1-1-2010

Towards Sustainability : Prioritizing Retrofit Options For Toronto's Single-Family Homes

Katarzyna M. Blaszak
Ryerson University

TOWARDS SUSTAINABILITIY: PRIORITIZING RETROFIT OPTIONS FOR TORONTO'S SINGLE-FAMILY HOMES

by

Katarzyna Marzena Blaszak

Bachelor of Applied Science, University of Toronto, 2004

A thesis

presented to Ryerson University

in partial fulfillment of the

requirements for the degree of

Master of Applied Science

in the Program of

Building Science

Toronto, Ontario, Canada, 2010

Author’s Declaration Page

I hereby declare that I am the sole author of this thesis or dissertation.

I authorize Ryerson University to lend this thesis or dissertation to other institutions or individuals for the purpose of scholarly research.

I further authorize Ryerson University to reproduce this thesis or dissertation by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

ABSTRACT

TOWARDS SUSTAINABILITIY: PRIORITIZING RETROFIT OPTIONS FOR TORONTO'S SINGLE-FAMILY HOMES

Master of Applied Science, 2010

Katarzyna Marzena Blaszak

Building Science

Ryerson University

This study investigates a preliminary retrofit ranking framework for single-family homes on the basis of net environmental effect. Four archetype homes developed to represent Toronto's existing housing stock were modeled using HOT2000 to calculate the operational energy requirements. The embodied effects of selected retrofits were then calculated using the ATHENA Impact estimator and a list of environmental summary measures produced. A method of combining operational and embodied effects based on these eight summary measures was proposed and the functioning and sensitivities of the equation were explored. The method is preliminary and incorporates two factors, a weighting factor and building science factor, that require further research. Analysis of the simulated retrofits allowed generalizations about energy performance and prioritized retrofit recommendations for archetypes. In most retrofit cases operational energy dominates, however, the ranking equation shows the potential for certain conditions in which the embodied effects determine the ranking of a retrofit.

Acknowledgements

This thesis is a compilation of effort, support, knowledge, and patience from many sources. To all those who helped along way I extend my sincere and sleep deprived thanks.

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Terms and Abbreviations

ATHENA Impact Estimator: LCA modeling software

DHW / Domestic Hot Water: equipment and energy associated with providing hot water in the home

Embodied Effects: the environmental effects resulting from the life cycle of materials used in the house, for example air pollution and acidification

Energy Intensity: the amount of energy consumed divided by the area; useful for comparing the energy efficiency of different sized homes; measured in kWh/m^2

EPA: Environmental Protection Agency

Eutrophication: excess nutrients in bodies of water, depletes oxygen supply

GHG / Greenhouse gas: collective term for gases that contribute to global warming

HOT2000: energy modeling software

kWh / kilowatt hour: standard measurement unit of electrical energy

LCA / Life Cycle Assessment: method of quantifying cradle to grave environmental impacts

LEED: Leadership in Energy and Environmental Design; a green building program

Life Cycle: from raw material extraction, through operation, to demolition and disposal

Operational Effects: the environmental effects occurring from using the house, for example, heating and lighting; units kWh/m2, GJ

Parameter: as defined by HOT2000, a component (foundation wall, windows and doors, etc.) or property (air tightness) of the building envelope

Primary Energy: energy contained in raw fuels, for example a liter of natural gas

Site Energy: energy used in the house for heating, cooling, cooking, domestic hot water, etc. and shown on utility bills

1 INTRODUCTION

During The Enlightenment Thomas Malthus famously predicted the population explosion witnessed at the time would and in mass starvation and tragedy (Kovarik, n.d.). The Oil Crisis of the 1970s preceded a short period of intense research into energy conservation and alternative fuel sources. Around the turn of the 21st century evidence for climate change gained legitimacy and the Kyoto Protocol adopted in 1997 attempts to prevent "dangerous anthropogenic interference with the climate system" by setting reduction targets for carbon emissions (European Commission, 2008). It is in this worry about global warming and climate change that current energy efficiency programs and related research have their origin.

Today's sights have been set on improving the energy efficiency and impact of buildings. Programs have been developed by all levels of government. On the federal level, the government of Canada was administering the ecoENERGY – Homes program until the early part of 2010. Under this program homeowners signed up for home audits, conducted renovations, and received a grant upon successful completion (NRCan, 2010). At the provincial level there is the Home Energy Savings Program which mirrors the ecoENERGY program (Ontario Ministry of Energy, 2010). It is only one piece of Ontario's Climate Change Action Plan which aims to reduce greenhouse gas emissions by 6% from 1990 levels by 2014 (Ontario, 2008). At the municipal level the City also has developed a program based on ecoENERGY – Homes called Home Energy Assistance Program (HEAT) (Livegreen Toronto, 2010).

The foundation for these programs is energy demand reduction, conservation, and efficiency. If the energy is not needed the environmental effects that would have happened as a result of its production are avoided. This idea of avoided impacts is shaping City policy. As per City Council on June 2006:

> "To adopt a "conservation first" energy strategy that positions conservation and demand management as the preferred first action with renewable energy being the next highest priority to meet the energy needs of the City of Toronto's Divisions, Agencies, Boards, Commissions, and Corporations and the city as a whole."
>
> (Toronto, 2007)

The desire to reduce negative environmental effects is present. After desire, the next step to implementation is deciding on a focus. It is the intention of this research to help define this focus so that funds and resources can be allocated to get the best net environmental benefit at the individual single-family residential dwelling level.

The problem is that there is no comprehensive ranking of retrofit options. To be comprehensive the ranking would need to include operational and embodied environmental effects with weighting factors, account for durability, be specific to house style, and be regionally appropriate. Past work has predominantly focused on quantifying environmental impacts and comparing them individually (U.S. Green Building Council, 2010; Dong, 2005; Horvat et al., 2009). Operational and embodied effects as well as LCA methodology are often included, but the results are not combined to give a clear and comprehensive ranking of options. One system that does combine environmental effects into a single score is UK Ecopoints, but the regionally-specific and context-based nature of the results make them inappropriate to apply to other markets (Dickie and Howard, 2000).

1.1 Problem Definition

At this moment there is no adequate tool to assess the environmental effects of retrofit options for single-family homes. Therefore, the purpose of this study is to explore how the environmental effects arising from the existing built stock in Toronto might be used to help inform and rank retrofit options for single-family homes in an environmentally comprehensive manner.

1.2 Objectives

The research questions that arise from this problem include:

- What styles of houses should be included such a study?
    - What house styles are representative of Toronto's built stock?
    - Do different house styles have different retrofit options and priorities?
    - Does one house style have superior energy performance?

- What retrofits should be prioritized?
    - What components of the building envelope should be targeted?
    - What level of energy intensity can be reached?
    - What, if any, retrofits should be avoided?

- How could environmental effects be combined into a single, simple ranking?
    - Is there a common denominator between operational and embodied effects?
    - How should different environmental factors be weighted relative to others?
    - How could durability and life cycle be incorporated?

To answer these questions and meet the objective three primary steps undertaken:

1) Archetype development
2) Energy performance analysis
3) Preliminary combination of operational and embodied effects

Since this thesis is interested in ranking retrofit options for existing single-family homes the first objective was to develop archetype houses to be used as base cases for retrofits. These houses needed to fairly represent the range of existing single-family homes in Toronto in terms of vintage, style, and thermal characteristics. Detailed information on their geometry and building envelope construction was necessary to allow the houses to be modeled in HOT2000 and the ATHENA Impact Estimator.

The second objective of this thesis was to model the energy performance of the archetype houses using HOT2000. The purpose of this modeling was to draw conclusions from the results and have the necessary input information for the next stage of modeling. To accomplish this, the necessary HOT2000 input parameters, including the house characteristics defined above, but also mechanical systems and base loads were defined. The base case and iterative retrofit cases for each archetype were modeled and results recorded. The results were then analyzed, compared and conclusions on the energy performance characteristics and retrofit possibilities of each archetype were drawn.

The third objective of this thesis was to develop a prospective method to combine the operational and embodied effects of retrofits. The operational energy results from step two above were added to ATHENA Impact Estimator models of select retrofits to obtain a complete list of operational and embodied effects for a given retrofit option. These results were then combined with the preliminary equation developed for this purpose. As part of an initial effort to test out the validity, sensitivity and utility of the developed equation a selection of retrofit cases was ranked. Observations on the function of the ranking equation were recorded and may be useful in future research for further development of the ranking equation.

2 LITERATURE REVIEW

2.1 Environmental Effects: Embodied and Operational

The environmental effects resulting from a home's life cycle fall into two broad categories: embodied and operational. The first, embodied effects, result from the use of material resources. They include the effects that occur during the full life cycle, from extraction to end of service life. The second, operational effects, result from the use of fuel resources to operate the building. All of the energy used by the house – heating & cooling, domestic hot water, lighting, etc. – produces operational effects.

In order to determine which retrofit option has the best net environmental effect for a particular house, information about the type and magnitude of the environmental impacts is required.

Information on the individual environmental effects associated with homes is available. For example, the production of glass produces cadmium chloride, an acidifying irritant, and quartz dust, a carcinogen (Berge, 2009). In 2005 5.6% of Canada's greenhouse gas emissions (GHG) came from the residential sector (Demerse and Bramley, 2008). An average new house generates 2.5 tonnes of construction waste and the building industry as a whole contributes 15% of the total material in Canadian landfills (Grady, 1993).

While information on environmental effects associated with building materials is available it is not always consistent between sources. For example, compared with the above referenced 15%, a speaker at the 2009 Heritage Canada conference stated that construction waste makes up 33% of landfills (Natalie Bull, personal communication, September 25, 2009) and another source suggests a range of 11-50% (Kalen, et al., 1993). This variation is in large part due to the difficulty of quantifying environmental effects.

The Athena Institute, a North American leader in life cycle analysis, has compiled a list of eight environmental impacts, or summary measures, in the ATHENA Impact Estimator, along with their magnitude (Athena Institute, 2010). This is useful because all the environmental effects can be found in one location, however, they are still listed and measured as eight separate impacts.

On the scale of the world, however, these effects are not separate, independent variables with isolated effects, but rather all contribute to an overall impact on the environment. The quantity of carbon dioxide equivalents (CO_2 eq.) can be measured and recorded, but how would the effect this amount of CO_2 eq. has on the world as a whole be quantified? How would it be combined with other environmental effects? How would one kilogram of CO_2 eq. be compared with one kilogram of solid waste? These are the questions that arise when the problem is viewed on the scale of the world.

Some work has been done that attempts to address these questions. Weighting factors for environmental effects have been introduced into two well-known building ranking systems: LEED 2009 and UK Ecopoints. Both programs base their environmental impact category rankings on results from an expert panel. The caveat is that, since the weighting factors are based on rankings of specific categories, the results are only strictly applicable in context (U.S. Green Building Council, 2010; Dickie and Howard, 2000). UK Ecopoints goes a step further and uses the LCA results with their associated weighting factors to give a concrete, single-score ranking to materials and products. While these are valuable, they are meant to be used in the context in which they were created (Dickie and Howard, 2000).

2.2 Energy Use in Toronto

Data obtained for 1990 GHG emissions from residential buildings specifically for the Former City of Toronto show residential buildings contributing 31% of Toronto's GHG emissions (VandeWeghe and Kennedy, 2007). The higher proportion of the residential sector on Toronto compared to all of Canada (31% to 5.6%) can be attributed to Toronto's lack of heavy industry. The study did not further subdivide the data into multi-family and single-family homes, but given the number of single-family homes in Toronto, the focus of this thesis, their contribution to global warming will not be trivial. Furthermore, a 2007 report found that within the city core residential building operations have the biggest contribution to GHG emissions further strengthening the case to address residential energy usage (VandeWeghe & Kennedy, 2007).

When thinking about the environmental effects associated with energy use it is important to consider the fuel source. The magnitude of the resulting environmental effects changes with the fuel source (Bowick, 2010). Electricity, being an energy product rather than a raw fuel, must be traced back to its raw fuel before its environmental effects can be quantified. A further consideration is the site to source factor which converts the energy used in the home, site energy, to incorporate production and transmission losses to give the amount of source energy. For electricity the national average for Canada is 3.340 and for natural gas this factor is 1.047 (ENERGY STAR, 2009).

Toronto’s energy supply is a mix of natural gas, hydroelectric, nuclear and coal fired. Natural gas is primarily used for winter heating. Electricity, coming from a combination of hydroelectric, nuclear and coal, is used predominantly in the summer for cooling. In fact, 52% of a summer peak day’s electrical load is attributed to cooling (Toronto, 2007). Figure 2.1 below shows the breakdown of Toronto’s fuel mix. Electricity in Toronto comes mostly from non-renewable sources, but as can be seen in the figure 9% is renewable. This renewable portion comes from hydroelectric power (Toronto, 2007).

