case C Design 1 (Worst-Case)
Joint Compound (Tonnes)	1.2	1.2	1.2
Laminated Veneer Lumber (m3)	0.2	1.8	0.0
Large Dimension Softwood Lumber, kiln-dried (m3)	15	7	0
Low E Tin Argon Filled Glazing (m2)	272	0	0
Low E Tin Glazing (m2)	0	150	116
Metric Modular (Modular) Brick (m2)	0	80	0
Mortar (m3)	0	4	11
Nails (Tonnes)	0.55	0.39	0.22
Natural Stone (m2)	0	12	0
Organic Felt shingles 25yr (m2)	0	519	0
Oriented Strand Board (m2 (9mm))	302	873	1,302
Paper Tape (Tonnes)	0.01	0.01	0.01
Parallel Strand Lumber (m3)	0.00	0.08	0.00
Pine Wood Bevel Siding (m2)	0	27	0
PVC (kg)	0	1,643	0
Rebar, Rod, Light Sections (Tonnes)	0.03	0.69	0.53
Residential(30 ga.) Steel Cladding (m2)	0	16	0
Screws Nuts & Bolts (Tonnes)	0.02	0.04	0.28
Slate Roofing (m2)	0.0	3.1	0.0
Small Dimension Softwood Lumber, kiln-dried (m3)	24	20	2
Softwood Plywood (m2 (9mm))	737	403	0
Solvent Based Alkyd Paint (L)	1.9	2.8	1.9
Solvent Based Varnish (L)	0.00	0.46	0.00
Spruce Wood Bevel Siding (m2)	761	27	0
Stucco over metal mesh (m2)	0	20	0
Vinyl Siding (m2)	0	178	0
Water Based Latex Paint (L)	1,931	1,819	1,781
Weeping Tile (m)	73	73	73
Welded Wire Mesh / Ladder Wire (Tonnes)	0.00	0.07	0.20
Wide Flange Sections (Tonnes)	0.44	0.47	1.48

Table B10: Best and Worst Case Detached Dwelling BOM (cont.)

Material/Assembly	Case A Design 6 (Best-Case)	Case B Design 1 (Baseline)	Case C Design 1 (Worst-Case)
14/2 NMD90 Wire (m)	710	710	710
12/2 NMD90 Wire (m)	73	95	73
10/3 NMD90 Wire (m)	22	22	22
8/3 NMD90 Wire (m)	22	22	22
3 AWG Bare Wire (m)	13	13	13
00 AWG R90 Insulated Conductor Wire (m)	34	34	34
Light Box (unit)	26	26	26
Switch or Receptacle Box (unit)	110	110	110
13mm Copper Pipe (m)	42	42	42
19mm Copper Pipe (m)	96	115	96
40mm ABS Pipe (m)	52	52	52
50mm ABS Pipe (m)	18	18	18
75mm ABS Pipe (m)	45	45	45
100mm ABS Pipe (m)	40	40	40
41mm PVC Conduit (m)	8.4	8.4	8.4
Ductwork (kg)	976	766	976
19mm Copper Pipe (m)	0	19	0
Radiators (kg)	0	79	0
Natural Gas Furnace (unit)	0.0	1.7	0.0
Oil Furnace (unit)	0.00	0.18	3.00
Propane Furnace (unit)	0.00	0.03	0.00
Wood Furnace (unit)	0.11	0.11	0.00
Natural Gas Boiler (unit)	0.00	0.26	0.00
Oil Boiler (unit)	0.00	0.03	0.00
Propane Boiler (unit)	0.00	0.00	0.00
Electric Baseboard (W)	0	4,321	0
Heat Pump (unit)	3.9	0.3	0.0
Central Air Conditioner (unit)	4.0	3.1	3.1
HRV (unit)	3.0	3.0	3.0
Natural Gas Water Tank (unit)	4.0	2.9	0.0
Electric Water Tank (unit)	0.0	1.0	0.0
Oil Water Tank (unit)	0.0	0.1	4.0

Table B11: Building Stock BOM (2010-2049)

Material/Assembly	Case A Design 6 (Best-Case)	Case A Design 1	Case B Design 1 (Baseline)	Case C Design 1 (Worst-Case)
#15 Organic Felt (m2)	0.00E+00	0.00E+00	1.67E+09	1.37E+09
#30 Organic Felt (m2)	2.98E+09	2.98E+09	2.33E+08	1.08E+09
1/2" Regular Gypsum Board (m2)	5.73E+09	5.73E+09	3.98E+09	2.90E+05
5/8" Fire-Rated Type X Gypsum Board (m2)	1.24E+08	1.24E+08	1.24E+08	1.24E+08
5/8" Regular Gypsum Board (m2)	0.00E+00	0.00E+00	1.75E+09	5.73E+09
6 mil Polyethylene (m2)	2.15E+09	2.15E+09	2.06E+09	2.15E+09
Air Barrier (m2)	1.88E+09	1.88E+09	1.25E+09	0.00E+00
Aluminum (Tonnes)	2.63E+06	1.84E+06	1.61E+06	8.01E+06
Ballast (aggregate stone) (kg)	2.40E+11	2.40E+11	2.40E+11	2.40E+11
Batt. Fiberglass (m2 (25mm))	4.04E+07	2.69E+07	8.49E+09	0.00E+00
Batt. Rockwool (m2 (25mm))	0.00E+00	0.00E+00	2.39E+09	4.22E+08
Blown Cellulose (m2 (25mm))	2.95E+10	1.20E+10	8.37E+08	0.00E+00
Cedar Shingles (m2)	1.44E+09	1.44E+09	9.07E+07	0.00E+00
Cedar Wood Bevel Siding (m2)	0.00E+00	0.00E+00	7.18E+07	0.00E+00
Clay Tile (m2)	0.00E+00	0.00E+00	1.53E+07	1.02E+09
Cold Rolled Sheet (Tonnes)	0.00E+00	0.00E+00	9.58E+04	2.46E+05
Concrete 20 MPa (flyash 35%) (m3)	2.30E+08	2.30E+08	0.00E+00	0.00E+00
Concrete 20 MPa (flyash av) (m3)	0.00E+00	0.00E+00	2.17E+08	9.81E+07
Concrete Blocks (Blocks)	0.00E+00	0.00E+00	2.10E+09	1.44E+10
Concrete Tile (m2)	0.00E+00	0.00E+00	1.22E+07	0.00E+00
Dimpled Waterproof Membrane (m2)	7.00E+08	7.00E+08	7.00E+08	7.00E+08
EPDM membrane (white, 60 mil) (kg)	7.52E+08	5.01E+08	4.52E+08	3.83E+08
Expanded Polystyrene (m2 (25mm))	3.53E+09	0.00E+00	0.00E+00	0.00E+00
Exterior Insulation and Finish System (EIFS) (m2)	0.00E+00	0.00E+00	1.18E+08	0.00E+00
Extruded Polystyrene (m2 (25mm))	0.00E+00	0.00E+00	0.00E+00	1.08E+09
Fiber Cement (m2)	0.00E+00	0.00E+00	5.91E+07	0.00E+00
Fibreglass (kg)	0.00E+00	0.00E+00	8.51E+07	0.00E+00
Foam Polyisocyanurate (m2 (25mm))	0.00E+00	0.00E+00	3.89E+08	9.38E+09
Galvanized Sheet (Tonnes)	1.96E+06	1.96E+06	3.94E+06	4.60E+06
Galvanized Studs (Tonnes)	0.00E+00	0.00E+00	1.34E+06	4.42E+07
Glazing Panel (Tonnes)	6.34E+05	6.34E+05	6.34E+05	6.34E+05
Hollow Structural Steel (Tonnes)	6.59E+05	6.59E+05	8.90E+05	2.11E+06

Table B11 (cont.): Building Stock BOM (2010-2049)

Material/Assembly	Case A Design 6 (Best-Case)	Case A Design 1	Case B Design 1 (Baseline)	Case C Design 1 (Worst-Case)
Joint Compound (Tonnes)	5.86E+06	5.86E+06	5.86E+06	5.86E+06
Laminated Veneer Lumber (m3)	3.02E+06	3.02E+06	8.91E+06	0.00E+00
Large Dimension Softwood Lumber, kiln-dried (m3)	7.14E+07	7.14E+07	3.24E+07	0.00E+00
Low E Tin Argon Filled Glazing (m2)	5.96E+08	0.00E+00	0.00E+00	0.00E+00
Low E Tin Glazing (m2)	0.00E+00	3.98E+08	3.46E+08	3.04E+08
Metric Modular (Modular) Brick (m2)	0.00E+00	0.00E+00	3.74E+08	0.00E+00
Mortar (m3)	0.00E+00	0.00E+00	1.75E+07	5.45E+07
Nails (Tonnes)	1.82E+06	1.58E+06	1.37E+06	7.85E+05
Natural Stone (m2)	0.00E+00	0.00E+00	5.64E+07	0.00E+00
Organic Felt shingles 25yr (m2)	0.00E+00	0.00E+00	1.24E+09	0.00E+00
Oriented Strand Board (m2 (9mm))	1.41E+09	1.41E+09	4.10E+09	6.11E+09
Paper Tape (Tonnes)	6.92E+04	6.92E+04	6.92E+04	6.92E+04
Parallel Strand Lumber (m3)	1.97E+05	1.97E+05	6.00E+05	0.00E+00
Pine Wood Bevel Siding (m2)	0.00E+00	0.00E+00	7.18E+07	0.00E+00
PVC (kg)	0.00E+00	0.00E+00	3.93E+09	0.00E+00
Rebar, Rod, Light Sections (Tonnes)	1.20E+05	1.04E+05	3.43E+06	2.65E+06
Residential(30 ga.) Steel Cladding (m2)	0.00E+00	0.00E+00	6.06E+07	0.00E+00
Screws Nuts & Bolts (Tonnes)	9.24E+04	9.24E+04	1.69E+05	1.36E+06
Slate Roofing (m2)	0.00E+00	0.00E+00	1.50E+07	0.00E+00
Small Dimension Softwood Lumber, kiln-dried (m3)	9.50E+07	8.04E+07	9.21E+07	1.00E+07
Softwood Plywood (m2 (9mm))	3.47E+09	3.47E+09	1.90E+09	0.00E+00
Solvent Based Alkyd Paint (L)	9.10E+06	9.10E+06	1.35E+07	9.10E+06
Spruce Wood Bevel Siding (m2)	2.03E+09	2.03E+09	7.18E+07	0.00E+00
Stucco over metal mesh (m2)	0.00E+00	0.00E+00	9.31E+07	0.00E+00
Vinyl Siding (m2)	0.00E+00	0.00E+00	5.45E+08	0.00E+00
Water Based Latex Paint (L)	4.00E+09	3.98E+09	3.74E+09	3.64E+09
Weeping Tile (m)	3.48E+08	3.48E+08	3.48E+08	3.48E+08
Welded Wire Mesh / Ladder Wire (Tonnes)	0.00E+00	0.00E+00	3.30E+05	9.60E+05
Wide Flange Sections (Tonnes)	1.10E+06	1.10E+06	1.81E+06	7.02E+06