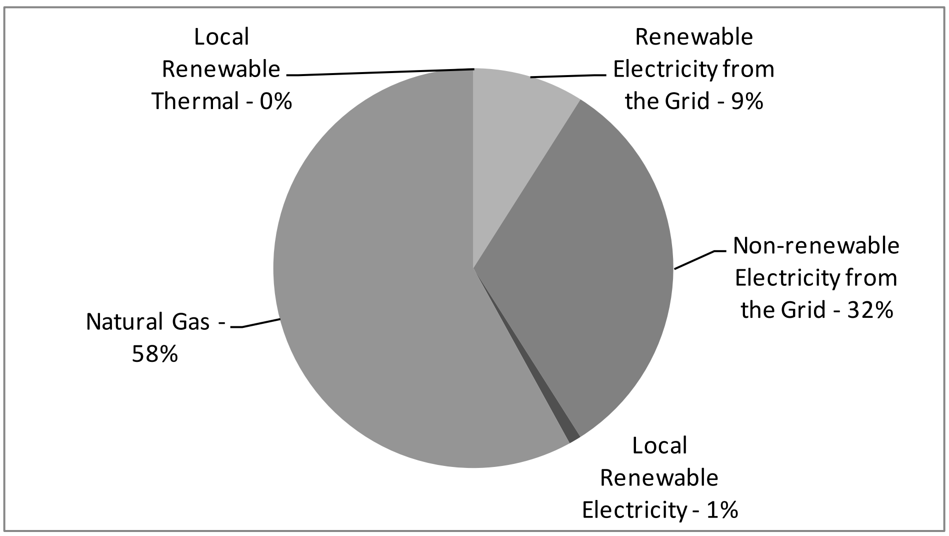


Figure 2.1 Toronto's energy supply mix

(Adapted from Toronto, 2007)

The combustion of fossil fuels used by Toronto’s homes releases pollutants (sulphur dioxide (SO_2), nitrogen oxides (NO_x), ground-level ozone, particulate matter, carbon monoxide, carbon dioxide, volatile organic compounds such as benzene and heavy metals such as mercury) that contribute to environmental problems such as smog, acid rain, climate change, air quality, etc. (Environment Canada, 2009). The more energy is used, the more pollutants are released. This is the driver behind energy efficiency and energy conservation programs; negative environmental impact falls as energy use falls.

An important part of developing programs to reduce energy use involves quantifying current energy use. This knowledge can then be used for two things. First, it provides an average base case which can be using to compare energy use in different homes. Second, having an average starting point is helpful when setting targets for energy intensity reductions.

To allow for fair comparison energy usage is generally calculated in two ways. Energy intensity, or kilowatt hour per square meter of the home's floor area (kWh/m^2), is useful because it normalizes square footage allowing homes of different sizes to be compared. Energy consumption, measured in Joules and often prefixed with Mega (MJ) or Giga (GJ) when talking about annual home demand, is the total energy used. These two metrics allow one to distinguish between whether home's low energy performance comes from it being well built or just small.

CanmetENERGY, a part of Natural Resources Canada, undertook a study called The Urban Archetypes Project to study residential energy consumption in eight communities across the country (NRCan, 2007). Two communities from the study, Ottawa and Clarington, ON, have a similar climate and construction style to Toronto. In Ottawa a detached, single-family home built in the 1980s can expect to have an energy intensity in the vicinity of 648MJ/m^2 (180kWh/m^2). For a home built at the turn of the century the energy intensity ranges between 1006 – 1308MJ/m^2 (279 – 363kWh/m^2). The energy intensity range for a mid-1800s home was 1252 - 1580MJ/m^2 (348 – 439kWh/m^2) (NRCan - CanmetENERGY, 2009).

Figure 2.2 - Energy consumption data showing annual energy service (from top to bottom of the left-most column: lighting & appliances, domestic hot water, space heating), cost, and annual GHG emissions for The Urban Archetypes project, Ottawa, Ontario.

These results are further validation of increasing energy intensities with increase house age that has been stated by other sources (NRCan, 2000). In Clarington, ON the energy intensities ranged from 681 – 957MJ/m^2 (189 – 266kWh/m^2) (NRCan - CanmetENERGY, 2009). It is expected that these energy intensity ranges are similar to those of Toronto's building stock.

2.3 Retrofitting to Reduce Energy Demand

The building envelope is loosely defined as a separation between the interior and exterior environment. It includes the roof, walls, windows, exterior doors and the basement. The building envelope controls movement of heat, air, moisture, and light and, therefore, plays a large part in determining the operational energy requirements of the home. If the intention of retrofits is to reduce energy demand the building envelope is an obvious target.

For a typical, turn-of-the-century, home two-thirds to three-quarters of energy use is space heating (NRCan - CanmetENERGY, 2009). Increasing the thermal resistance of the building envelope by adding insulation is one good way to reduce this value. For example, basements account for 20-35% of an average Canadian home's total heat loss so insulating just this small component of the building envelope can have a marked effect on energy demand (National Resources Canada, 2005). The figure below shows the building envelope; all potential insulation locations.

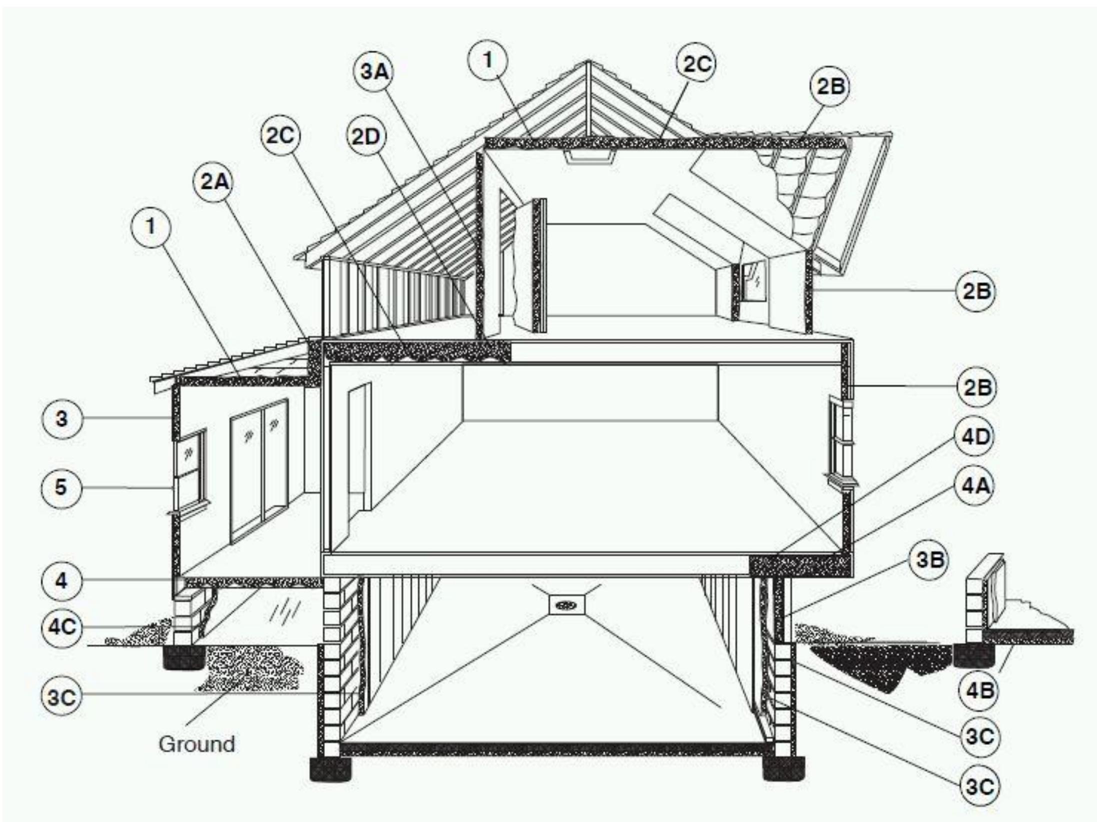


Figure 2.3 - Insulation locations on the building envelope. 1 – unfinished attic spaces, 2 – finished attic rooms, 3 – exterior walls, 4 – floors above cold spaces, 5 caulk and seal windows and doors.

Insulation of the building envelope is not the only effective retrofit solution. Canada Mortgage and Housing (CMHC) recommends a combination of air sealing, insulation, and replacement and/or weatherstripping of windows and doors (CMHC, 1998).

One question that comes up when considering existing buildings and energy efficiency is whether it is better to retrofit or demolish and build a new, energy efficient house instead. The new, energy efficient home must be presumed to have a lower energy intensity than the retrofitted existing home for this question to be interesting.

Do the embodied effects from construction of an entire new home outweigh the operational effects of the existing home's worse energy performance? Generally, the operational effects dominate (Dong, 2005; Fix, 2010). However, these studies focused on the embodied energy component rather than any of the other embodied effects such as acidification or eutrophication. In fact, the Dong, 2002 study noted that the demolish and rebuild option was superior from an operational energy perspective, but was worse in terms of solid waste and pollution release.

3 METHODOLOGY

It is the objective of this thesis to combine all the embodied effects, not solely embodied energy, with the operational effects in order to develop a preliminary, comprehensive assessment of the relative environmental impact of retrofit options.

3.1 Project Scope

The scope of this project is limited to building envelope retrofits applicable to Toronto's single-family housing stock. Within that statement are three bounds; geographic, house type and retrofit target. Building envelope retrofits are targeted and include, for example, insulation and air tightness levels.

Geographically, the current City of Toronto is bounded roughly by the Rouge River/Pickering Town Line to the east, Etobicoke Creek/Hwy 427 to the west, Steeles to the north, and Lake Ontario to the south. It was created when the Former City of Toronto amalgamated with Etobicoke, York, North York, East York and Scarborough in 1998. Previously this area had been called the Metropolitan Toronto Area (MTA), and should not be confused with the Greater Toronto Area (GTA) which includes the MTA as well as Peel, Durham, York and Halton. The focus of this study is on the Former City of Toronto, an area with dense, existing urban housing.

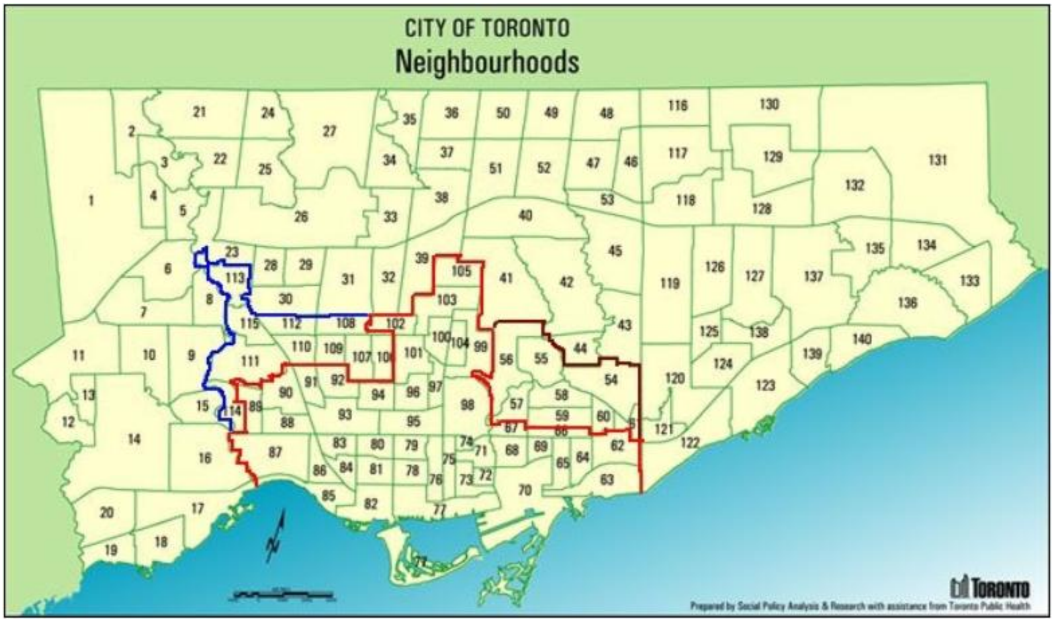


Figure 3.1 - Boundaries of the Former City of Toronto.

(Toronto, 2010)

The study is also specifically interested in detached, single-family houses. For the purposes of this report single-family housing will be defined by the type of house rather than actual occupancy. Regardless of whether a house is occupied by a family or used as a rooming house all single-detached houses are included. To focus the analysis semi-detached, row houses, trailers, multi-plexes, and apartment buildings are specifically excluded. Additionally, the ownership situation, be it owned, rented, leased or part of a condominium, does not affect the inclusion or exclusion of a home. It should be noted that the process and results from this study can reasonably be extended to semi and row houses as well as smaller multi-plex units such as tri-plexes.