Table B11 (cont.): Building Stock BOM (2010-2049)

Material/Assembly	Case A Design 6 (Best-Case)	Case A Design 1	Case B Design 1 (Baseline)	Case C Design 1 (Worst-Case)
14/2 NMD90 Wire (m)	2.85E+09	2.85E+09	2.85E+09	2.85E+09
12/2 NMD90 Wire (m)	3.20E+08	3.20E+08	4.80E+08	4.90E+08
10/3 NMD90 Wire (m)	9.51E+07	9.51E+07	9.51E+07	9.51E+07
8/3 NMD90 Wire (m)	9.51E+07	9.51E+07	9.51E+07	9.51E+07
3 AWG Bare Wire (m)	5.62E+07	5.62E+07	5.62E+07	5.62E+07
00 AWG R90 Insulated Conductor Wire (m)	1.55E+08	1.55E+08	1.55E+08	1.55E+08
Light Box (unit)	1.07E+08	1.07E+08	1.07E+08	1.07E+08
Switch or Receptacle Box (unit)	4.38E+08	4.38E+08	4.38E+08	4.38E+08
13mm Copper Pipe (m)	1.62E+08	1.62E+08	1.62E+08	1.62E+08
19mm Copper Pipe (m)	3.73E+08	3.73E+08	4.60E+08	3.73E+08
40mm ABS Pipe (m)	2.01E+08	2.01E+08	2.01E+08	2.01E+08
50mm ABS Pipe (m)	6.80E+07	6.80E+07	6.80E+07	6.80E+07
75mm ABS Pipe (m)	1.75E+08	1.75E+08	1.75E+08	1.75E+08
100mm ABS Pipe (m)	1.56E+08	1.56E+08	1.56E+08	1.56E+08
41mm PVC Conduit (m)	3.84E+07	3.84E+07	3.84E+07	3.84E+07
Ductwork (kg)	2.61E+09	2.61E+09	1.80E+09	2.03E+09
Radiators (kg)	0.00E+00	0.00E+00	3.25E+08	0.00E+00
Natural Gas Furnace (unit)	2.08E+06	2.08E+06	3.94E+06	0.00E+00
Oil Furnace (unit)	0.00E+00	0.00E+00	5.25E+05	6.06E+06
Propane Furnace (unit)	0.00E+00	0.00E+00	7.35E+04	0.00E+00
Wood Furnace (unit)	4.25E+05	4.25E+05	4.25E+05	0.00E+00
Natural Gas Boiler (unit)	0.00E+00	0.00E+00	6.27E+05	0.00E+00
Oil Boiler (unit)	0.00E+00	0.00E+00	1.96E+05	0.00E+00
Propane Boiler (unit)	0.00E+00	0.00E+00	1.48E+04	0.00E+00
Electric Baseboard (W)	0.00E+00	0.00E+00	2.31E+10	2.39E+10
Heat Pump (unit)	7.12E+06	7.12E+06	5.50E+05	0.00E+00
Central Air Conditioner (unit)	7.90E+06	4.97E+06	4.97E+06	4.97E+06
HRV (unit)	8.20E+06	8.20E+06	8.20E+06	8.20E+06
Natural Gas Water Tank (unit)	6.89E+06	2.68E+06	5.95E+06	0.00E+00
Electric Water Tank (unit)	3.36E+06	7.58E+06	3.90E+06	2.68E+06
Oil Water Tank (unit)	0.00E+00	0.00E+00	3.99E+05	7.58E+06

Table B12: Building Stock Energy Efficiency Scenario BOM[1] Changes (2010-2049)

Item	7 years		4 Years		0 years	
	Diff	% Diff	Diff	% Diff	Diff	% Diff
Aluminum (Tonnes)	2.07E+05	12.9	3.59E+05	22.3	6.35E+05	39.4
Batt. Fiberglass (m2 (25mm))	5.35E+09	63.0	7.58E+09	89.3	1.06E+10	124.4
Batt. Rockwool (m2 (25mm))	1.45E+09	60.7	2.06E+09	86.0	2.86E+09	119.8
Blown Cellulose (m2 (25mm))	4.56E+08	54.5	6.46E+08	77.2	9.00E+08	107.5
EPDM membrane (white, 60 mil) (kg)	6.98E+07	15.5	1.29E+08	28.6	2.26E+08	50.0
Expanded Polystyrene (m2 (25mm))	4.22E+08	N/A	6.19E+08	N/A	8.81E+08	N/A
Extruded Polystyrene (m2 (25mm))	1.02E+09	N/A	1.50E+09	N/A	2.13E+09	N/A
Fibreglass (kg)	1.47E+07	17.3	2.40E+07	28.2	4.25E+07	50.0
Foam Polyisocyanurate (m2 (25mm))	2.49E+08	64.1	3.53E+08	90.8	4.92E+08	126.4
Galvanized Studs (Tonnes)	3.59E+04	2.7	3.92E+04	2.9	4.35E+04	3.3
Laminated Veneer Lumber (m3)	2.17E+05	2.4	2.37E+05	2.7	2.63E+05	3.0
Low E Tin Argon Filled Glazing (m2)	4.03E+07	N/A	5.08E+07	N/A	6.86E+07	N/A
Low E Tin Glazing (m2)	1.29E+07	3.7	4.81E+07	13.9	1.04E+08	30.2
Nails (Tonnes)	7.98E+04	5.8	1.34E+05	9.8	2.23E+05	16.3
PVC (kg)	5.96E+08	15.2	1.13E+09	28.8	1.97E+09	50.0
Screws Nuts & Bolts (Tonnes)	8.42E+03	5.0	9.18E+03	5.4	1.02E+04	6.0
Small Dimension Softwood Lumber, kiln-dried (m3)	6.46E+06	7.0	7.90E+06	8.6	1.01E+07	11.0
Water Based Latex Paint (L)	8.92E+05	0.0	1.50E+06	0.0	2.51E+06	0.1
Central Air Conditioner (unit)	1.33E+06	26.7	1.89E+06	38.0	2.93E+06	59.0

[1]Changes relative to Baseline. Baseline materials not shown do not change.

Table B13: 60-Year Case B Design 1 (Baseline) Dwelling GWP, by stage

Dwelling Design	Global Warming Potential (t CO_2 eq.)								
	Manufac-turing	Construc-tion	Mainte-nance	End Of Life	Space Heating	Space Cooling	DHW	Appliances/ Lighting	Total
Vancouver R6 B1	22.9	3.8	8.5	1.2	57.6	0.2	51.4	12.6	158.2
Vancouver S6 B1	25.5	4.3	9.9	1.3	100.7	0.2	51.5	12.5	205.9
Vancouver D7 B1	36.7	6.2	14.3	1.9	151.8	0.4	55.5	14.0	280.8
Calgary R4 B1	22.6	3.7	8.9	1.1	264.2	6.4	88.7	315.5	711.1
Calgary S4 B1	25.2	4.0	10.3	1.2	372.8	7.5	88.7	314.7	824.3
Calgary D2 B1	34.1	5.2	14.1	1.6	499.6	11.4	103.2	337.0	1,006.2
Saskatoon R1 B1	20.2	3.1	9.4	1.0	275.2	17.8	94.0	238.7	659.3
Saskatoon S1 B1	22.5	3.3	10.7	1.0	382.8	21.5	93.9	239.2	775.0
Saskatoon D1 B1	33.5	4.9	15.2	1.6	572.1	32.6	110.3	267.9	1,038.1
Winnipeg R2 B1	19.4	3.1	9.8	1.0	125.3	0.6	44.0	5.8	208.9
Winnipeg S2 B1	21.6	3.5	11.0	1.1	185.8	0.7	44.0	5.8	273.5
Winnipeg D2 B1	30.6	5.0	14.9	1.6	269.7	0.9	50.0	6.3	379.0
Toronto R6 B1	23.9	3.4	11.1	1.2	163.9	14.9	74.8	89.8	383.0
Toronto S6 B1	26.6	3.6	12.4	1.3	251.1	17.8	74.8	90.3	478.0
Toronto D6 B1	37.1	4.9	16.7	1.8	342.4	26.6	81.1	100.9	611.5
Montreal R5 B1	21.6	3.2	8.4	1.2	42.3	0.1	9.7	1.9	88.5
Montreal S5 B1	24.0	3.4	9.7	1.3	65.6	0.2	9.7	1.9	115.8
Montreal D1 B1	30.3	4.1	12.9	1.6	89.8	0.2	10.9	2.2	151.9
Moncton R4 B1	24.0	3.6	8.4	1.1	336.0	6.3	126.7	180.5	686.5
Moncton S4 B1	26.9	3.8	9.7	1.2	485.3	7.5	126.7	193.9	855.0
Moncton D1 B1	35.3	4.7	12.9	1.6	651.2	10.1	141.9	204.9	1,062.6
Halifax R7 B1	26.9	4.3	9.1	1.3	385.1	6.2	157.5	324.7	915.1
Halifax S7 B1	30.4	4.5	10.6	1.4	561.0	7.1	157.6	325.1	1,097.7
Halifax D5 B1	39.9	5.7	14.2	1.8	748.8	10.1	175.3	344.0	1,339.8
Charlottetown R2 B1	22.4	3.2	8.0	1.0	252.8	2.9	114.9	135.1	540.3
Charlottetown S2 B1	25.0	3.4	9.2	1.1	355.0	3.4	115.2	135.4	647.7
Charlottetown D3 B1	38.0	5.1	13.8	1.7	533.0	5.2	131.0	145.9	873.7
St. John's R2 B1	21.8	3.0	6.9	1.0	126.2	0.1	41.1	40.0	240.1
St. John's S2 B1	24.4	3.2	8.1	1.1	190.6	0.1	41.1	40.0	308.8
St. John's D2 B1	36.1	4.6	12.2	1.6	298.4	0.2	44.1	44.2	441.3

Table B14: 60-Year Case B Design 1 (Baseline) Dwelling TPE, by stage

Dwelling Design	Total Primary Energy Use (GJ)								
	Manufac-turing	Construc-tion	Mainte-nance	End Of Life	Space Heating	Space Cooling	DHW	Appliances/ Lighting	Total
Vancouver R6 B1	388	56	190	18	1,751	24	1,193	1,346	4,967
Vancouver S6 B1	431	63	216	20	2,894	28	1,194	1,344	6,190
Vancouver D7 B1	630	92	314	28	4,339	49	1,292	1,526	8,269
Calgary R4 B1	365	53	185	16	4,344	91	1,524	4,466	11,045
Calgary S4 B1	406	57	211	18	6,212	106	1,525	4,454	12,989
Calgary D2 B1	555	75	290	24	8,342	160	1,772	4,769	15,987
Saskatoon R1 B1	320	44	177	14	4,794	274	1,595	3,665	10,883
Saskatoon S1 B1	357	48	201	15	6,712	330	1,595	3,673	12,930
Saskatoon D1 B1	539	71	295	23	10,075	500	1,871	4,114	17,489
Winnipeg R2 B1	333	46	185	15	3,782	162	1,152	1,381	7,056
Winnipeg S2 B1	371	51	208	16	5,493	189	1,153	1,389	8,871
Winnipeg D2 B1	534	73	293	23	7,941	270	1,321	1,517	11,973
Toronto R6 B1	402	54	216	18	3,997	567	1,648	3,376	10,277
Toronto S6 B1	447	56	242	20	5,980	680	1,648	3,395	12,467
Toronto D6 B1	632	76	337	27	8,258	1,014	1,789	3,797	15,931
Montreal R5 B1	364	50	181	17	3,313	104	938	1,241	6,208
Montreal S5 B1	405	52	206	19	5,005	126	937	1,247	7,997
Montreal D1 B1	513	62	272	23	6,536	168	1,070	1,426	10,069
Moncton R4 B1	374	56	178	16	7,513	124	2,429	3,523	14,212
Moncton S4 B1	418	58	203	18	10,855	147	2,429	3,786	17,914
Moncton D1 B1	552	74	273	23	14,115	196	2,722	4,000	21,955
Halifax R7 B1	423	65	198	19	6,213	88	2,238	4,602	13,846
Halifax S7 B1	477	69	226	20	9,086	101	2,238	4,608	16,825
Halifax D5 B1	631	86	304	26	12,043	143	2,490	4,876	20,600
Charlottetown R2 B1	348	50	171	15	4,739	54	1,761	2,522	9,660
Charlottetown S2 B1	388	53	194	16	6,626	63	1,765	2,526	11,632
Charlottetown D3 B1	599	80	294	25	10,079	98	2,010	2,722	15,907
St. John's R2 B1	339	47	157	15	4,155	4	1,249	1,560	7,526
St. John's S2 B1	379	50	180	16	6,205	5	1,251	1,559	9,646
St. John's D2 B1	569	72	271	24	9,159	6	1,345	1,720	13,166

Table B15: 60-Year Case B Design 1 (Baseline) Dwelling Impacts

Dwelling Design	Global Warming (kg CO_2 eq.)	Acidification (moles of H+ eq.)	HH Respiratory (kg PM2.5 eq.)	Eutrophi-cation (kg N eq.)	Ozone Depletion (kg CFC-11 eq.)	Smog (kg NOx eq.)	Solid Waste (kg)
Vancouver R6 B1	158,214	72,072	484	381	5.09E-02	299	100,432
Vancouver S6 B1	205,916	92,111	598	385	5.10E-02	359	110,965
Vancouver D7 B1	280,784	124,521	832	474	5.47E-02	511	160,260
Calgary R4 B1	711,120	318,388	1,582	397	4.70E-02	1,461	154,515
Calgary S4 B1	824,340	366,869	1,821	405	4.71E-02	1,568	167,685
Calgary D2 B1	1,006,172	447,021	2,245	460	5.27E-02	1,857	213,853
Saskatoon R1 B1	659,251	291,696	1,466	393	1.33E-01	1,257	130,017
Saskatoon S1 B1	774,992	340,454	1,710	402	1.33E-01	1,386	142,621
Saskatoon D1 B1	1,038,144	454,551	2,319	495	1.41E-01	1,836	202,281
Winnipeg R2 B1	208,939	93,244	571	391	1.91E-01	325	87,547
Winnipeg S2 B1	273,467	120,825	720	396	1.91E-01	391	97,229
Winnipeg D2 B1	378,961	167,267	1,023	459	1.92E-01	573	139,086
Toronto R6 B1	383,037	169,366	943	475	1.97E-01	699	120,757
Toronto S6 B1	477,974	208,647	1,146	483	1.97E-01	811	134,124
Toronto D6 B1	611,500	266,225	1,500	566	2.10E-01	1,065	184,128
Montreal R5 B1	88,482	34,427	329	387	1.12E-01	314	98,757
Montreal S5 B1	115,803	42,569	398	392	1.12E-01	392	108,896
Montreal D1 B1	151,934	57,132	581	419	1.29E-01	618	136,360
Moncton R4 B1	686,485	218,458	992	430	7.37E-02	1,786	130,873
Moncton S4 B1	855,024	270,306	1,231	454	7.38E-02	2,236	149,558
Moncton D1 B1	1,062,576	331,975	1,509	504	7.34E-02	2,709	192,172
Halifax R7 B1	915,110	300,831	1,391	513	5.42E-02	2,181	177,988
Halifax S7 B1	1,097,654	351,288	1,631	533	5.43E-02	2,565	201,539
Halifax D5 B1	1,339,801	424,421	1,995	599	5.41E-02	3,103	254,887
Charlottetown R2 B1	540,337	150,862	819	393	3.55E-02	1,020	115,866
Charlottetown S2 B1	647,714	168,353	925	403	3.56E-02	1,167	127,481
Charlottetown D3 B1	873,719	219,916	1,269	515	4.24E-02	1,590	184,896
St. John's R2 B1	240,125	58,142	357	315	9.20E-03	624	87,467
St. John's S2 B1	308,770	72,385	447	325	9.28E-03	793	97,310
St. John's D2 B1	441,331	100,034	605	410	1.24E-02	1,044	144,514