3.2 Project Process

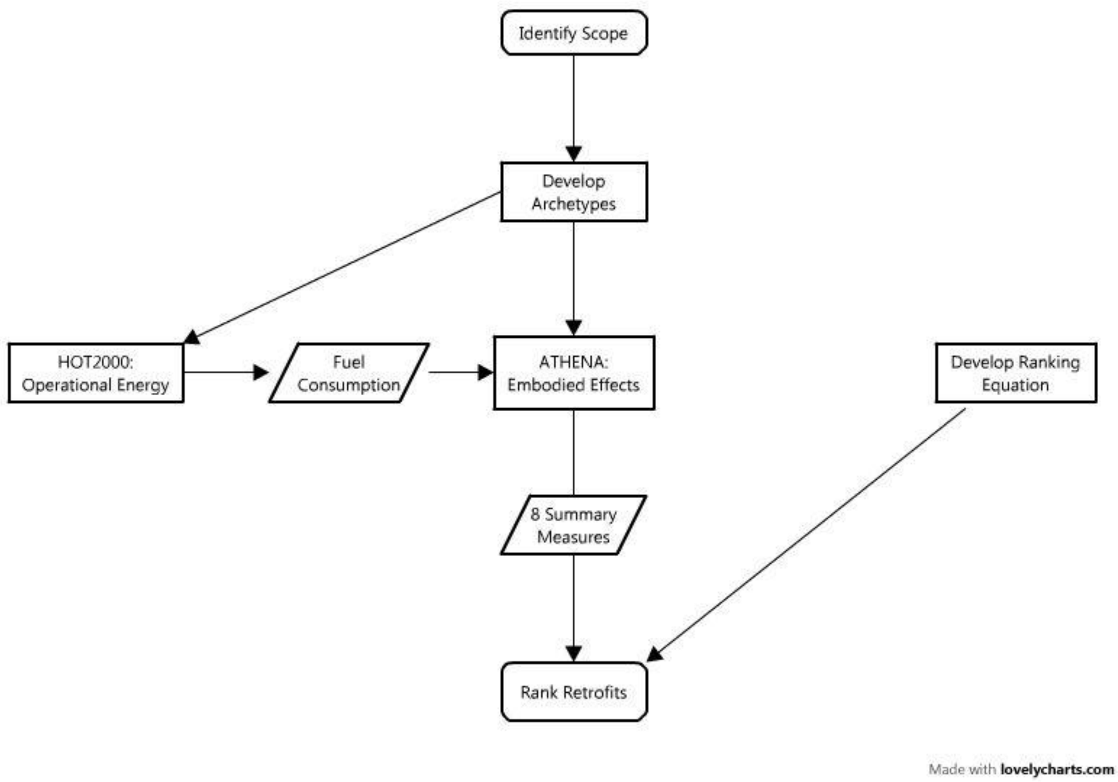


Figure 3.2 - Flow chart showing the retrofit ranking development process.

This thesis is divided into three main sections: archetype development, energy performance analysis, and the combination of environmental effects.

Briefly, the archetype section seeks to develop four houses typical of Toronto's single-family built stock. These four archetypes will be defined and described to allow them to be used with HOT2000 and the ATHENA Impact Estimator.

The energy performance analysis will be done using HOT2000. From this program operating energy results for the base and retrofitted cases will be obtained. These results will them be analyzed to identify trends within and between the four archetypes.

The final stage, combination of all the environmental effects into one ranking, depends on the ATHENA Impact Estimator to calculate the operational and embodied effects for eight environmental metrics: primary energy consumption, weighted resource use, global warming potential, human health respiratory effects potential, eutrophication potential, ozone depletion potential, and smog potential. These summary measures will be combined using a developed equation and a selection of retrofit cases will be tested and rated to judge the equation.

4 ARCHETYPES

In this section a set of four homes representative of the range of Toronto's built stock and with all characteristics necessary for input into HOT2000 and the ATHENA Impact Estimator defined were developed.

4.1 Location

The City of Toronto produces and publishes data and reports on the demographics and housing stock in Toronto. One set of reports, the Toronto Neighbourhood Profiles, lists the type (detached, semi, row, etc.) and number of homes based on geographic location. These neighbourhood reports are adapted from Statistics Canada data by the City's Social Policy Analysis and Research unit. (City of Toronto, 2010)

The housing data contained in these reports was conducted within the Former City of Toronto boundary. Specifically, data was collected on the number, vintage, and type of housing in each neighbourhood. The results were tabulated to identify areas with higher than average concentrations of single-family homes. A map of the neighbourhoods with number of single-family units is included below in Figure 4.1.

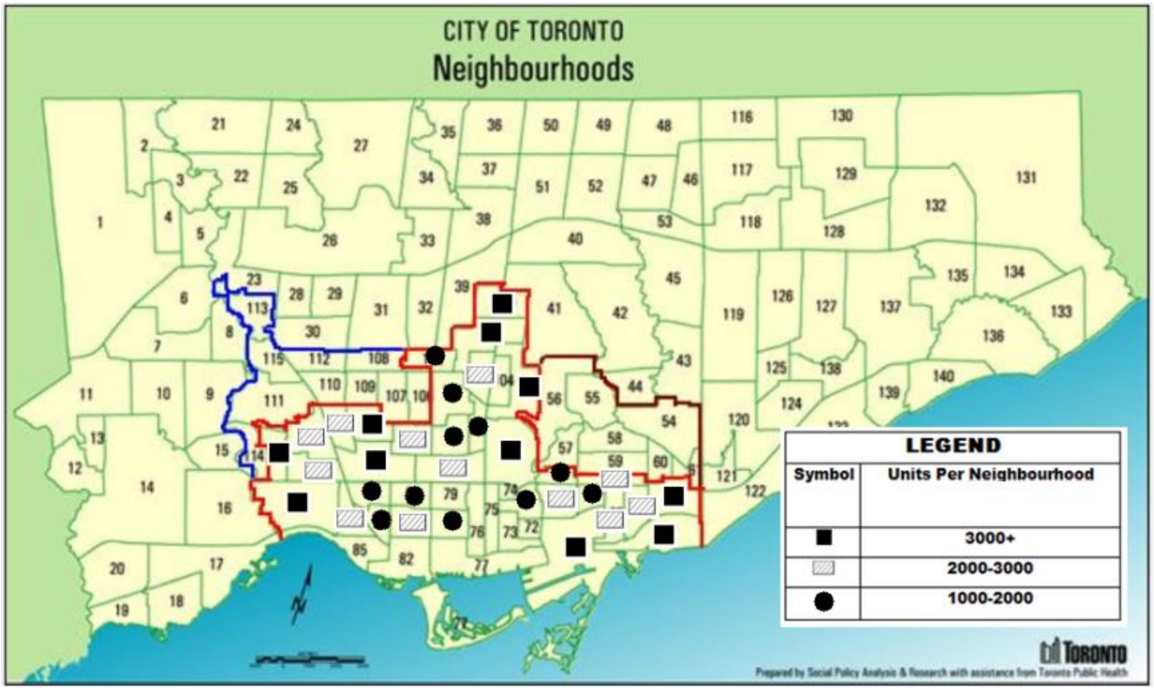


Figure 4.1 - Concentration of single-family homes in the Former City of Toronto

(adapted from Toronto, 2010)

The region to the east, roughly between Riverdale and the Beach - henceforth referred to as East - had a concentration of single-family homes at greater than 2000 units/neighbourhood. An area to the west of the core, henceforth referred to as West, and located roughly north and south of Bloor in the High Park and Parkdale area also had a concentration of at least 2000 single family units/neighbourhood. The third and final area, North, was located roughly along the eastern side of Yonge Street north of Bloor Street. These areas became the focus for data collection during the archetype development stage. Please refer to Appendix 1 – Neighbourhood Profiles Tabulated - for the tabulated data.

4.2 A Brief History of Toronto's Housing:

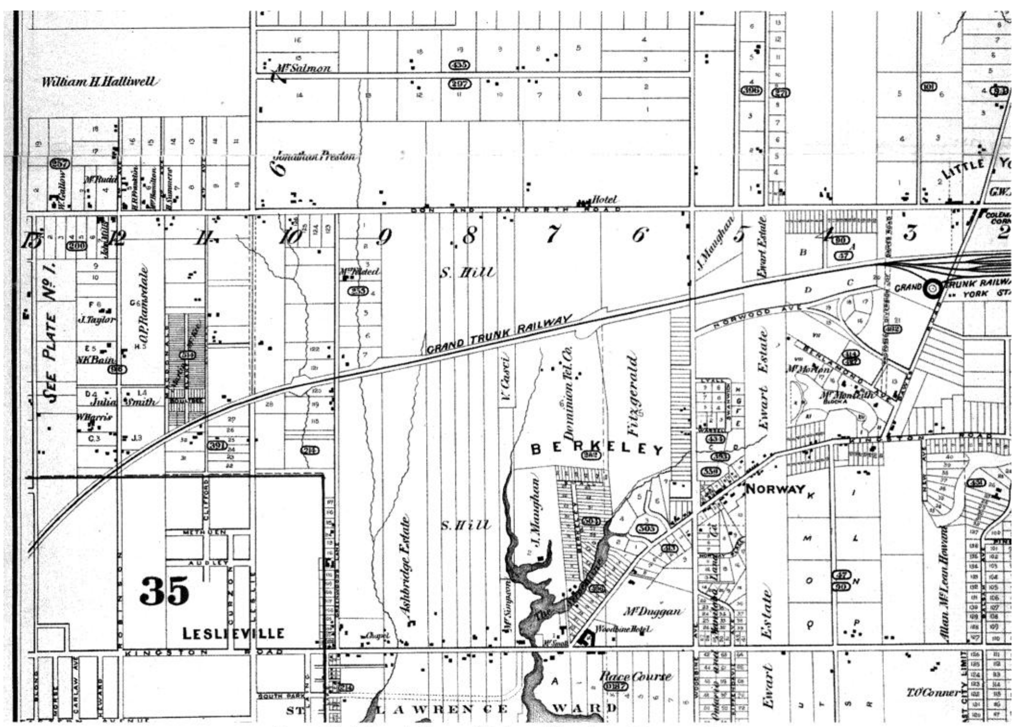
4.2.1 The Early Years: Masonry Prevails

Toronto is known for having a variety of neighbourhoods with distinct house styles (http://www.toronto.ca/demographics/neighbourhoods.htm). Beneath the architectural surface, however, are many similarities in construction that become apparent during a study of the history of Toronto's housing stock.

Development in Toronto started near Lake Ontario in what is now considered the East End. It is in these areas, roughly bound by Parliament, Broadview, Front, and Bloor Street that Toronto's oldest homes are found. Industry was concentrated along the lakefront and docks; the surrounding area became a residential suburb for factory workers and the well-to-do built estates farther away from the bustle and pollution. In the mid-1800s the railway came in along the waterfront and cut residents off from the Lake (ROM, 1984).

As early as the 1830s the city was being subdivided and developed. During the subdivision boom of the 1850s Rosedale was developed (ROM, 1984). Rosedale remains a single-family neighbourhood to this day. These subdivisions of land greatly increased the number of buildable lots and subsequently much of Toronto's early housing was built during the latter half of the 1800s (ROM). Some examples of neighbourhoods developed during this time period include Kensington Market (1884), and the Annex (1895) The building trend was westward, partly because of the obstacle of the Don River, partly because the trend fed itself, and partly because people with the means to move away moved away from the industrial core (ROM, 1984). One example of this trend was Parkdale, which was developed in the 1870s as a home for the business elite. Subdivision and development of Toronto's land continued into the 20th century with neighbourhoods such as Lawrence Park, Monarch Park, Danforth-Woodbine Park and the Silverthorne Park Addition all developed by the 1930s (ROM, 1984).

Some of the earliest surviving maps of Toronto are fire insurance plans made in the 1880s. Like most cities, Toronto's built stock was shaped by the resources around it; in Toronto's case these are timber and clay. As a result a large portion of the built stock in Toronto was constructed of wood or brick. Fire insurance plans showing the distribution and type of dwellings, colour-coordinated to show brick stone or wood exteriors, were developed by the insurance companies to map out and analyze their liabilities.



Goad's Fire Map of East York - Circa 1884

Partial scan of entire map from the City of Toronto Archives (March 3, 2007) - Note land holdings of W. Harris just below the Danforth to the West of Robinson Road (now Pape Avenue). Also, of interesting note is Blong Avenue. Peter A. MacDonald, who would marry Annie L. Harris in 1902, was the son of Sarah (Blong) MacDonald.

Figure 4.2 - One of Toronto's fire maps

(Harris, 2008)

Fire and the threat of fire played a significant role in shaping Toronto's housing stock. In fact, after one of Toronto's great fires the insurance companies banded together and refused to insure any wooden buildings (O'Brien, 2009). Additionally, beyond the insurance considerations, fire protection by-laws were the only regulations applied to buildings in Toronto until the early 20th century (ROM, 1984). These by-laws were divided into three levels of regulation which controlled construction materials and methods. Land owners could petition to increase the regulation level in their zone, the result of which was some affluent neighbourhoods using the by-laws to prevent lower quality houses, and their "poor" tenants from building in their neighbourhood. These policies and influences resulted in the trend of quality homes being constructed of masonry and Torontonians exhibiting a strong preference towards brick-clad homes (Maclean-Hunter, 1945).

Despite the pressure imposed by fire considerations, many homes were still built of wood. Less affluent neighbourhoods contained clusters of homes built of and/or clad in wood, however, many of these neighbourhoods have not survived. Not only were these neighbourhoods built of less durable materials and to lower standards they were also targeted for demolition and redevelopment by the government. In the 1950-60s the federal government provided grants for cities to demolish derelict and substandard buildings and build municipally owned housing corporations. Substantial parts of Toronto's downtown were razed during this period as part of the redevelopment plan. Many social housing projects in Toronto, such as Regent Park, were built during this period (CMHC, 2010).

Figure 4.3 - Toronto streetscape

Figure 4.4 - Regent Park

(Toronto Neighbourhood Guide, 2010)

The subdivision of land, fire by-laws and the demolition of entire neighbourhoods were all major factors in creating the Toronto of today. The majority of Toronto's remaining Century homes are the quality, load-bearing masonry homes of the affluent and middle classes due in large part to fire by-laws and subdivisions. These homes are found in neighbourhoods of similar style and construction such as Parkdale, the Annex, and Riverdale and are the basis for the Century archetype used in this study.

4.2.2 The Great Depression and War Years: Canada's Housing Boom

The 1940-50s were a time of critical housing shortages all over Canada and Toronto was no exception. High demand combined with low supply to create what has been described as Canada's worst housing shortage (CMHC , 2010). There were three main reasons for the low supply, all stemming from the Great Depression: low housing starts, deterioration, and overcrowding.

During the Depression housing starts dropped to an all-time low. Housing starts also fell drastically during the war years as materials and labour were diverted to defense. The result was a low number of new houses built over two decades. Additional to this, the deferral of home maintenance during the Depression intensified the situation. Homes deteriorated, some to the point of requiring major renovations or even demolition. These elements ensured that the supply of homes remained low into the 1940s. On the demand side, during the Depression some families "doubled up" in one home to save money. This resulted in pent-up demand once the economic climate improved (Wade, 1986). This pent-up demand coincided with veterans returning and a population surge. Families were demanding affordable homes for first-time buyers (Kapelos, 2009)

To address the situation Wartime Housing Limited (WHL), Canada's first large scale housing program, was established in 1941. The organization was charged with building temporary homes to rent out to war industry workers and returning veterans. Speed and economy were the key principles behind the WHL home designs. As one publication stated, "Every dollar that is not needed for housing is a dollar more for munitions" (Somerville, 1942). Four model homes were designed: Type 1, a 24x24' 4-room bungalow; Type 2, a mirror image of Type 1; Type 3, a larger version of Type 1; and Type 4, a two-storey, 24x28' four bedroom house. They were built on cedar pole foundations out of prefabricated floor/roof/wall/etc. panels that were bolted together on site (Coon, 1942). The homes were built in developments of at most 200-300. For visual interest, and to avoid creating shortages of any particular material, there were three roof colours, four different exterior finishes, and different porch designs. The houses were organized in blocks along winding roads and cul-de-sacs (Somerville, 1942). Between 1941 and 1947 approximately 26,000 units of these "temporary" houses were built by WHL across Canada (Wade, 1986).

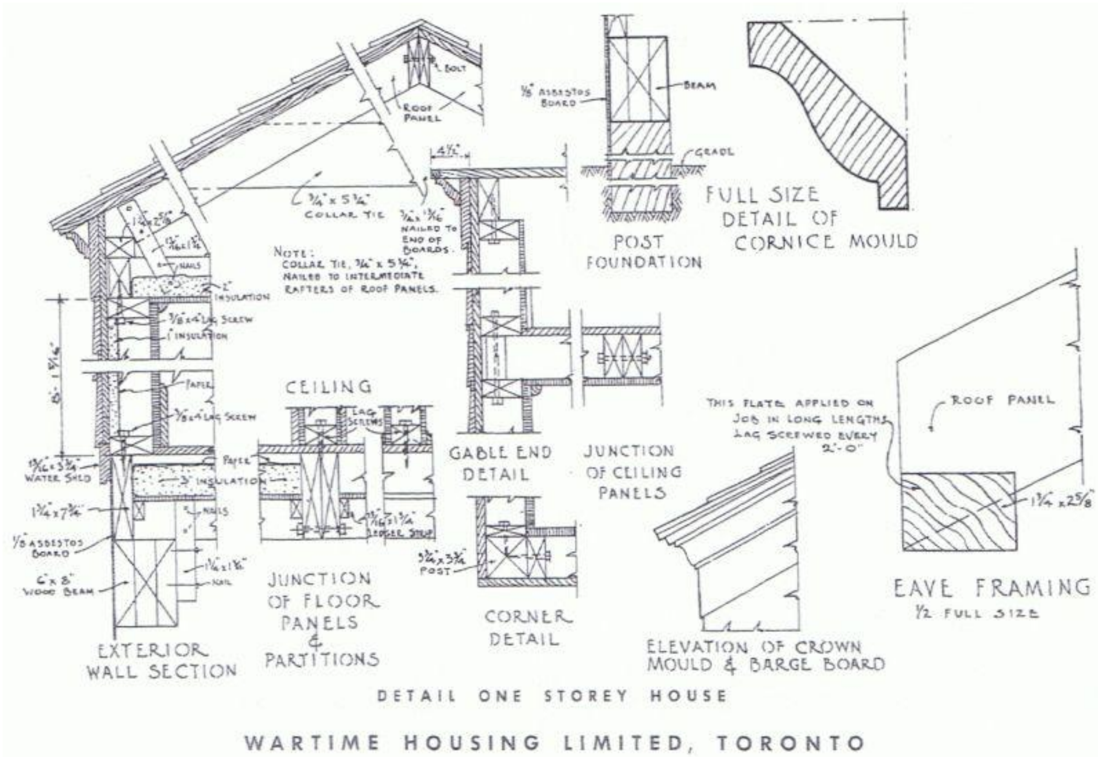


Figure 4.5 - Cross-section of a Wartime Housing Limited house

(Coon, 1942)

After the creation of the Central Mortgage and Housing Corporation (renamed Canada Mortgage and Housing Corporation in 1979), CMHC, in 1946 WHL was dissolved and the "temporary" stock of WHL homes were sold, often to the current renters (Wade, 1986). Thus this mass of wartime and early post-war homes were absorbed into the permanent housing stock.

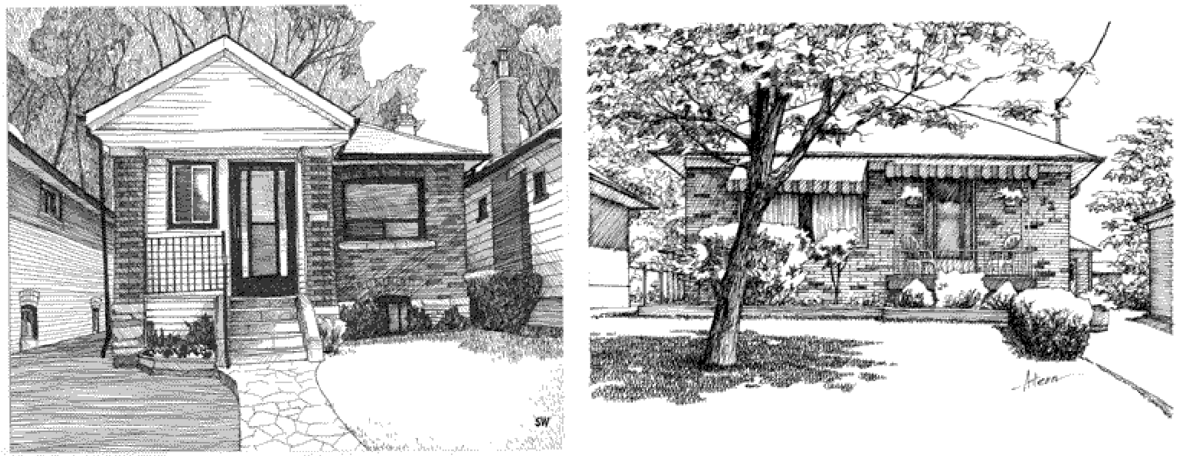


Figure 4.6 - Two examples of Wartime homes common in Toronto

(Toronto Neighbourhood Guide, 2010)

During this period the government was very much involved in promoting home ownership and improving housing standards (CMHC, 1947). One of CMHC's stated goals was to promote contemporary single-family homes.

> "Home-building signifies many things – a lasting source of happiness, a kindly environment in which to raise children, a closer tie with community life, a new stake in the land"
>
> (CMHC, 1947)

In addition to the WHL and CMHC programs the National Housing Act was enacted in 1944. All homes built subsequent to the Act were built at least to its standards and hence the quality of the housing stock improved.

As part of the push toward homeownership, the CMHC published its first catalogue of single-family house designs, *67 Homes for Canadians,* in 1947. The book was based on the WHL designs and a nation-wide design competition. Its intent was to promote affordable, modern starter homes for families through these pattern books and guaranteed financing. This was the first of many, and over the years CMHC published over 500 architect-commissioned small house designs, disseminating the designs and ideas all over Canada (Kapelos, 2009).

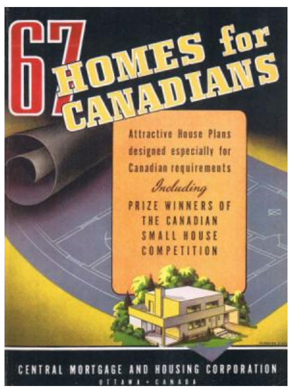


Figure 4.7 - CMHC pattern book cover

Figure 4.8 - CMHC pattern book house

(CMHC, 1947)

Initially the houses in the small house series were less than 100m^2 (1000 ft^2). Over time, as incomes increased and access to materials and trades improved, the "small" house grew. Mr. and Mrs. Canada, the intended client for CMHC's Canadian Small House Competition designs, were interested in a "contemporary", but not "freakish" home with a healthy interior, option for a garage and larger glazing areas (CMHC, 1947). By the time the small house project was abandoned in the 1970s the 'small' house had grown to 2000ft^2 (Kapelos, 2009).

This federal push towards home ownership and better standards in construction changed the face of the built stock. Many Toronto neighbourhoods and homes were built during this period and to these standards. The majority of these remain, albeit with significant renovations such as garages, finished basements and additions. Pockets of these "small" houses can be found around Toronto. East York in particular has a large concentration of these wartime homes.

These affordable, ubiquitous, single-story, 100m^2 homes are the basis for the second archetype in this study, the Wartime Bungalow.

4.2.3 The 1970s: Operation Renovation

As previously described, the 1950s and 60s were a period of housing demolition in Toronto's core. For two decades the first choice of governments, communities, and urban planners was to demolish and rebuild old, substandard homes and entire neighbourhoods. It was not until the 1970s that the conservation and preservation movement in Toronto managed to make headway and halt the rate of demolition (CMHC, 2010). Funding for the demolition of substandard housing was eventually abolished and this period of neighbourhood demolition came to an end.

In the 1970s, support for renovation, rather than demolition, garnered government support with the implementation of the Residential Rehabilitation Assistance Program (RRAP) in 1974. The program, which is still in place today, provides financial assistance for necessary home repairs. The result was that money became available for old and substandard homes to be renovated rather than demolished (CMHC, 2010). By the 1980s new home building and renovation businesses had a similar dollar value (CMHC, 2010) showing that the renovation industry had become an established and viable alternative to demolition.

The result of this policy shift was the mixed vintage housing seen in Toronto today. Without further razing of neighbourhoods, new homes of this time-period were built as in-fill housing or in small developments. Subdivisions of several hundred units were mostly a thing of the past.

The homes built during this time period were required to conform to the newly published Ontario Building Code (OBC). The OBC was based on the National Building Code (NBC) and established requirements for the geometry, structure, mechanical systems and thermal performance of the house. Minimum insulation levels for exterior walls, for example, were RSI-2.1, and vapour barriers were mandatory. With respect to the thermal performance of the building envelope the code was focused on limiting deterioration to the building and keeping the occupants comfortable rather than efficient use of resources. This can be seen in the following excerpt:

> "9.26.2.1: buildings of residential occupancy shall be provided with sufficient thermal insulation to prevent moisture condensation on the interior surfaces of walls, ceilings and floors during the winter and to ensure comfortable conditions for the occupants."
>
> (OBC, 1975)

House styles from this period vary, but common 1970s design is a two-story, rectangular home with large glazing areas. These houses can be seen all over Toronto as individual infills or in small groups of less than a dozen homes. Sometimes they are used as single-family houses, other times they are used as multi-unit residential MUR triplexes. Regardless of use their construction is identical and they are the basis for the 1970s OBC archetype.

Figure 4.9 - Two examples of 1970s houses in Toronto. The 1970s house on the right sits beside a Wartime bungalow.

(Toronto Neighbourhood Guide, 2010)

4.2.4 Modern Housing: Towards Sustainability

In the 1980s, research, in particularly CMHC sponsored research, focused on indoor air quality, ventilation and moisture. Many new products and construction practices were developed and in the 1990s building science became an established field (CMHC, 2010). After the oil crisis of the 1970s, energy efficiency and resource conservation were stated goals in construction. This was the case at least at the end of the 70s and into the early 1980s. Over the following decades, energy and resource efficiency have fallen and risen in popularity and support. Many programs were developed: R-2000, ecoENERGY, 'green refund', etc. to promote sustainability in construction. While these programs and goals of individual homeowners have resulted in some very efficient homes, the majority of the housing stock continues to be built to the minimum legal requirements; the OBC.