Table B16: 60-Year Case A Design 1 Dwelling Impacts

Dwelling Design	Global Warming (kg CO_2 eq.)	Acidification (moles of H+ eq.)	HH Respiratory (kg PM2.5 eq.)	Eutrophi-cation (kg N eq.)	Ozone Depletion (kg CFC-11 eq.)	Smog (kg NOx eq.)	Solid Waste (kg)
Vancouver R6 A1	60,534	32,842	283	456	3.16E-01	237	86,395
Vancouver S6 A1	66,814	37,152	324	459	3.16E-01	278	92,214
Vancouver D7 A1	87,505	49,760	464	539	3.16E-01	396	129,900
Calgary R4 A1	673,828	302,313	1,494	362	4.56E-02	1,322	138,112
Calgary S4 A1	774,340	345,781	1,711	368	4.57E-02	1,391	145,488
Calgary D2 A1	929,548	414,448	2,085	416	4.57E-02	1,586	178,932
Saskatoon R1 A1	605,992	270,976	1,362	362	1.32E-01	1,061	111,901
Saskatoon S1 A1	706,086	314,608	1,584	368	1.32E-01	1,144	118,814
Saskatoon D1 A1	922,583	410,857	2,113	448	1.32E-01	1,431	161,259
Winnipeg R2 A1	50,147	28,577	255	487	4.59E-01	258	75,602
Winnipeg S2 A1	56,393	32,871	295	489	4.59E-01	305	81,194
Winnipeg D2 A1	73,868	44,655	432	544	4.56E-01	449	113,054
Toronto R6 A1	313,047	150,241	833	572	4.64E-01	885	119,336
Toronto S6 A1	373,448	179,607	989	581	4.64E-01	1,060	131,884
Toronto D6 A1	464,444	224,991	1,284	656	4.62E-01	1,364	175,118
Montreal R5 A1	40,785	24,957	274	473	3.63E-01	279	83,236
Montreal S5 A1	45,343	29,135	328	477	3.63E-01	347	88,953
Montreal D1 A1	56,492	40,283	498	489	3.47E-01	563	109,417
Moncton R4 A1	477,176	187,031	995	360	6.37E-02	995	96,118
Moncton S4 A1	566,973	226,684	1,235	370	6.38E-02	1,184	103,646
Moncton D1 A1	678,487	274,540	1,515	403	6.38E-02	1,341	129,432
Halifax R7 A1	660,372	268,600	1,339	405	3.96E-02	1,436	134,976
Halifax S7 A1	751,017	309,291	1,574	413	3.96E-02	1,573	142,748
Halifax D5 A1	879,174	365,487	1,910	461	3.97E-02	1,792	173,895
Charlottetown R2 A1	434,013	197,112	1,083	309	3.54E-02	877	99,353
Charlottetown S2 A1	510,277	232,226	1,292	316	3.55E-02	1,001	105,883
Charlottetown D3 A1	671,606	307,478	1,780	410	3.56E-02	1,326	148,402
St. John's R2 A1	155,556	49,638	325	389	2.54E-01	570	74,390
St. John's S2 A1	181,204	59,223	404	396	2.54E-01	713	79,981
St. John's D2 A1	239,821	78,197	540	473	2.65E-01	911	115,550

Table B17: 60-Year Case C Design 1 (Worst-Case) Dwelling Impacts

Dwelling Design	Global Warming (kg CO_2 eq.)	Acidification (moles of H+ eq.)	HH Respiratory (kg PM2.5 eq.)	Eutrophi-cation (kg N eq.)	Ozone Depletion (kg CFC-11 eq.)	Smog (kg NOx eq.)	Solid Waste (kg)
Vancouver R6 C1	293,900	60,252	383	353	4.44E-02	358	106,608
Vancouver S6 C1	385,683	72,457	433	358	4.44E-02	409	115,592
Vancouver D7 C1	530,873	100,098	608	446	4.45E-02	555	163,234
Calgary R4 C1	1,386,994	640,239	3,023	490	4.57E-02	3,840	290,724
Calgary S4 C1	1,787,449	824,832	3,864	540	4.57E-02	4,927	354,652
Calgary D2 C1	2,302,851	1,064,443	4,997	644	4.57E-02	6,343	461,025
Saskatoon R1 C1	1,152,521	532,405	2,549	461	1.32E-01	3,007	227,584
Saskatoon S1 C1	1,462,396	675,505	3,210	498	1.32E-01	3,798	273,133
Saskatoon D1 C1	2,049,470	947,748	4,517	638	1.32E-01	5,320	390,533
Winnipeg R2 C1	442,450	64,989	351	384	1.83E-01	362	92,821
Winnipeg S2 C1	580,195	80,134	404	390	1.83E-01	421	101,356
Winnipeg D2 C1	802,284	111,345	569	456	1.83E-01	570	142,598
Toronto R6 C1	492,276	117,869	641	452	1.87E-01	635	122,968
Toronto S6 C1	619,490	134,574	706	458	1.88E-01	702	132,921
Toronto D6 C1	808,332	171,626	917	535	1.88E-01	878	179,216
Montreal R5 C1	395,546	61,085	363	375	1.01E-01	339	103,892
Montreal S5 C1	526,081	75,777	416	381	1.01E-01	395	112,803
Montreal D1 C1	644,689	95,207	529	399	1.01E-01	477	139,385
Moncton R4 C1	821,778	273,566	1,096	428	6.36E-02	1,988	148,237
Moncton S4 C1	1,049,836	348,112	1,361	455	6.36E-02	2,516	169,546
Moncton D1 C1	1,302,563	434,545	1,715	511	6.36E-02	3,118	214,830
Halifax R7 C1	1,309,855	504,893	2,183	521	3.95E-02	3,480	246,734
Halifax S7 C1	1,674,578	644,579	2,753	566	3.95E-02	4,425	294,406
Halifax D5 C1	2,091,655	807,562	3,464	657	3.95E-02	5,522	371,685
Charlottetown R2 C1	827,795	380,981	1,853	385	3.53E-02	2,259	192,606
Charlottetown S2 C1	1,057,114	486,413	2,339	413	3.53E-02	2,866	228,789
Charlottetown D3 C1	1,503,403	692,591	3,346	551	3.54E-02	4,068	333,757
St. John's R2 C1	434,130	67,776	339	285	9.06E-03	422	91,221
St. John's S2 C1	560,792	82,223	391	291	9.07E-03	480	99,638
St. John's D2 C1	790,644	115,963	570	371	9.12E-03	647	145,472

Table B18: 60-Year Case B Design 6 Dwelling Impacts

Dwelling Design	Global Warming (kg CO_2 eq.)	Acidification (moles of H+ eq.)	HH Respiratory (kg PM2.5 eq.)	Eutrophi-cation (kg N eq.)	Ozone Depletion (kg CFC-11 eq.)	Smog (kg NOx eq.)	Solid Waste (kg)
Vancouver R6 B6	75,667	41,041	355	412	1.08E-01	305	103,405
Vancouver S6 B6	87,121	47,553	410	414	1.09E-01	346	114,747
Vancouver D7 B6	119,401	65,521	592	502	1.12E-01	494	166,185
Calgary R4 B6	470,642	219,183	1,143	410	8.81E-02	1,323	149,514
Calgary S4 B6	502,635	234,498	1,238	413	8.81E-02	1,386	161,535
Calgary D2 B6	578,069	270,999	1,477	464	9.37E-02	1,602	205,348
Saskatoon R1 B6	415,769	192,867	1,019	445	2.44E-01	1,087	125,316
Saskatoon S1 B6	456,959	211,917	1,130	450	2.44E-01	1,167	137,023
Saskatoon D1 B6	582,737	271,266	1,494	536	2.53E-01	1,510	194,362
Winnipeg R2 B6	75,213	39,764	325	421	2.52E-01	279	88,891
Winnipeg S2 B6	95,725	49,891	395	424	2.52E-01	322	98,986
Winnipeg D2 B6	130,490	68,585	571	483	2.53E-01	458	142,337
Toronto R6 B6	201,872	98,247	628	499	2.53E-01	589	118,494
Toronto S6 B6	230,811	112,095	719	503	2.53E-01	652	131,073
Toronto D6 B6	289,372	141,354	950	581	2.67E-01	838	180,785
Montreal R5 B6	52,173	29,224	300	465	2.51E-01	273	102,350
Montreal S5 B6	62,433	34,388	351	467	2.51E-01	314	113,357
Montreal D1 B6	80,214	44,186	467	489	2.68E-01	406	142,278
Moncton R4 B6	360,944	124,585	609	442	1.67E-01	979	116,249
Moncton S4 B6	411,321	142,116	704	450	1.67E-01	1,118	129,468
Moncton D1 B6	482,011	168,272	877	486	1.67E-01	1,326	166,968
Halifax R7 B6	524,294	200,998	989	505	1.07E-01	1,467	154,653
Halifax S7 B6	571,226	217,094	1,086	511	1.07E-01	1,586	170,251
Halifax D5 B6	656,512	249,945	1,299	562	1.07E-01	1,835	214,495
Charlottetown R2 B6	279,842	115,390	660	403	8.42E-02	765	111,052
Charlottetown S2 B6	311,333	123,379	721	407	8.43E-02	825	121,767
Charlottetown D3 B6	386,266	152,300	952	506	9.10E-02	1,053	176,626
St. John's R2 B6	109,518	37,874	273	309	2.47E-02	370	88,398
St. John's S2 B6	129,280	44,361	325	313	2.48E-02	430	98,511
St. John's D2 B6	171,025	60,909	482	390	2.78E-02	583	146,884