Since 1975 when the first building code was published, many revisions have been made. Thermal requirements for the building envelope most directly affect energy performance and resource use. The figure below shows a comparison of insulation categories between the 1975 and 2006 OBC.

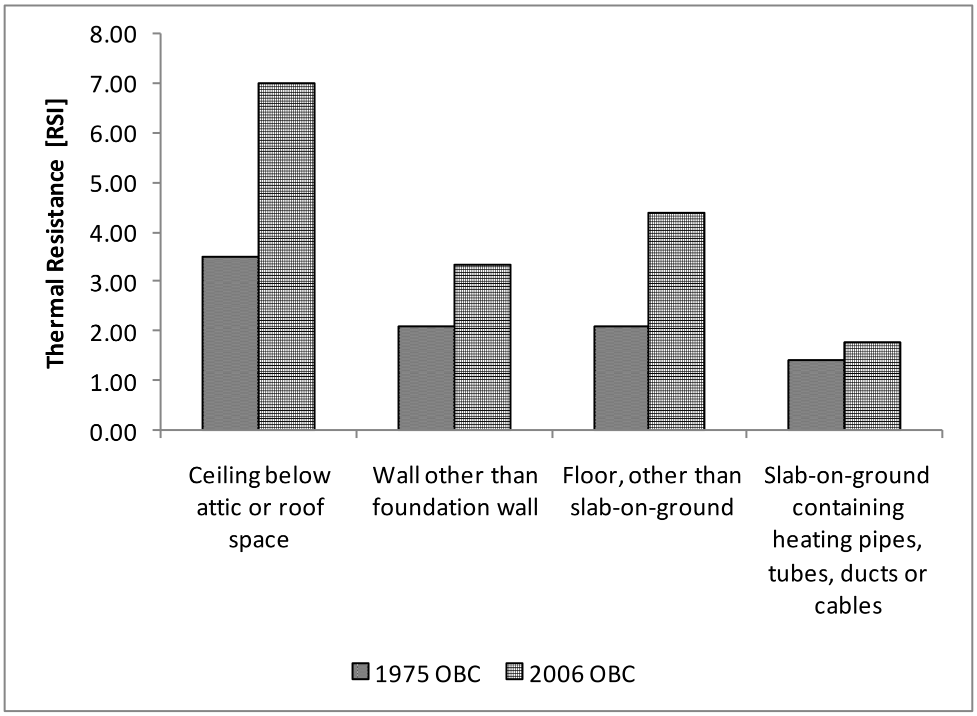


Figure 4.10 - Levels of insulation required by the Ontario Building Code.

(adapted from OBC, 1975; OBC 2006)

As can be seen in the figure, significant changes have been implemented with the addition of the new Part 12: Energy Conservation section in the OBC. Insulation requirements in the ceiling, walls, and exposed floors have approximately doubled. Additionally, stated objectives of the OBC now include resource conservation (water and energy), environmental integrity, and conservation of buildings, along with health (indoor conditions, sanitation and privacy and view to outdoors). These objectives are meant to be progressive and result in homes built with better energy performance. The changes in the 2006 OBC will continue the trend of improving energy performance that started in the middle of the century.

This trend continues with modern homes, however, the trend towards larger homes also continues (Bowick, 2010). The result is that homes are more efficient, but because they are larger they may actually use more energy than smaller, older homes. The trend to larger glazing areas has abated. Glazing areas remain high when compared with a Century house or Wartime Bungalow, but they are not continuing to increase.

Figure 4.11 - Modern townhouse row in Liberty Village, Toronto

(Toronto Neighbourhood Guide, 2010)

Subdivisions and developments where many units are built is a trend that has returned. Re-zoning and redevelopment of industrial and vacant lots has provided an opportunity for builders to develop a large area of land. The most common development on these sites are row houses and freehold condominiums, however both of those are outside the scope of this report. The

Modern archetype house shares the look, materials, and construction methods of the row houses of these developments, but is a single-detached home.

4.2.5 The Four Archetypes

The archetypes developed are intended to represent a large portion of Toronto's housing stock; to be ubiquitous in the Toronto area. Looking at Toronto's neighbourhoods and history, four styles of houses - the archetypes developed - are evident. Well established subdivisions of Century homes in various states of repair surround the downtown core. Rows and rows of post-war bungalows, built from pattern books and CMHC catalogues stand on quiet streets. Blocky, 2-storey homes of the 1970s pepper Toronto's neighbourhoods. Tall, thin modern homes, easily identified by their front-facing, attached garages, are scattered throughout. These are the four "looks" of houses to be studied. They are ubiquitous in Toronto's landscape and a walk through Toronto's residential neighbourhoods will show many examples of these houses. Next, the specific building envelope characteristics to be defined for each archetype was determined.

4.3 Archetype Characteristics

The characteristics needed to meet the needs of this study, namely to be analyzed using HOT2000 and the ATHENA Impact Estimator. Towards this end the inputs required for these programs were compiled and from these the following list of characteristics was developed:

- construction
    - structural design – load bearing masonry or light wood-frame, foundation, etc.
    - levels of insulation – separately in the walls, ceiling, foundation, etc.
    - materials – cladding, types of insulation, etc.
    - glazing – amount, type, and orientation
- geometry
    - size – volume, heated floor area, etc.
    - shape – rectangular or non-rectangular, number of storeys, etc.
- vintage
    - year, decade or period of construction
- features
    - enclosed porches, deep overhangs, finished attics and basements, etc.

The information gathered on archetype features was used to add depth to the computer models. For example, full-width porch overhangs shade windows and attached garages apply a factor to the wall's thermal resistance. The vintage information was used to make assumptions about typical characteristics, such as in the case of Century homes, which are load-bearing masonry with finished attics, and a useful proxy when more specific information is not readily available.

4.4 Data Collection and Analysis

Data on the construction, geometry and features of the archetypes was collected from a variety of sources, including published literature, interviews, publicly accessible databases, and visual inspections. When specific information was not available, for example in the case of lintel construction, general construction practice was used to make approximations. The data was then compiled and analyzed to develop the typical construction, geometry and features presented. Please refer to Appendix 2 – House Dimensions for this data.

The geometry and features of a house were readily discerned by visual observation. Geometry includes such characteristics as overall dimensions, number of stories and shape. Features include porches, overhangs, garages, finished attics, etc. Not all of the information on features and geometry can be obtained from a visual inspection of the exterior of the house. Some features, a finished attic, for example, can only be verified from the interior of the house.

To overcome this limitation interviews were used to supplement the data collected from published literature and visual inspections. Interviews were conducted with Steve Yeates of the Cabbagetown Preservation Association and a small number of homeowners [S. Yeates, personal communication, June 1, 2010; J. Kwok, personal communication, June 3, 2010; R. Richman, personal communication, June 3, 2010). Additionally, a 1920s home in Riverdale and a Wartime Bungalow in East York were visited and measurements and observations were recorded.

Three characteristics required more attention: insulation, dimensions, and glazing area. These characteristics have a material effect on energy performance and modeling. For this reason a more thorough and reliable classification was performed.

4.4.1 Insulation

After establishing the geometry for each of the four archetypes, their building envelopes had to be defined.

The majority of archetype-specific data came from the ecoENERGY database. This database contains information compiled during home audits conducted as a part of government sponsored home retrofit programs (such as EnerGuide for houses and ecoENERGY). The general public is permitted to submit a request for this data, sorted by variables of interest. The data requested for this study was building envelope characteristics (levels of insulation, building tightness, etc.) for single-family homes in Toronto. A sample set of approximately 80,000 homes was obtained which included mostly detached, some attached, and a small number of multi-unit residential (MURs) as well divided by vintage. A copy of the data obtained is contained in Appendix 3 – ecoENERGY Database.

From this data the following was used for the Toronto region:

Table 4.1 Data from the ecoENERGY database used in the development of house archetypes. (ecoENERGY database, 2010)

Parameter	Vintage	Pre-retrofit	Post-retrofit
ACH (@50Pa)	1945 or older	11.24	8.10
	1946 - 1960	7.50	5.91
	1971 - 1980	5.75	4.80
	2001-2009	3.42	3.52
ELA (cm2)	1945 or older	2,204	1,532
	1946 - 1960	1,356	1,038
	1971 - 1980	1,145	934
	2001-2009	985	874
Ceiling insulation (RSI)	1945 or older	2.74	4.36
	1946 - 1960	3.66	5.08
	1971 - 1980	4.18	5.40
	2001-2009	5.76	6.97
Wall insulation (RSI)	1945 or older	1.27	1.69
	1946 - 1960	1.54	1.78
	1971 - 1980	1.95	2.08
	2001-2009	2.90	2.93
Windows (RSI)	1945 or older	0.24	0.47
	1946 - 1960	0.26	0.47
	1971 - 1980	0.28	0.47
	2001-2009	0.35	0.47
Foundation insulation (RSI)	1945 or older	0.52	1.20
	1946 - 1960	0.74	1.33
	1971 - 1980	1.16	1.48
	2001-2009	2.01	2.35
Floor area (m2)	1945 or older	208	209
	1946 - 1960	193	194
	1971 - 1980	216	216
	2001-2009	282	282

(ecoENERGY, database excerpt 2010)

The values in the ecoENERGY database provided the base case model inputs. Material choices were based on visual observations of archetypal homes and common construction practice. If necessary data was not a part of the ecoENERGY database values from the appropriate OBC, the 2006 for the Modern home for example, were used instead.

4.4.2 Dimensions

For the Century, 70s OBC and Modern archetypes, house dimensions were compiled from MLS data (The Canadian Realtor Association, 2010). Two methods were employed to estimate house width. The first method involved using the lot sizes included in all MLS listings to obtain an estimate of house width. The lot width, after subtracting the distance between the house and lot line, provides a reliable estimate for house width. The second method involved using the interior dimensions provided in the MLS listings in conjunction with interior photos of the house to recreate the floor plan and estimate the width of the house. This method is less reliable due to the difficulty of determining the floor plan based on limited data, but when combined with the first method a useful range for house width is developed.

Due to the difficulty of finding a sufficient quantity of 70s OBC and Modern homes on MLS the data used had to be supplemented from other sources. For the 70s OBC archetype appropriate designs were selected from the CMHC pattern books and used along with the MLS data. For the Modern house, data was supplemented with new home builder’s models. Detached, single-family models within the Former City of Toronto were not found, however, the builder chosen, Monarch, had a development close to the geographic boundaries of the study that matched the appearance of the Modern archetype. Whenever data collected for glazing area estimates was useful for dimensions and geometry it was incorporated.

The Wartime archetype was developed solely from selected floor plans found in CMHC pattern books. Since these books explicitly state the dimensions of the homes, and because a large sample set of house designs fitting the appearance of a Wartime Bungalow were found, the dimensions of the Wartime home are averages of the take-offs. Thus, they do not require the two step width estimation method used for the other archetypes.

To ensure that the overall sizes of the houses were reasonable the ecoENERGY database values for floor area and volume were used as the target. The ecoENERGY database contains average heated floor areas for houses based on their vintage. These vintages were paired with the four archetypes and four target heat floor space areas were recorded. Using the widths estimated previously and the target floor area, the lengths of each house were calculated. The results are presented below.

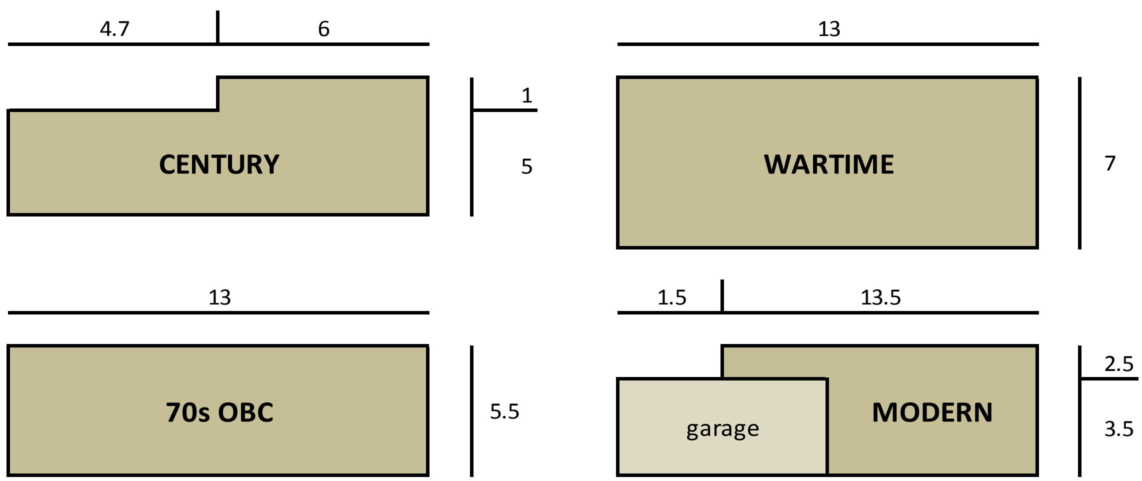


Figure 4.12 - Archetype geometry, plan view. All dimensions in meters.