Table B19: 60-Year Case A Design 6 (Best-Case) Dwelling Impacts

Dwelling Design	Global Warming (kg CO_2 eq.)	Acidification (moles of H+ eq.)	HH Respiratory (kg PM2.5 eq.)	Eutrophi-cation (kg N eq.)	Ozone Depletion (kg CFC-11 eq.)	Smog (kg NOx eq.)	Solid Waste (kg)
Vancouver R6 A6	56,874	31,958	284	490	3.73E-01	243	89,941
Vancouver S6 A6	61,108	35,383	319	491	3.73E-01	270	96,769
Vancouver D7 A6	80,425	47,748	462	571	3.73E-01	382	136,797
Calgary R4 A6	454,323	211,059	1,078	377	8.66E-02	1,240	136,923
Calgary S4 A6	481,698	224,267	1,157	380	8.66E-02	1,285	144,388
Calgary D2 A6	548,749	256,958	1,372	425	8.67E-02	1,467	179,038
Saskatoon R1 A6	392,949	182,178	944	419	2.44E-01	985	112,587
Saskatoon S1 A6	428,623	199,023	1,039	422	2.44E-01	1,045	120,044
Saskatoon D1 A6	540,211	252,143	1,362	499	2.44E-01	1,328	165,872
Winnipeg R2 A6	44,903	26,399	241	521	5.20E-01	226	77,371
Winnipeg S2 A6	48,912	29,683	274	522	5.20E-01	254	83,475
Winnipeg D2 A6	63,442	39,687	393	575	5.17E-01	353	116,604
Toronto R6 A6	192,328	93,656	577	589	5.21E-01	535	105,596
Toronto S6 A6	210,436	103,479	643	592	5.21E-01	595	114,133
Toronto D6 A6	258,199	128,623	843	661	5.18E-01	765	153,991
Montreal R5 A6	42,781	25,230	254	552	5.02E-01	227	87,069
Montreal S5 A6	46,498	28,480	290	553	5.02E-01	257	93,707
Montreal D1 A6	m,	35,569	383	560	4.86E-01	330	115,236
Moncton R4 A6	306,265	110,296	547	400	1.57E-01	765	97,786
Moncton S4 A6	338,119	123,948	629	404	1.57E-01	841	105,362
Moncton D1 A6	385,503	144,580	777	434	1.57E-01	965	132,303
Halifax R7 A6	462,258	183,876	897	422	9.22E-02	1,250	135,366
Halifax S7 A6	488,832	196,521	978	425	9.22E-02	1,308	143,413
Halifax D5 A6	549,693	223,894	1,168	470	9.22E-02	1,482	176,126
Charlottetown R2 A6	248,386	116,215	649	324	8.41E-02	674	98,821
Charlottetown S2 A6	271,171	127,606	725	327	8.41E-02	719	105,317
Charlottetown D3 A6	330,207	157,374	953	411	8.42E-02	901	148,991
St. John's R2 A6	99,268	34,856	237	385	2.70E-01	328	75,998
St. John's S2 A6	107,033	39,087	277	388	2.70E-01	372	82,109
St. John's D2 A6	133,510	51,961	408	461	2.80E-01	492	119,336

Table B20: 60-Year Case B Design1 (Baseline) Dwelling Resource Use

Dwelling Design	NRPE (GJ)	RPE (GJ)	TPE (GJ)	Coal (kg)	Crude Oil (L)	Natural Gas (m^3)	Uranium (kg)	Wood (kg)
Vancouver R6 B1	2,881	2,086	4,967	3,017	9,220	58,853	0.03	24,945
Vancouver S6 B1	3,804	2,386	6,190	3,428	11,747	77,620	0.04	30,888
Vancouver D7 B1	5,233	3,037	8,269	4,850	18,152	103,178	0.06	44,938
Calgary R4 B1	10,895	151	11,045	191,845	14,042	135,646	0.11	17,487
Calgary S4 B1	12,828	161	12,989	200,857	15,954	178,152	0.12	19,469
Calgary D2 B1	15,797	191	15,987	230,704	20,256	230,110	0.14	26,382
Saskatoon R1 B1	10,412	471	10,883	151,525	13,555	147,915	0.08	21,103
Saskatoon S1 B1	12,424	506	12,930	162,196	16,664	188,372	0.09	25,586
Saskatoon D1 B1	16,842	647	17,489	206,040	24,868	259,950	0.12	41,716
Winnipeg R2 B1	3,821	3,235	7,056	7,671	8,508	78,677	0.03	24,954
Winnipeg S2 B1	5,047	3,824	8,871	8,993	10,470	105,321	0.03	30,836
Winnipeg D2 B1	7,174	4,798	11,973	11,630	15,821	145,556	0.05	50,897
Toronto R6 B1	9,730	547	10,277	63,448	15,190	99,109	10.47	25,254
Toronto S6 B1	11,848	620	12,467	71,867	19,336	130,580	11.86	30,369
Toronto D6 B1	15,159	772	15,931	89,469	27,074	166,607	14.69	46,565
Montreal R5 B1	2,170	4,038	6,208	3,427	19,319	12,552	0.92	39,129
Montreal S5 B1	2,914	5,083	7,997	3,903	26,073	16,075	1.16	51,619
Montreal D1 B1	4,375	5,694	10,069	4,936	35,377	19,179	1.31	93,106
Moncton R4 B1	13,473	739	14,212	105,835	142,993	30,257	7.54	68,472
Moncton S4 B1	17,003	911	17,914	130,359	179,516	37,238	9.31	93,723
Moncton D1 B1	20,836	1,119	21,955	159,838	225,014	46,622	11.39	107,205
Halifax R7 B1	13,500	345	13,846	225,773	151,174	18,113	0.24	51,308
Halifax S7 B1	16,426	399	16,825	260,337	189,222	21,739	0.28	68,844
Halifax D5 B1	20,116	483	20,600	311,324	235,188	27,520	0.34	86,613
Charlottetown R2 B1	9,423	237	9,660	98,074	106,060	24,660	2.76	50,696
Charlottetown S2 B1	11,378	254	11,632	103,856	138,706	27,747	2.91	68,232
Charlottetown D3 B1	15,586	321	15,907	127,822	196,503	36,935	3.55	109,311
St. John's R2 B1	4,362	3,164	7,526	5,907	74,235	8,423	0.08	52,006
St. John's S2 B1	5,782	3,864	9,646	6,967	96,391	10,335	0.09	71,999
St. John's D2 B1	7,877	5,290	22,456	10,054	138,079	15,274	0.13	87,036

Table B21: 60-Year Case A Design 1 Dwelling Resource Use

Dwelling Design	NRPE (GJ)	RPE (GJ)	TPE (GJ)	Coal (kg)	Crude Oil (L)	Natural Gas (m^3)	Uranium (kg)	Wood (kg)
Vancouver R6 A1	1,074	2,653	3,728	2,144	5,377	16,082	0.02	26,586
Vancouver S6 A1	1,275	3,016	4,290	2,397	5,811	17,935	0.02	33,657
Vancouver D7 A1	1,743	3,751	5,494	3,328	8,204	22,901	0.03	49,089
Calgary R4 A1	10,358	144	10,502	174,837	10,976	137,571	0.09	18,300
Calgary S4 A1	12,121	151	12,272	178,511	11,737	180,480	0.09	21,349
Calgary D2 A1	14,732	173	14,905	194,117	14,294	235,142	0.10	29,919
Saskatoon R1 A1	9,718	397	10,115	124,965	7,631	155,217	0.06	21,774
Saskatoon S1 A1	11,531	413	11,944	129,130	8,349	197,451	0.06	27,213
Saskatoon D1 A1	15,356	486	15,843	149,206	11,508	275,760	0.08	44,958
Winnipeg R2 A1	901	4,739	5,640	9,346	4,812	4,461	0.02	25,650
Winnipeg S2 A1	1,090	5,770	6,861	11,202	5,252	4,830	0.02	32,528
Winnipeg D2 A1	1,639	7,411	9,050	14,441	7,410	6,501	0.03	54,141
Toronto R6 A1	10,285	879	11,163	100,400	9,588	35,742	17.10	26,895
Toronto S6 A1	12,425	1,060	13,485	121,240	10,883	42,498	20.70	33,139
Toronto D6 A1	15,559	1,312	16,871	150,001	14,211	52,917	25.56	49,943
Montreal R5 A1	1,328	3,735	5,062	2,527	6,870	4,316	0.84	40,263
Montreal S5 A1	1,705	4,521	6,226	2,820	7,657	4,733	1.02	53,852
Montreal D1 A1	2,787	5,218	8,005	3,506	9,506	5,774	1.17	96,350
Moncton R4 A1	9,717	314	10,031	43,423	52,319	111,080	2.97	69,285
Moncton S4 A1	11,865	343	12,208	47,162	56,813	143,232	3.21	95,603
Moncton D1 A1	14,008	379	14,386	51,499	62,161	184,219	3.44	110,447
Halifax R7 A1	10,740	221	10,961	133,012	53,366	112,324	0.14	52,967
Halifax S7 A1	12,677	231	12,909	136,215	55,088	149,341	0.14	71,662
Halifax D5 A1	15,085	260	15,345	146,845	60,476	191,877	0.16	89,976
Charlottetown R2 A1	8,462	199	8,661	79,131	9,309	115,562	2.24	51,388
Charlottetown S2 A1	10,184	210	10,394	81,615	10,102	147,726	2.30	69,920
Charlottetown D3 A1	13,757	249	14,005	91,417	13,671	208,746	2.54	112,695
St. John's R2 A1	3,066	3,028	6,094	4,795	44,417	5,554	0.06	52,701
St. John's S2 A1	3,866	3,562	7,428	5,513	51,914	6,242	0.07	73,690
St. John's D2 A1	4,867	4,660	22,456	7,760	68,520	8,795	0.09	90,576