4.4.3 Glazing Areas

Glazing areas and orientations are important elements that affect a home's operating performance significantly (PHPP, 2007). NRCan recommends glazing make up 15% of the wall area and be concentrated on south and west facing walls (NRCan, 2009). This is highly geographically sensitive. Also, since recommendations are vary over time and are not necessarily followed by homebuilders to determine glazing area for the archetypes estimates were compiled from a number of sources.

MLS data is useful for estimating overall dimensions, width in particular, but since all elevations are not visible it cannot be used to estimate glazing percentages. Other sources of information were used to determine acceptable glazing percentages as described in the following section.

To collect data, homes, photos of homes, and floor plans were reviewed and estimates of total glazing areas recorded. To facilitate data collection a spreadsheet was developed. Some general assumptions were made about the relative sizes of windows including:

- basement windows are 38x64' unless otherwise stated
- small windows (kitchens, bathrooms, stairs, etc.) are 3' in height
- medium windows (bedrooms) are 4' in height
- large windows (living room, dining room, etc.) are 5' in height
- sliding doors are including in the glazing area and are 6' in height

Data for the Century house was collected from visual observations, measurements of the Riverdale House, and an interview with Steve Yeats of the Cabbagetown Preservation Association. Data for the Wartime Bungalow was collected from CHMH's pattern books dating from the 1950-60s. Due to the availability of a large number of appropriate floor plan for quantity take-offs, these numbers are considered reliable. Data for the 70s OBC house was also collected from appropriate models found in the CMHC pattern books. There was a smaller sample size of 70s OBC homes, however, there is little variation between them so the numbers are still considered reliable. Data for the Modern house was a compilation of take-offs from floors plans of new homes by Monarch and appropriate houses from the CMHC pattern books.

The data collected was analyzed to determine average glazing as a percentage of wall orientation. Since the orientation of the house varies with its location wall orientation was defined as front, rear or side elevation for the purposes of this report. The table below summarized the results while the raw data is available in Appendix 4a through 4d – Glazing Areas.

Table 4.2 Glazing expressed as a percentage of wall area.

	Century	Wartime	70s OBC	Modern
front	20	20	20	15
side	3	8	5	3
rear	20	15	25	25

This data was also used when determine an average width and length for the homes.

4.5 Archetype Houses

The table below summarizes the build of the four archetype houses. Following the table are short, written descriptions of each archetype.

Table 4.3 Summary description of the four archetype houses.

Archetypes		Century	Wartime	70s OBC	Modern
Heated Floor Area		208m2	182m2	216m2	239m2
Building					
	No. Storeys	2 1/2	1	2	2
	Plan Shape	L-shape	rectangular	rectangular	L-shape
	Vintage	<1940	1940-60	1970s	>2000
	Lot Placement	adjacent to neighbours	driveway on one side	driveway on one side	adjacent to neighbours
	Features	finished attic, full-width porch	half-width porch	partly raised basement, narrow awning	attached garage, walkout basement, narrow porch
	Roof	gable front, flat rear	hip	hip	hip with gable accents
	Structure	double-wythe brick	light-wood frame	light-wood frame	light-wood frame
	Cladding	brick	brick	brick	brick
Insulation [RSI]					
	Ceiling	2.74	3.66	4.18	5.76
	Walls	1.11	1.41	1.71	2.90
	Foundation	0.52	0.74	1.16	2.01
Air Leakage [ACH]		11.24	7.5	5.75	3.42
Glazing [%]					
	Front	20	20	20	15
	Side	3	8	5	3
	Rear	20	15	25	25

4.5.1 Century Home:

Figure 4.13 - Century home archetype

(Toronto Neighbourhood Guide, 2010)

The Century House archetype is situated on a long, narrow lot. Due to this constraint, Toronto's houses are often long, narrow, and close to the lot line. This plan shape ensures that side windows get very little direct sunlight. The 'L'-shaped footprint is one solution to the daylighting issue. The front of the house is wider and approximately half-way down the length the house the width narrows by one meter. The narrowing provides enough space for a backyard-facing window to be installed, bringing light and ventilation into the center of the house. The wide section at the front has a gable roof while the narrow back section is covered by a flat roof. It is very common for this gable roof to be converted living space and not uncommon to find a deck on the flat roof with a walk-out from the gable.

The Century House is a $208m^2$, 2 ½ storey, 'L' shaped house with a full height basement and living space in the attic. The roof is a shingled, steep (7/12) gable at the front and flat built-up roof at the rear. At the front of the house there is a deep porch which is an effective shade for the big main floor window. There are a total of 15 windows; 3 in the basement, 3 in the gable roof, and the remainder in the main walls. At the front and rear of the house are standard hinged doors. Some houses have had French doors or sliding patio doors retrofitted in the back, but their numbers are not overwhelming. Structurally the house is double-wythe brick on a brick or rubble foundation. The interior is finished with lath & plaster and no air barrier or vapour retarder is expected.

There is little if any original insulation, but it can be assumed that at some point insulation was added to the ceiling and if the basement is finished to the basement as well. The ecoENERGY average RSI values are used for all insulation parameters except the main walls. It is not a fair assumption that homeowners of double-wythe brick homes have built out the interior walls to add insulation. The main wall RSI-value in the ecoENERGY database is likely attributable to wood-framed homes from the same time period which are more likely to have had insulation retrofitted into the walls.

4.5.2 Wartime Bungalow:

Figure 4.14 - Wartime home archetype

(Toronto Neighbourhood Guide, 2010)

Wartime bungalows are often found together in quantity. Their history suggests that many were built as part of a subdivision, both during the war years and afterwards by developers. This suburban configuration resulted in more space between the houses than is commonly seen with the other archetypes. Often these bungalows also have a driveway or carport on one side along with a side entry door.

Their geometry is simple. Most Wartime Bungalows are rectangular, single-storey buildings with a flight of stairs leading to the front door and a covered, half-width porch. Sometimes half of the front wall protrudes, making space for the porch to appear recessed. The roof is a lightly sloped (3/12) hip roof clad in glass felt shingles. Sometimes there is a gable accent, but it doesn't disrupt the main classification of the hip roof. Structurally the building is a light wood-framed home and in Toronto they are often clad in brick.

The interior of the house is small, generally around $100m^2$, not including the basement. As per the ecoENERGY database the final heated floor area, in this case twice the main floor area, is $182m^2$. All of these houses can be assumed to have concrete block foundations and most have been finished to provide additional living space. The house has a total of 11 windows, four of which are basement windows. The interior finishes in the house could be either lath & plaster or gypsum board as both were in use during the decades these houses were built (CMHC, 1954). In some homes tar paper has been installed behind the brick veneer to act as, one presumes, a weather barrier.

Insulation materials seem to have become the norm in quality construction of this time period. WHL and CMHC house designs both show insulation in the wall, roof and floor (reference the construction detail) and 58.5% of Ontarians said they would "definitely" insulate their homes (Maclean-Hunter, 1945). The RSI-values from the ecoENERGY database can reasonably be applied to all components of these houses.

4.5.3 70s OBC:

Figure 4.15 - 70s OBC home archetype

(Toronto Neighbourhood Guide, 2010)

The 70s OBC archetype is a two-storey, rectangular house with a total heated floor area of 216m^2 as per the ecoENERGY database. The house is a rectangular prism with a lightly sloped (3/12) hip roof clad in glass felt shingles with no gables, accents or dormers. There is a flight of stairs up to the main entrance. At times, this style of house features an awning covering the porch; however, this was not included in the archetype. The house has been modeled with a driveway along one side which, similarly to the Wartime Bungalow, ensures the side windows get some daylight.

There are 17 widows on the house, four of which are basement windows. The basement is full height, but a little shallower than the other archetypes. Consequently more of the foundation wall is above grade and the basement windows are slightly larger.

Structurally the house is a light wood-frame with brick veneer. Since it would have been built to code, which at the time required a vapour retarder and varying levels of insulation, these components are expected in the envelope. The interior walls are made of gypsum board. The thermal characteristics of the building envelope are taken from the ecoENERGY database.

4.5.4 Modern:

Figure 4.16 - Modern home archetype

(Toronto Neighbourhood Guide, 2010)

Toronto's Modern home archetype is a 239m^2, 2-storey, 'L'-shaped house with an attached garage connect to the basement and accessible from the front of the house. Since garage access is flush with grade and not sloping downwards this creates a walk-out basement situation.

The main entrance is on the second level, up a flight of steps and shaded by a narrow porch. The house has 17 glazing units. Two of these units are sliding patio doors that give access to the backyard and a deck on the 2nd floor. This deck shades the sliding door below. The hip roof has a shallow slope (3/12) and one or more gable accents on the front elevation.

The house is a light wood-frame with brick veneer. The levels of insulation for building envelope components have been taken from the ecoENERGY database. Where the database information is unavailable, as in the case of insulation above unheated garages and doors between unheated garages and the interior, the 2006 OBC values have been used.

5 INPUTS AND PROCESSES

5.1 Retrofits

5.1.1 Retrofit Options

All retrofit options to be considered involve the building envelope. The structure of the HOT2000 program lends itself to a subdivision of the following building envelope components: ceilings, main walls, foundation, windows, doors, and ventilation. Due to the small relative weighting of doors and this similarity in function and retrofit options to windows – both are openings in the building envelope and both can either be replaced or weatherstripped – the windows and doors form one parameter in this report. These five parameters – ceilings, walls, foundation, windows & doors, and ventilation – are used as a basis of comparison for heat loss through the building envelope.

Insulation:

The retrofits considered for the building envelope closely follow the list of CMHC recommended renovations (CMHC, 1998). Insulation upgrades are considered for the ceiling, main wall, foundation wall, and floor slab. Four main insulation materials are considered for modeling: fiberglass batt; dense-packed, blown-in cellulose; Icynene spray foam; and polyurethane spray foam. Polyurethane foam is a closed-cell material while Icynene is a proprietary open-cell foam. All four are available in HOT2000's dropdown menus to facilitate modeling. In the ATHENA Impact Estimator polyurethane foam is unavailable, but polyisocyanurate can be used as a fair proxy (Bowick, 2010).

Windows and Doors:

Windows and door retrofits were all replacements. For windows, two replacement options were selected. The first was replacement with a conventional, sealed double-glazed unit. This case was meant to be a proxy for today's commonly sold windows. The second window replacement case is an upgrade. HOT2000 allows the user to choose from two heat mirror glazing options. For each retrofit case set to heat mirror windows the north elevations were given TC88 heat mirror windows and the south, east and west elevations were modeled with HM66. TC88 is the twin film window, essentially making it a light-weight quadruple glazed window while HM66 has one film, making it equivalent to a triple glazed unit.

Doors were only assigned one retrofit option. When doors were replaced during retrofit modeling they were replaced with the highest RSI-value door available in HOT2000: a steel, polyurethane-core unit. Doors are such a small portion of overall heat loss that modeling an intermediate thermal insulation level was considered unnecessary.

5.1.2 Air Leakage Rates and Reductions

Air leakage has a significant effect on the energy performance of a house. As conditioned air leaks out through unintentional openings in the building envelope, unconditioned air enters to replace it. This unconditioned air must be warmed or cooled, depending on the season, increasing the load and energy use. In Canada, air tightness is measured under standard test conditions and reported in air changes per hour (ACH) at 50Pa. The ACH number represents the number of times the entire volume of air in the house enters/exits in one hour. The leakier a home's envelope, the higher the ACH number, and the more energy is spent conditioning this air.

Generally speaking, the newer a home, the tighter its envelope (MacDonald, 2008). Applying this trend, the archetype houses suggest that they should have decreasing ACH values. The ecoENERGY database follows this trend with the Century House at 11.24 ACH, Wartime at 7.50, 70s OBC at 5.75, and Modern 3.42. These values are used for each archetype base case.

The post-retrofit values for ACH rates are more difficult to quantify. No post-retrofit database outlining the ACH reductions to be expected with specific retrofits exists. Unlike the other retrofits, the results from air sealing reductions in ACH are neither linear nor guaranteed. For this reason the air leakage reductions used during HOT2000 modeling have been developed from a series of interviews held with industry experts from both Canada and the US (L. Wigington, personal communication, July 12, 2010; M. Blasnik, personal communication, July 14, 2010; D. Fugler, personal communication, July 12, 2010; G. Labbe, personal communication, July 16, 2010; J. Bunting, personal communication, 2010; K. Pressnail, personal communication, 2010; P. Duffy, personal communication, 2010).

The importance of sequential air tightness testing was noted during the interviews. Blower door test data, during which the building is pressurized (or depressurized) and ACH at a standard 50Pa pressure difference is calculated, would be useful in determining expected air leakage reductions, but sequential air tightening data is unavailable in Canada. The air sealing industry in the US has been using the blower door test longer and more thoroughly than in Canada, but also does not have this data readily available. Only one person contacted knew of a study on sequential air tightening and this report was never published and could not be located.