Table B22: 60-Year Case C Design 1 (Worst-Case) Dwelling Resource Use

Dwelling Design	NRPE (GJ)	RPE (GJ)	TPE (GJ)	Coal (kg)	Crude Oil (L)	Natural Gas (m^3)	Uranium (kg)	Wood (kg)
Vancouver R6 C1	4,254	1,498	5,752	8,169	83,691	18,494	0.10	7,795
Vancouver S6 C1	5,553	1,538	7,092	9,222	114,632	20,907	0.11	8,721
Vancouver D7 C1	7,637	1,792	9,428	12,606	159,063	27,564	0.15	13,158
Calgary R4 C1	19,240	442	19,681	583,105	24,071	70,521	0.31	7,068
Calgary S4 C1	24,776	570	25,347	754,679	30,314	89,708	0.39	7,937
Calgary D2 C1	31,925	748	32,673	971,588	39,376	115,796	0.50	11,106
Saskatoon R1 C1	16,336	1,346	17,682	435,466	14,213	107,887	0.22	5,975
Saskatoon S1 C1	20,719	1,717	22,436	554,719	17,488	136,407	0.26	6,737
Saskatoon D1 C1	29,051	2,413	31,464	776,494	25,031	191,398	0.38	10,689
Winnipeg R2 C1	6,295	1,826	8,122	10,436	141,116	13,494	0.09	6,341
Winnipeg S2 C1	8,251	1,909	10,159	11,741	188,557	16,420	0.10	7,142
Winnipeg D2 C1	11,425	2,201	13,626	15,707	261,377	22,952	0.14	10,690
Toronto R6 C1	9,584	458	10,042	53,234	115,642	27,579	7.79	7,797
Toronto S6 C1	11,503	495	11,998	56,473	157,381	30,916	8.14	8,723
Toronto D6 C1	14,658	607	15,265	67,811	211,058	39,052	9.55	12,747
Montreal R5 C1	5,752	1,584	7,336	8,998	125,270	13,023	0.44	7,426
Montreal S5 C1	7,607	1,658	9,265	10,161	170,341	15,823	0.46	8,322
Montreal D1 C1	9,317	1,920	11,238	12,695	208,693	19,700	0.54	10,689
Moncton R4 C1	14,825	988	15,813	139,376	158,290	38,080	9.81	7,069
Moncton S4 C1	18,968	1,272	20,240	178,247	203,235	47,891	12.62	7,937
Moncton D1 C1	23,525	1,592	25,116	221,134	251,843	59,964	15.62	10,688
Halifax R7 C1	18,018	636	18,654	407,888	150,815	24,910	0.46	8,159
Halifax S7 C1	23,021	816	23,837	523,148	193,128	30,792	0.56	9,110
Halifax D5 C1	28,756	1,035	29,791	652,959	241,306	39,006	0.70	12,344
Charlottetown R2 C1	14,540	749	15,289	317,541	21,296	57,921	9.14	6,340
Charlottetown S2 C1	18,588	962	19,550	407,464	26,684	73,498	11.75	7,140
Charlottetown D3 C1	26,426	1,377	27,804	578,087	38,421	105,069	16.67	11,521
St. John's R2 C1	6,189	1,323	7,512	9,380	139,151	12,813	0.10	6,340
St. John's S2 C1	7,986	1,365	9,351	10,719	182,578	15,568	0.11	7,140
St. John's D2 C1	11,267	1,555	22,456	15,457	257,028	22,516	0.16	11,106

Table B23: 60-Year Case B Design 6 Dwelling Resource Use

Dwelling Design	NRPE (GJ)	RPE (GJ)	TPE (GJ)	Coal (kg)	Crude Oil (L)	Natural Gas (m^3)	Uranium (kg)	Wood (kg)
Vancouver R6 B6	1,266	1,579	2,846	3,383	7,286	21,654	0.04	19,845
Vancouver S6 B6	1,459	1,657	3,115	3,894	8,274	25,142	0.04	22,321
Vancouver D7 B6	2,008	1,997	4,005	5,542	12,159	33,479	0.07	31,482
Calgary R4 B6	6,756	143	6,899	171,899	11,982	42,831	0.10	17,425
Calgary S4 B6	7,274	151	7,425	176,001	12,967	52,558	0.11	19,415
Calgary D2 B6	8,424	177	8,601	194,864	16,216	65,622	0.13	26,305
Saskatoon R1 B6	6,108	418	6,525	131,758	9,075	56,457	0.08	15,545
Saskatoon S1 B6	6,773	442	7,215	138,516	10,331	67,664	0.08	17,752
Saskatoon D1 B6	8,698	553	9,251	171,054	14,864	89,549	0.12	27,481
Winnipeg R2 B6	1,239	2,042	3,281	5,976	6,453	19,386	0.03	16,702
Winnipeg S2 B6	1,601	2,238	3,839	6,742	7,458	26,945	0.04	19,269
Winnipeg D2 B6	2,209	2,669	4,878	8,721	10,835	36,859	0.05	28,501
Toronto R6 B6	5,706	432	6,138	49,577	9,381	33,741	8.00	20,190
Toronto S6 B6	6,383	469	6,852	53,707	10,755	41,575	8.63	22,718
Toronto D6 B6	7,879	570	8,449	65,085	14,679	52,925	10.34	31,420
Montreal R5 B6	997	2,099	3,096	3,869	8,800	8,064	0.49	20,405
Montreal S5 B6	1,206	2,378	3,584	4,423	10,638	9,901	0.56	23,958
Montreal D1 B6	1,593	2,760	4,353	5,651	13,655	12,851	0.66	32,401
Moncton R4 B6	6,551	414	6,965	58,043	70,402	19,283	3.98	21,173
Moncton S4 B6	7,512	469	7,981	65,556	80,449	22,300	4.49	26,533
Moncton D1 B6	8,764	549	9,313	75,855	94,157	27,428	5.13	33,501
Halifax R7 B6	7,352	249	7,601	150,086	67,845	13,817	0.17	22,468
Halifax S7 B6	8,063	270	8,334	159,419	76,295	15,933	0.19	26,834
Halifax D5 B6	9,308	317	9,625	179,138	89,323	20,154	0.22	34,223
Charlottetown R2 B6	4,810	209	5,019	81,674	26,196	19,645	2.29	19,225
Charlottetown S2 B6	5,343	221	5,564	84,083	34,429	21,514	2.34	23,913
Charlottetown D3 B6	6,619	272	6,890	97,384	46,918	27,877	2.68	36,555
St. John's R2 B6	1,689	1,596	3,285	5,100	29,224	7,305	0.06	18,281
St. John's S2 B6	2,046	1,765	3,811	5,896	34,491	8,794	0.06	23,189
St. John's D2 B6	2,689	2,094	22,456	8,451	44,388	13,013	0.09	32,375

Table B24: 60-Year Case A Design 6 (Best-Case) Dwelling Resource Use

Dwelling Design	NRPE (GJ)	RPE (GJ)	TPE (GJ)	Coal (kg)	Crude Oil (L)	Natural Gas (m^3)	Uranium (kg)	Wood (kg)
Vancouver R6 A6	848	1,822	2,670	2,457	5,967	13,008	0.02	21,959
Vancouver S6 A6	917	1,906	2,823	2,784	6,459	13,783	0.02	25,733
Vancouver D7 A6	1,217	2,274	3,491	3,885	9,142	17,450	0.03	36,611
Calgary R4 A6	6,469	145	6,615	167,058	10,627	40,885	0.08	18,690
Calgary S4 A6	6,919	154	7,073	169,912	11,213	50,021	0.08	21,911
Calgary D2 A6	7,924	180	8,104	186,134	13,721	62,092	0.10	30,763
Saskatoon R1 A6	5,752	398	6,150	123,211	7,374	55,527	0.06	16,637
Saskatoon S1 A6	6,341	419	6,759	128,257	7,950	66,545	0.06	19,953
Saskatoon D1 A6	8,045	519	8,564	155,735	11,098	87,960	0.08	31,631
Winnipeg R2 A6	614	2,366	2,980	5,749	5,103	4,749	0.02	17,829
Winnipeg S2 A6	686	2,651	3,337	6,450	5,545	5,176	0.02	21,548
Winnipeg D2 A6	924	3,168	4,092	7,993	7,795	7,020	0.03	32,653
Toronto R6 A6	5,397	428	5,825	47,395	7,962	30,979	7.78	22,305
Toronto S6 A6	5,967	481	6,448	52,969	8,661	33,047	8.69	26,131
Toronto D6 A6	7,310	592	7,902	64,958	11,501	39,572	10.58	35,768
Montreal R5 A6	757	2,101	2,858	2,963	6,706	4,612	0.48	22,002
Montreal S5 A6	857	2,298	3,155	3,321	7,258	5,054	0.52	26,820
Montreal D1 A6	1,100	2,681	3,781	4,133	8,850	6,212	0.61	36,553
Moncton R4 A6	5,521	329	5,850	44,334	52,729	29,192	3.02	22,438
Moncton S4 A6	6,158	356	6,513	47,473	56,218	36,253	3.21	29,030
Moncton D1 A6	6,982	401	7,383	52,514	62,190	45,296	3.49	37,651
Halifax R7 A6	6,539	225	6,765	129,284	51,760	24,437	0.13	24,610
Halifax S7 A6	7,015	238	7,253	132,279	53,167	31,959	0.13	30,308
Halifax D5 A6	7,936	275	8,211	144,378	58,955	40,686	0.15	38,543
Charlottetown R2 A6	4,380	197	4,577	74,457	8,722	33,226	2.10	20,349
Charlottetown S2 A6	4,836	208	5,044	75,880	9,263	41,653	2.12	26,190
Charlottetown D3 A6	5,893	254	6,147	85,965	12,584	54,745	2.37	40,872
St. John's R2 A6	1,448	1,637	3,085	4,312	26,054	4,945	0.04	19,408
St. John's S2 A6	1,627	1,743	3,370	4,896	27,790	5,429	0.04	25,468
St. John's D2 A6	2,010	2,010	22,456	6,896	33,530	7,658	0.05	36,835

Table B25: Baseline Stock Results, by stage (2010-2049)