Five air sealing techniques were developed from the interviews: non-invasive, semi-invasive, exterior/interior, cellulose, and foam. The first two, non-invasive and semi-invasive, can be done on their own or in conjunction with the last three.

The first, non-invasive, is a comprehensive non-destructive air sealing procedure. Holes in the building envelope are sealed as much as possible without damage to finishes. Examples of the air sealing tasks involved in this method include sealing penetrations through exposed walls, ceilings, in basements and attics, and weatherstripping windows and doors.

The second method is invasive air sealing. The main difference is that whereas in the non-invasive method finishes are not damaged, here removal of existing finishes is expected. An example of semi-invasive air sealing include removing drywall at the tops of walls to access and seal top plates in the walls. Furthermore, it is assumed that invasive air sealing will be done with the aid of a blower door so that sequential air tightness measurements can be taken and sealing of air leakage paths continued until the desired result is reached.

The three methods that involve the replacement or addition of wall components are Exterior/Interior, Cellulose, and Foam. Exterior/Interior includes any method that uses sealed sheets of a barrier material. An exterior example is installing XPS, taping over the gaps and connecting as best as possible to the remaining air barrier system in the house. An interior example is using polyethylene as an air barrier and vapour retarder. Cellulose refers to dense-pack cellulose, installed at densities of approximately 51-56kg/m^3 (3.2-3.5lb/ft^3), blown into wall cavities. Foam requires the removal of existing gypsum boards to expose, or construct, wood-framing which is then filled with a spray-foam. This analysis assumes all methods were applied to the walls. When they are applied to ceilings or basements only, adjustments have been made to account for the portion of air leakage through each component.

Presented below is the air leakage reduction chart. Each of the five columns show one of the air sealing methods discussed above, while the rows are house archetypes. The number listed in the cell is either the percentage reduction expected, or in the case of cellulose and foam combined with semi-invasive air sealing the final ACH rate expected. The percentage reduction for these final ACH rates is given in brackets.

Table 5.1 Summary of air leakage reductions for various retrofit options.

	Air Sealing Measures							
	Non-invasive: caulking, sealing baseboards, weatherstripping doors, attics, etc. Anything that doesn't involve damaging finishes	**Semi- invasive:** same as non-invasive plus removing some drywall to access sill plates, etc.	**Exterior/Interior:** rigid insulation on exterior taped and sealed somehow to remainder of air barrier, tyvek house wrap, poly etc.		**Cellulose:** dense-pack cellulose into all applicable cavities		**Foam:** full gut and application of Icynene with attention paid to air sealing	
House Archetypes			no additional air sealing	combined with semi-invasive	no additional air sealing	combined with semi-invasive	no additional air sealing	combined with semi-invasive
Century: double-wythe brick, 2 storey plus finished attic	20	40	30	45	30	3 ACH (75%)	35	2 ACH
Wartime: wood-framed, Wartime Housing Limited bungalow	15	30	30	40	30	3 ACH (60%)	35	2 ACH
70's OBC: 2-storey, rectangular home built to 1975 OBC	12	24	20	35	20	3 ACH (50%)	25	2 ACH
Modern: 3-storey, rectangular, attached garage, built to 2005 OBC	5	15	10	30	10	2.75 ACH (10%)	15	2 ACH

Effort was taken to ensure that the percentage reductions for each category were relative to all other categories. In some cases this meant the percent reductions chosen were slightly outside the range found in the interviews. This was necessary because the interviews did not address all permutations and interpolation based on closely related information was necessary on a limited case basis in the air sealing table.

Additionally, there is a further reduction factor applied after the air sealing reduction when windows are replaced. If the original windows were old and leaky, as in the base case of Century, the reduction is a further 10%. If the windows were either old or leaky, as in the base case of Wartime, the reduction factor is 5%. For all other window replacements there is no reduction factor applied.

During the interviews the participants were also asked questions on general trends in air sealing. There was consensus about the reductions obtainable reduced as the starting ACH decreased. Generally speaking, this suggests that older houses, which tend to have leakier envelopes, have more to gain from air sealing than newer, tighter, houses. There was also consensus that retrofit air sealing measures done from the interior are more effective than those done from the exterior. There are two reasons for this. First, with exterior air sealing it is difficult to connect to the interior air barrier. Second, if the air barrier is on the exterior of the walls warm, moist air moves freely further into the building envelope and the chance of the water vapour condensing and causing damage is greater. The interviewees were also in agreement on a blower door being an integral part of a thorough air sealing retrofit. All semi-invasive air sealing retrofits assume the use of a blower door to test the effectiveness during air sealing. There was no consensus on whether window replacement was an integral and necessary part of thorough air sealing measures.

5.1.3 Iterative Retrofitting

To begin, the four house archetypes were individually modeled using HOT2000. These files are the base cases for the archetypes, prior to any changes or retrofits. For each case the operational energy report was run and the results recorded. To facilitate comparison between the cases the results were converted into an energy use per unit area, or energy intensity [kWh/m^2]. This allowed the four archetypes to be compared based on the merits of the building envelopes and not on building size. The cases were then compared at a macro level before focus was shifted to each archetype individually.

From this point each base case was studied to determine which component(s) in the Building Parameters Summary contributed most to heat loss. These components were then upgraded and a new report was produced. This cycle was repeated until satisfactory results were obtained or retrofit limitations were reached.

The iterative method used for the HOT2000 retrofit modeling can be summarized as follows:

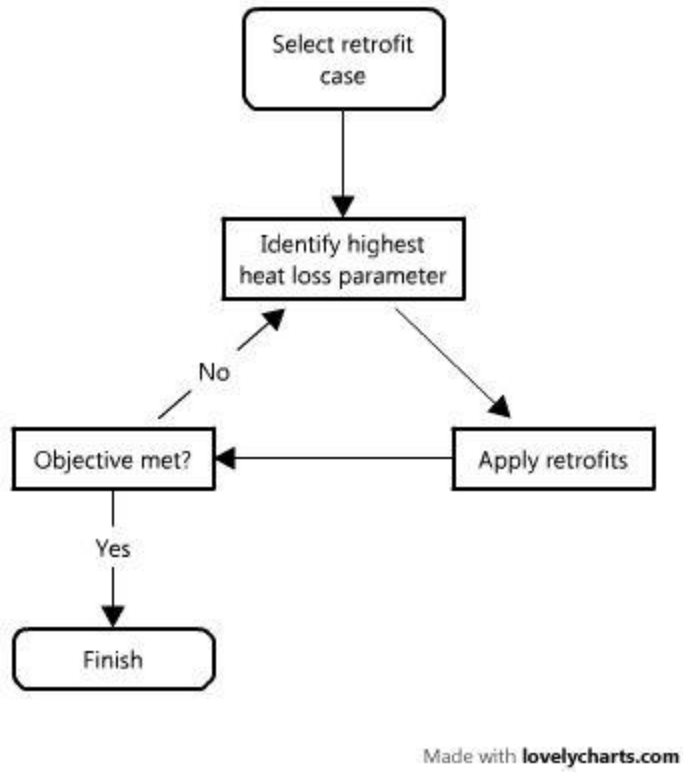


Figure 5.1 - Flow chart of HOT2000 retrofit process.

5.1.4 Energy Intensity Target

The model is considered successful when heating & cooling energy intensity drops below 100 kWh/m^2. Below this point it is assumed that homeowners will use changes to mechanical systems and reductions in DHW and appliance loads to further reduce their energy intensity.

This target, 100kWh/m^2, was chosen because it is the beginning of low energy design.

Low energy building design is a combination of improvements to the building envelope, use of efficient equipments and use of renewable energy sources (Fadi et al., 2009). This thesis considers improvements to the building envelope only. It is also important to define what is meant by energy intensity in a low-energy building. Energy intensity can include heating and cooling only or heating and cooling along with other loads such as domestic hot water (DHW), lighting, and appliances (Abel, 1994). In this thesis heating and cooling energy intensity was used for the target value because it focuses specifically and only on the building envelope effects and building envelope changes are the only changes considered in this work.

There is a wealth of information on low energy homes from all over the world and different time periods. Freiburg, Germany, one of the C40 Cities addressing climate change though construction standards, set their level of heating load (no cooling is included in the house design) for low-energy housing at or below 65kWh/m^2 (C40 Cities, 2010). The IEA Task 13 homes built around the world are another example. Their energy goal was 25% of the typical consumption for heating, domestic hot water, and electricity in their respective locations. One of these homes was built in Waterloo, ON and it achieved an energy intensity of 60kWh/m^2 (Thomsen et al., 2005). In Sweden the low-energy moniker was applied to houses that used half of the typical energy load. For these homes, all identical terraced houses, the energy intensity for heating and cooling, DHW, and appliances ranged from 49.2kWh/m^2 to 101.7kWh/m^2 (Karlsson and Moshfegh, 2007). There are also very low energy homes that strive for even lower energy intensities including Passivhaus and Zero Energy Homes (Parker, 2008).

As can be seen in some of the above examples, low-energy construction is often defined as a portion of typical energy intensity. For a Toronto home in the ecoENERGY database total energy intensity averages 204kWh/ m^2. Using a targeted savings of 50% over conventional design the energy intensity target for a low-energy home in Toronto would be 100kWh/m^2. This is a marked improvement over conventional construction, and yet not at the strictest end of the low-energy standard. Passivhaus, for example, demands a heating and cooling energy intensity of 15kWh/m^2. Including DHW and appliances the primary energy intensity increases to less than 120kWh/m^2 annually. (Building Research Establishment Ltd., 2008).

Since any home can be forced below this 100kWh/m^2 target if enough insulation is packed into the building envelope additional guidelines were followed during retrofit modeling. These guidelines are based on two assumptions. First, homeowners strongly prefer retrofits that maintain the original floor space of the house on above ground floors. Second, polyurethane spray foam, being an intensive retrofit, was considered a different class of insulation than the other three materials.

To acknowledge these assumptions three tiered categories – first circle, second circle, and third circle – of success were created. If a house could be modeled to an energy intensity of below 100kWh/m^2 without losing interior floor space on the above ground walls to insulation and little or no polyurethane was needed the retrofit was classed successful within first circle bounds. If a house needed either mass application of polyurethane spray foam or the above ground walls to be thickened to allow for insulation by up to 89mm to reach the 100kWh/m^2 target it was considered a second circle success. If, however, the house required even more intensive retrofits to reach the 100kWh/m^2 energy intensity target it was classed a third circle success.

5.2 HOT2000 Inputs

5.2.1 Mechanical Systems and Occupants

Since the objective of the study was to obtain data on the full effect of environmental degradation of houses, more than just the building envelope had to be considered. HOT2000 uses inputs in the mechanical system and occupant loads in calculations of energy use. For the purposes of this report, which requires the relative difference between cases, all mechanical systems and associated variables were held constant. In this way only the incremental gains or losses attributable to the retrofits were used in the results.

In summary:

- The heating and cooling temperatures were set to 21°C
- Sizing indoor temperature was set to
  - 22°C heating
  - 20°C cooling
- Base loads were kept at HOT2000 defaults for 2 adults and 2 children
- An 80% efficient natural gas furnace with continuous pilot light was selected for heating
- A conventional, add-on air conditioner with a COP of 3 was selected for cooling
- A natural gas induced draft fan tank was selected for domestic hot water

5.2.2 Thermal Bridging

To address thermal bridging in the building envelope a new User-defined Code needed to be created. HOT2000 by default models one material flush against another. In the case of wood-framed walls installed on the interior of the foundation, for example, the studs are pressed up against the concrete foundation wall. Using the User-defined Code editor allows each layer of material to be input separately. The final result is a case with, from exterior to interior, the concrete foundation wall, 64mm of insulation, 38x64 framing filled with insulation, and gypsum board.

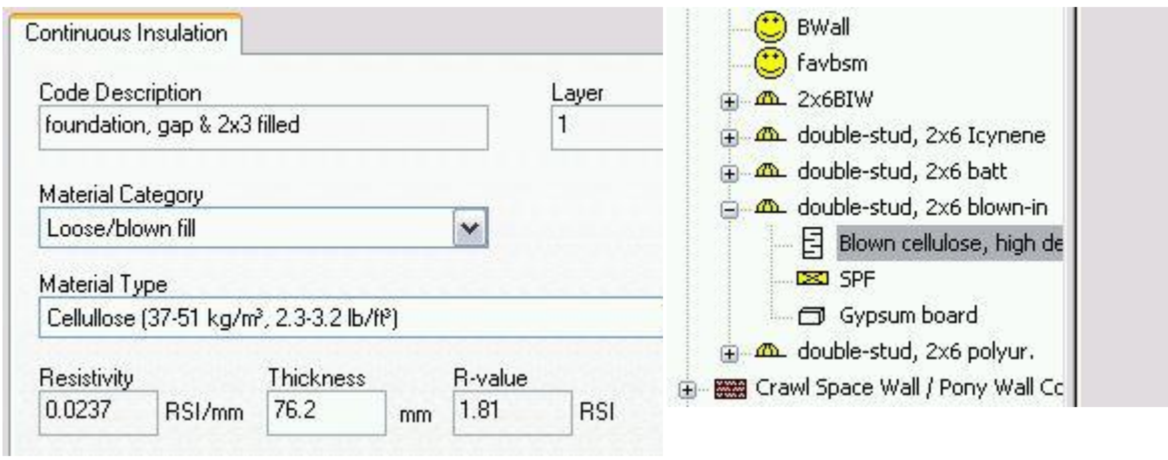


Figure 5.2 - Screenshots of HOT2000 inputs for thermally broken, double-stud walls.