Impact/Resource	Manufacturing	Construction	Maintenance	Space Heating	Space Cooling	DHW	Appliances /Lighting	Total
Global Warming (kg CO2 eq.)	1.78E+11	2.55E+10	2.03E+10	5.86E+11	2.37E+10	1.35E+11	2.33E+11	1.20E+12
Acidification (moles of H+ eq.)	1.07E+11	1.33E+10	1.29E+10	2.26E+11	1.08E+10	5.33E+10	1.03E+11	5.27E+11
HH Respiratory Effects (kg PM2.5 eq.)	1.30E+09	2.11E+07	1.43E+08	1.12E+09	4.94E+07	2.44E+08	4.63E+08	3.34E+09
Eutrophication (kg N eq.)	1.71E+09	1.33E+07	1.10E+08	4.66E+07	2.79E+06	7.77E+06	2.75E+07	1.92E+09
Ozone Depletion (kg CFC-11 eq.)	1.83E+05	9.87E-01	1.60E+05	1.68E+02	2.33E-01	8.81E-01	2.17E+00	3.43E+05
Smog (kg NOx eq.)	8.37E+08	2.94E+08	8.94E+07	8.04E+08	5.96E+07	1.15E+08	5.91E+08	2.79E+09
Solid Waste (kg)	4.50E+10	7.29E+10	1.82E+10	2.49E+10	2.86E+09	4.56E+09	2.90E+10	1.97E+11
NRPE (MJ)	2.80E+12	3.79E+11	3.80E+11	1.22E+13	7.02E+11	2.57E+12	4.86E+12	2.39E+13
RPE (MJ)	1.91E+11	5.99E+09	3.23E+10	1.85E+12	1.20E+11	4.22E+11	1.06E+12	3.68E+12
TPE (MJ)	2.99E+12	3.85E+11	4.12E+11	1.40E+13	8.22E+11	2.99E+12	5.92E+12	2.75E+13
Coal (kg)	1.75E+10	4.61E+07	1.62E+09	6.19E+10	8.67E+09	1.09E+10	8.78E+10	1.89E+11
Crude Oil (L)	1.75E+10	8.42E+09	3.57E+09	3.93E+10	4.86E+08	5.74E+09	6.86E+09	8.19E+10
Natural Gas (m3)	3.28E+10	4.69E+08	4.17E+09	1.66E+11	2.31E+09	4.59E+10	1.79E+10	2.70E+11
Uranium (kg)	2.88E+05	3.23E+04	3.43E+04	4.61E+06	1.10E+06	9.61E+05	4.78E+06	1.18E+07
Wood (kg)	1.27E+11	0.00E+00	1.90E+09	4.85E+10	0.00E+00	0.00E+00	0.00E+00	1.78E+11

Table B26: Baseline Stock Results, by province (2010-2049)

Impact/Resource Use	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL	Total
Global Warming (kg CO2 eq.)	7.03E+10	3.79E+11	4.32E+10	2.00E+10	4.93E+11	6.88E+10	4.50E+10	6.01E+10	8.26E+09	1.43E+10	1.20E+12
Acidification (moles of H+ eq.)	3.36E+10	1.72E+11	1.94E+10	9.34E+09	2.22E+11	3.02E+10	1.48E+10	2.00E+10	2.32E+09	3.97E+09	5.27E+11
HH Respiratory (kg PM2.5 eq)	2.60E+08	9.38E+08	1.07E+08	6.53E+07	1.43E+09	3.19E+08	7.72E+07	1.06E+08	1.51E+07	2.93E+07	3.34E+09
Eutrophication kg N eq.)	2.16E+08	3.32E+08	3.93E+07	4.40E+07	8.61E+08	2.97E+08	4.02E+07	5.17E+07	9.75E+06	2.58E+07	1.92E+09
Ozone Depletion (kg CFC-11 eq)	1.54E+04	2.51E+04	7.92E+03	1.22E+04	2.17E+05	5.70E+04	4.13E+03	3.19E+03	5.17E+02	4.75E+02	3.43E+05
Smog (kg NOx eq.)	1.91E+08	7.89E+08	8.78E+07	4.44E+07	1.04E+09	3.09E+08	1.23E+08	1.50E+08	1.75E+07	4.03E+07	2.79E+09
Solid Waste (kg)	1.63E+10	5.24E+10	5.58E+09	3.47E+09	8.05E+10	2.31E+10	5.11E+09	7.85E+09	1.06E+09	2.19E+09	1.97E+11
NRPE (MJ)	1.26E+12	5.94E+12	6.96E+11	3.68E+11	1.17E+13	1.70E+12	8.68E+11	9.01E+11	1.45E+11	2.49E+11	2.39E+13
RPE (MJ)	6.28E+11	7.96E+10	2.72E+10	2.22E+11	5.99E+11	1.90E+12	4.65E+10	2.30E+10	3.32E+09	1.49E+11	3.68E+12
TPE (MJ)	1.89E+12	6.02E+12	7.23E+11	5.90E+11	1.23E+13	3.60E+12	9.15E+11	9.24E+11	1.48E+11	3.98E+11	2.75E+13
Coal (kg)	2.00E+09	8.21E+10	8.31E+09	6.90E+08	6.99E+10	3.47E+09	6.70E+09	1.36E+10	1.21E+09	5.34E+08	1.89E+11
Crude Oil (L)	5.34E+09	9.73E+09	1.25E+09	1.09E+09	2.51E+10	1.40E+10	9.22E+09	1.03E+10	1.77E+09	4.06E+09	8.19E+10
Natural Gas (m3)	2.31E+10	8.61E+10	1.05E+10	7.09E+09	1.29E+11	9.39E+09	2.28E+09	1.68E+09	4.23E+08	7.36E+08	2.70E+11
Uranium (kg)	2.33E+04	6.68E+04	6.74E+03	4.61E+03	1.07E+07	4.48E+05	4.55E+05	1.70E+04	3.20E+04	5.22E+03	1.18E+07
Wood (kg)	1.87E+10	2.38E+10	3.24E+09	4.22E+09	6.80E+10	4.32E+10	5.98E+09	5.72E+09	1.32E+09	3.67E+09	1.78E+11

Table B27: Building Stock Results (2010-2049)

Impact/Resource	Case A Design 6 (Best-Case)	Case A Design 1	Case B Design 1 (Baseline)	Case C Design 1 (Worst-Case)
Global Warming (kg CO_2 eq)	5.84E+11	9.10E+11	1.20E+12	2.23E+12
Acidification (moles of H+ eq)	2.94E+11	4.37E+11	5.27E+11	7.67E+11
HH Respiratory Effects (kg PM2.5 eq)	2.14E+09	2.81E+09	3.34E+09	4.17E+09
Eutrophication (kg N eq)	2.03E+09	1.96E+09	1.92E+09	1.92E+09
Ozone Depletion (kg CFC-11 eq)	9.89E+05	8.11E+05	3.43E+05	3.04E+05
Smog (kg NOx eq)	2.08E+09	2.58E+09	2.79E+09	4.64E+09
Solid Waste (kg)	1.67E+11	1.84E+11	1.97E+11	3.33E+11
NRPE (MJ)	1.09E+13	2.13E+13	2.39E+13	3.40E+13
RPE (MJ)	2.52E+12	4.13E+12	3.68E+12	2.27E+12
TPE (MJ)	1.34E+13	2.54E+13	2.75E+13	3.62E+13
Coal (kg)	1.37E+11	2.03E+11	1.89E+11	5.00E+11
Crude Oil (L)	3.92E+10	4.05E+10	8.19E+10	3.25E+11
Natural Gas (m^3)	7.84E+10	1.69E+11	2.70E+11	1.26E+11
Uranium (kg)	8.23E+06	1.96E+07	1.18E+07	8.60E+06
Wood (kg)	1.46E+11	1.81E+11	1.78E+11	6.03E+10

Table B28: Building Stock Energy Efficiency Scenario Results (2010-2049)

Impact/Resource Use	Baseline	7 Years	4 Years	0 Years
Global Warming (kg CO_2 eq)	1.20E+12	1.02E+12	9.12E+11	6.96E+11
Acidification (moles of H+ eq)	5.27E+11	4.62E+11	4.26E+11	3.49E+11
HH Respiratory (kg PM2.5 eq)	3.34E+09	3.12E+09	2.99E+09	2.68E+09
Eutrophication (kg N eq)	1.92E+09	1.96E+09	1.97E+09	2.00E+09
Ozone Depletion (kg CFC-11 eq)	3.43E+05	4.24E+05	4.59E+05	5.22E+05
Smog (kg NOx eq)	2.79E+09	2.76E+09	2.73E+09	2.60E+09
Solid Waste (kg)	1.97E+11	1.93E+11	1.91E+11	1.87E+11
NRPE (MJ)	2.39E+13	1.95E+13	1.73E+13	1.27E+13
RPE (MJ)	3.68E+12	3.45E+12	3.14E+12	2.52E+12
TPE (MJ)	2.75E+13	2.30E+13	2.04E+13	1.52E+13
Coal (kg)	1.89E+11	1.75E+11	1.67E+11	1.50E+11
Crude Oil (L)	8.19E+10	7.08E+10	6.45E+10	5.11E+10
Natural Gas (m^3)	2.70E+11	2.08E+11	1.75E+11	1.06E+11
Uranium (kg)	1.18E+07	1.06E+07	9.85E+06	8.24E+06
Wood (kg)	1.78E+11	1.64E+11	1.56E+11	1.40E+11

Appendix C: Analysis Program Screenshots

Figure C1: Residential Archetype Materials Calculator Screenshot

	A	B	C	E	F	G	H	I	J	K	L
1	**Residential Archetype Materials Calculator v1.0**			%	Replace-ment (years)						
3	Spread Footings					Label	Length	Width	Area	rebar	
4	300 deep footing	0.711	Concrete 20 MPa (flyash av) (m3)	100	1000	F1	0.949	0.949	0.900	0.009	
5		0.000	Concrete 20 MPa (flyash 25%) (m3)	0	1000	F2	0.949	0.949	0.900	0.009	
6		0.000	Concrete 20 MPa (flyash 35%) (m3)	0	1000	F3	0.755	0.755	0.570	0.005	
7											
8	15M reinforcing	0.023	Rebar, Rod, Light Sections (Tonnes)	100	1000	Total			2.370	0.023	
9											
10											
11	Interior Slab on Grade					Label	Length	Width	Area		
12	Slab thickness	0.100	m			S1	7.625	9.836	75.000		
13		7.500	Concrete 20 MPa (flyash av) (m3)	100	1000						
14		0.000	Concrete 20 MPa (flyash 25%) (m3)	0	1000						
15		0.000	Concrete 20 MPa (flyash 35%) (m3)	0	1000						
16											
17	wire mesh	0.033	Welded Wire Mesh / Ladder Wire (Tonnes)	50	1000						
18	6mil poly	75.000	6 mil Polyethylene (m2)	100	1000						
19											
20	XPS insulation thickness	0.05	m								
21		0.000	Extruded Polystyrene (m2 (25mm))	0	1000						
22	EPS insulation thickness	0.050	m								
23		0.000	Expanded Polystyrene (m2 (25mm))	0	1000						
24											
25	200mm aggregate	26399.824	Ballast (aggregate stone) (kg)	100	1000						
26											
27											
28	Garage Slab on Grade					Label	Length	Width	Area		
29	Slab thickness	0.100	m			S2	6.100	6.100	37.210		
30		3.721	Concrete 20 MPa (flyash av) (m3)	100	1000						

D1 D2 D3 D4 D5 D6 D7 D8 D9 D10 D11 All Results

Figure C2: Res-BEAT Screenshot

Athena Institute

Building Stock Impact Estimator v1.0

Execute Analysis | Reset Worksheet | Clear Input

Input

Archetyp	Design	Province	City	Service L''	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	202
D6	B1	ON	Windsor	70	1835	1835	1835	1835	1835	1835	1835	1835	1835	1835	1
D7	B1	BC	Kamloops	70	409	409	409	409	409	409	409	409	409	409	
D7	B1	BC	Kelowna	70	1372	1372	1372	1372	1372	1372	1372	1372	1372	1372	1
D7	B1	BC	Prince George	70	429	429	429	429	429	429	429	429	429	429	
D7	B1	BC	Vancouver	70	7506	7506	7506	7506	7506	7506	7506	7506	7506	7506	7
D7	B1	BC	Victoria	70	1139	1139	1139	1139	1139	1139	1139	1139	1139	1139	

Results

			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	202
Primary Energy Consumption (MJ)	Manufacturing	Total	7.338E+10	7.338E+10	7.338E+10	7.338E+10	7.338E+10	7.338E+10	7.338E+10	7.338E+10	7.338E+10	7.338E+10	7.338
	Construction	Total	1.063E+10	1.063E+10	1.063E+10	1.063E+10	1.063E+10	1.063E+10	1.063E+10	1.063E+10	1.063E+10	1.063E+10	1.063
	Maintenance	Total	0	0	0	0	0	432634486	432634486	432634486	432634486	432634486	86526
	End - Of - Life	Total	0	0	0	0	0	0	0	0	0	0	
	Operating Energy	Space Heating	1.4749E+10	2.95E+10	4.425E+10	5.9E+10	7.374E+10	8.849E+10	1.032E+11	1.18E+11	1.327E+11	1.475E+11	1.62
		Space Cooling	904127358	1.808E+09	2.712E+09	3.617E+09	4.521E+09	5.425E+09	6.329E+09	7.233E+09	8.137E+09	9.041E+09	9.945
		DHW	5096873667	1.019E+10	1.529E+10	2.039E+10	2.548E+10	3.058E+10	3.568E+10	4.077E+10	4.587E+10	5.097E+10	5.607
		Appliances/Lighting	5936360631	1.187E+10	1.781E+10	2.375E+10	2.968E+10	3.562E+10	4.155E+10	4.749E+10	5.343E+10	5.936E+10	6.53
		Total	2.6686E+10	5.337E+10	8.006E+10	1.067E+11	1.334E+11	1.601E+11	1.868E+11	2.135E+11	2.402E+11	2.669E+11	2.93
Weighted Resource Use kg	Manufacturing	Total	3.4271E+10	3.427E+10	3.427E+10	3.427E+10	3.427E+10	3.427E+10	3.427E+10	3.427E+10	3.427E+10	3.427E+10	3.427
	Construction	Total	1944161.51	1944161.5	1944161.5	1944161.5	1944161.5	1944161.5	1944161.5	1944161.5	1944161.5	1944161.5	1944
	Maintenance	Total	0	0	0	0	0	23530748	23530748	23530748	23530748	23530748	4706
	End - Of - Life	Total	0	0	0	0	0	0	0	0	0	0	
	Operating Energy	Space Heating	165161499	330322999	495484498	660645997	825807497	990968996	1.156E+09	1.321E+09	1.486E+09	1.652E+09	1.817
		Space Cooling	0	0	0	0	0	0	0	0	0	0	
		DHW	65697198.6	131394397	197091596	262788794	328485993	394183191	459880390	525577588	591274787	656971986	7226
		Appliances/Lighting	1390656.5	2781313	4171969.5	5562626	6953282.5	8343939	9734595.5	11125252	12515909	13906565	1529

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Glossary

Definitions of environmental impact indicators have been provided by the Athena Sustainable Material Institute; the characterization factors for each indicator are primarily based on the EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) LCIA methodology. Other terms have been given definitions specifically for this report in order to provide clarity and consistency to the reader. Some of the terms have ambiguous meanings and definitions may differ somewhat between literature.

Acidification: as per TRACI, acidification comprises processes that increase the acidity (hydrogen ion concentration, [H+]) of water and soil systems. Acidification is a more regional rather than global impact, affecting fresh water and forests as well as human health when high concentrations of SO_2 are attained. The acidification potential of an air emission is calculated on the basis of the number of H+ ions that can be produced, and is therefore expressed as potential H+ equivalents on a mass basis.

Dynamic LCA results: effects presented as a function of time.

Embodied effects: the combined effects of manufacturing, construction, maintenance, and end of life stages.

Eutrophication: in TRACI, eutrophication is defined as the fertilization of surface waters by nutrients that were previously scarce. This measure encompasses the release of mineral salts and their nutrient enrichment effects on waters – typically made up of phosphorous and nitrogen compounds and organic matter flowing into waterways. The result is expressed on an equivalent mass of nitrogen (N) basis. The characterization factors estimate the eutrophication potential of a release of chemicals containing N or P to air or water, per kilogram of chemical released, relative to 1 kg N discharged directly to surface freshwater.

Global warming: TRACI uses global warming potentials, midpoint metric proposed by the International Panel on Climate Change (IPCC), for the calculation of the potency of greenhouse gases relative to CO_2. The 100-year time horizons recommended by the

IPCC and used by the United States for policy making and reporting are adopted within TRACI. Global warming potential (GWP) can be considered one of the most accepted LCIA categories due to the methodology and science behind the GWP calculation. GW_{P100} will be expressed on equivalency basis relative to CO_2 – that is, equivalent CO_2 mass basis i.e. tonnes of CO_2.

Human health (HH) respiratory effects (Criteria air pollutants): the midpoint level selected by TRACI is used, based on exposure to elevated particulate matter (PM) less than 2.5 micrometers in diameter. Particulate matter is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Emissions of SO_2 and NO_x lead to formation of the secondary particulates sulphate and nitrate. Particles can be suspended in the air for long periods of time. Some particles are large or dark enough to be seen as soot or smoke. Others are so small that individually they can only be detected with an electron microscope. Many manmade and natural sources emit PM directly or emit other pollutants that react in the atmosphere to form PM. These solid and liquid particles come in a wide range of sizes. Particles less than 10 micrometers in diameter (PM10) pose a health concern because they can be inhaled into and accumulate in the respiratory system. Particles less than 2.5 micrometers in diameter (PM2.5) are referred to as "fine" particles and are believed to pose the greatest health risks. Because of their small size (approximately 1/30th the average width of a human hair), fine particles can lodge deep in the lungs.

Non-renewable Primary energy (NRPE): energy drawn directly from earth from fossil fuel and nuclear sources, including for feedstock purposes. For this research the combustion of biomass is included in NRPE.

Operating energy effects: the combined effects of space heating, space cooling, domestic hot water, and appliance and lighting end-uses.

Ozone depletion: stratospheric ozone depletion is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substances. International consensus exists on the use of ozone depletion potentials, a metric proposed by the World Meteorological Organization for calculating the relative importance of CFCs, hydrochlorofluorocarbons (HFCs), and halons expected to contribute significantly to the breakdown of the ozone layer. TRACI is using the ozone depletion potentials published in the Handbook for the International Treaties for the Protection of the Ozone Layer (UNEP-SETAC 2000), where chemicals are characterized relative to CFC-11.

Pre-combustion effects: effects associated with the production and transport of energy sources.

Renewable Primary Energy (RPE): energy sources drawn directly from earth from hydroelectric, wind, and photovoltaic sources.

Secondary Energy (SE): energy produced by the transformation of primary or secondary energy. For the purpose of this research SE is energy consumed at building site.

Smog (Photochemical ozone formation potential): under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x). The “smog” indicator is expressed on a mass of equivalent ethylene basis.

Solid waste: this indicator summarizes LCI solid waste flows and is expressed in kg. Does not include occupant related household waste.

Static LCA results: accumulated effects over the assumed dwelling service life or building stock study period.

Total Primary Energy (TPE): sum of all energy sources that are drawn directly from earth. TPE is equivalent to NRPE + RPE.