(HOT2000, 2010)

5.2.3 Attached Garages

Another interesting modeling point is the RSI-value factor applied to walls around an attached garage. A garage, or any other enclosed space, provides a buffer zone at the interface between itself and the house. This buffer zone captures heat escaping from the house and maintains an intermediate temperature between the indoor and outdoor space. The help menu in HOT2000 has a chart to be used when determining the attached garage factor.

Table 5.2 HOT2000 adjustment factors for attached garages.

Percentage of Attachment	Adjustment Factor		
	Uninsulated		Insulated
	Finished	Not finished	Finished
15%	1.05	1.03	1.08
30%	1.10	1.05	1.16
45%	1.16	1.08	1.24
60%	1.21	1.10	1.32
75%	1.26	1.13	1.40

(HOT2000, 2010)

The Modern archetype is the only house that is being modeled with an attached garage. For the Modern case the garage is unfinished and uninsulated with a percentage of attachment of 52%. Since the attachment percentage is in the middle between two categories (45% and 60%) the result will be interpolated. The final factor to be used for modeling is 1.09. This factor has been applied as a weighted average to the walls and ceilings surrounding the attached garage.

5.2.4 Input Files

The input files for the base case of each archetype are attached as Appendix 5a – 5d – HOT2000 Input Notes – Base Case.

5.3 ATHENA Impact Estimator Modeling

The end result expected from this modeling process was a complete list of the eight summary measures that the Athena program calculates. Since these summary measures can be calculated for both the operational and embodied components of the retrofit their effects can be summed and compared.

The operational component was calculated using the fuel volumes produced by the HOT2000 program for each retrofit case. The ATHENA Impact Estimator is able to calculate the resultant eight summary measures from $1m^3$ of natural gas and 1kWh of electricity for distinct locations, including Toronto. The conversion factors for Toronto were multiplied by the annual fuel requirements and by the life span of the modeled case to give the total amount of the summary measures arising from fuel use.

For the embodied component only the retrofit components needed to be modeled in Athena. All of existing components have already contributed their share of environmental effects; only the new materials involved in each retrofit case should be included. Furthermore, since two cases were being compared, only the difference between the cases was input into the program. For example, if Case 1 had window replacements and an insulated slab and Case 2 only had replaced windows the insulated slab would be the only element modeled in Athena. The effects from the windows are identical in both cases and cancel out. If either of these cases is later to be compared against a case without replaced windows they would need to be included.

For assemblies and elements Athena calculated maintenance effects as well. If a longer study period is modeled the total value of the environmental effects associated with maintenance will increase. Since the Athena results would be used with a range of study periods in the final stage of the thesis, a reasonable, intermediate life expectancy needed to be selected. Sixty years was selected for two reasons. First, it is near the middle of the life span range tested by the retrofit ranking equation. Second, CanmetENERGY recommends using a lifespan between 50 and 60 years for building and infrastructure life cycle analysis (NRCan, 2007).

5.4 Retrofit Ranking Equation

The final stage of the thesis attempted to combine the environmental effects from both the operational and embodied components for each retrofit case under consideration so that they could be comprehensively compared. To do this an equation was developed to combine the eight summary measure values into a single rating. The equation is a preliminary effort and incorporates factors and inputs that require further research before accurate and reliable results can be obtained. To explore its functioning, four pairs of cases, one from each of the archetypes, were selected. The pairs of cases were selected to showcase a unique aspect, for example the effect of window replacements, and analyzed to determine the effectiveness, limitations and sensitivity of the retrofit rankings.

5.4.1 Basis for Comparison

To fairly compare two or more variables they must have the same unit. Comparing a meter with a kilogram is not insightful. Operational energy can be recorded as an energy intensity, kWh/m^2, energy consumption, MJ, fuel volumes, or any number of energy based units. HOT2000, which was used to generate operational energy data for the retrofit options, reports the data in terms of quantities of fuel used. Electricity is displayed as a kilowatt hour, while natural gas values are given in cubic meters.

The ATHENA Impact Estimator presents data on eight summary measures, also known as embodied effects. Each of the embodied effects has a different unit. For example, global warming potential is measured in kg CO_2 eq., acidification in moles H+ eq., and primary energy in MJ.

In addition to providing these eight summary impacts for materials, the Impact Estimator also provides them for different types of fuel. This allows the operational effects, which are originally expressed as quantities of fuels, to be expressed using the same eight summary measures used for embodied effects. For references, the table below shows the multiplication factors used by the ATHENA Impact Estimator to calculate the eight summary measures for a given quantity and type of fuel.

Table 5.3 - Multiplication factors between fuel sources and summary measures adapted from the ATHENA Impact Estimator for Toronto.

100kWh of Electricity	Summary Measures	100m3 of Natural Gas
729.24	Primary Energy Consumption (MJ)	4186.31
37.33	Weighted Resource Use (kg)	153.52
27.01	Global Warming Potential (kg CO2 eq)	216.83
10.33	Acidification Potential (moles of H+ eq)	91.22
0.056	HH Respiratory Effects Potential (kg PM2.5 eq)	0.433
1.55E-05	Eutrophication Potential (kg N eq)	4.76E-04
3.10E-11	Ozone Depletion Potential (kg CFC-11 eq)	0.00E+00
0.011	Smog Potential (kg NOx eq)	0.059

5.4.2 Total Summary Measure Values

With these multiplication factors the fuel quantities reported by HOT2000 can be converted into the eight summary measures that the Athena Impact Estimator uses. In this way the operational data and embodied data is given the same unit, and fair comparisons between cases can be made. For clarity, one of the summary measures, smog potential, has been arbitrarily selected to be the focus of the discussion that follows.

At this point there are three variables that must be summed to get the total smog potential measurement. First, there is the smog potential associated with using the electricity the home requires. Second, there is the smog potential that results from burning the natural gas the home needs. Both of these variables are part of the operational energy of the house. The operational energy obtained from HOT2000 for each retrofit is an annual measurement. To get the full environmental effect the annual measurement must be multiplied by the number of years under consideration.

The third variable is the embodied energy component. It includes the smog potential that resulted from the extraction through to the end of service life of the materials used in the retrofit. This value is calculated by the ATHENA Impact Estimator. To model a retrofit case in the ATHENA Impact Estimator the length of time to be modeled, also known as the life cycle, needs to be input. Among other things the program uses this number, the number of years the house is in operation, to determine the maintenance cycle and number of replacements for the components entered. For example, if a 60 year life cycle is selected and windows have an average service life of 25 years they will be replaced twice during the timeframe in the model. This works well when the life cycle is defined and does not change, but becomes a problem when the life cycle is allowed to fluctuate.

The life cycle of a building element, for example a wood-framed window, is an average value and based on industry standards and expectations. It is the expected length of time that the element, in this case a window, will be functional and useful. Sometimes elements fail before the end of their service lives. If the window had a wooden frame and it was not properly maintained water could get in and cause damage, accelerating deterioration and shortening the service. If, however, the window is protected and maintained, the wooden frame is painted regularly and it is shuttered during storms, the owner may extend its service life.

The service life is important because it determines how often an element needs to be replaced. Every time an element needs to be replaced new raw materials need to be extracted, transported and processed into the new product. Every time this happens, the summary measures associated with embodied effects repeat. If the wood-framed window must be replaced every 10 years instead of 20 then twice as much related pollution and environmental degradation will occur. To address this issue and promote good retrofit practices the proposed equation includes a building science factor, or BSF.

5.4.2.1 BSF: Building Science Factor

Joseph Lstiburek of Building Science Corporation concludes that sustainability requires both energy efficiency and durability (Lstiburek, 2006). The environmental intensity of a building used twice as long is half as much. He also notes that as energy efficiency is improved amounts of insulation are increased and durability might be compromised because of the longer drying time and the subsequent moisture damage that result from the different, thicker wall assemblies (Lstiburek, 2006). Since energy efficient retrofits will change the moisture profile of the wall and have an effect on the durability and life cycle of the components these effects should be included in a comprehensive rating system. These effects can be accounted for using a Building Science Factor, BSF, which will increase or decrease the environmental effect of a retrofit choice based on its effect on durability.

The BSF should be based on research and building science principles to ensure it makes a useful contribution to the retrofit rankings. Many organizations have been conducting research into durability and best practices for construction. CMHC has a wealth of best practices information on a wide range of topics. Another good resource is Building Science Corporation. They have a selection of best practices guides and their insulating load bearing masonry document is particularly pertinent to the Century archetype (Straube and Schumacher, 2007). These sources provide data on past experiences with durability failures, the building science principles involved, effective solutions, and expected service lives for components. As such, they are a good foundation for the development of the BSF.

An interesting question that will need to be addressed when the BSF is being developed is how much it should increase or decrease the environmental effects. Balance will need to be established between the BSF's contribution, the weighting factors, and the eight summary measures. One measurement strategy to pursue would be to quantify portions of service life either gained or lost and converting them into the BSF. Initially these will need to be based on published research and best practice guides as mentioned above, but over time and with iterations of measured results from real-life cases the actual value of the BSF can be fine tuned and optimized for use with the retrofit ranking equation.

Several organizations have started looking at developing a durability standard. LEED incorporates durability into their credit system, MRc8, Durable Building. This LEED credit is based on CSA Standard S478-95 Guideline on Durability in Buildings and seeks to improve the durability of the building with either assemblies that meet or exceed the building service life or assemblies that allow for easy replacement (Athena Institute, 2006). At least one company, DIALOG, has begun work on developing a tool to make this credit "easier to achieve, by educating building owners on the benefits of durable building design in context of impact on capital and operational costs" (M. Touchie, personal communication, 2010). Joseph Lstiburek of Building Science Corporation also proposed using a ranking or score based on the increases to expected service life as part of a durability standard (Lstiburek, 2006). This work is similar to the

BSF factor proposed for future development in this thesis and is based on sound building science principles and backed up by research and case studies. The focus is on the service life and how it is affected by the retrofit options. The BSF should be developed in the context of life cycle analysis and the greater retrofit ranking equation, but these sources provide a good starting point and foundation for future work. The BSF values to be developed will be included in the equation presented below to adjust the environmental impact arising from embodied effects.

Equation 1, below, is used to calculate the total summary measure results for a retrofit case. Each of the eight summary measures is calculated one by one using the equation. The electricity and natural gas inputs are obtained from the HOT2000 modeling data. $SM_{embodied}$ is obtained from the summary measures table produced by the Athena program for each retrofit case. At the end of this iterative process there is a list of values for the eight summary measures.

$$SM_{total} = Y \times (Electricty \times Factor_{electricity} + Natural\ Gas \times Factor_{natural\ gas}) + BSF \times SM_{embodied} \quad (1)$$

Where:

SM_{total} = Total embodied and operational effects of the summary measure

Y = number of years (Note: needed for operational energy only)

Electricity = kWh

$Factor_{electricity}$ = ATHENA Impact Estimator conversion factor; operational electricity to summary measure

Natural Gas = m^3,

$Factor_{natural\ gas}$ = ATHENA Impact Estimator conversion factor; operational natural gas to summary measure

BSF = building science factor

$SM_{embodied}$ = summary measure value obtained from the ATHENA Impact Estimator (Note: already incorporates service life issues, number of years not required)

Table 5.4 – Sample of total summary measure values from Equation 1.

Summary Measures: Totals	Units	Case 1 COMBO+ CONT.	Case 2 2x6 BATT MAX
Primary Energy Consumption	MJ	8.68E+04	6.38E+04
Weighted Resource Use	kg	9.66E+03	1.01E+04
Global Warming Potential	kg CO2 eq	6.64E+03	3.39E+03
Acidification Potential	moles H+ eq.	1.44E+03	1.26E+03
HH Respiratory Effects Potential	kg PM2.5 eq.	5.70E+00	2.00E+01
Eutrophication Potential	kg N eq.	8.80E-03	1.06E-02
Ozone Depletion Potential	kg CFC-11 eq.	1.82E-05	2.66E-06
Smog Potential	kg NOx eq.	1.93E+01	5.18E+00

5.4.3 Combining the Summary Measures

The table above shows an example of the total values for each of the eight summary measures. These numbers include the effects from operational energy for 60 years as well as the embodied effect multiplied by the building science factor. They form a comprehensive list that can be used to judge the environmental footprint of a retrofit option. As previously discussed, the difficulty occurs when the two cases under consideration are better on some summary measures and worse on others.

To merge the eight summary measures into one value they either need to have the same unit or be normalized and unitless. Since there is no realistic way to convert all summary measures to the same or an equivalent unit, the method proposed in this thesis is normalization. Each summary measure will be converted into a ratio. This method related the two retrofit options to each other. This method of normalization is similar to that used in the UK Ecopoints program, which also strives to produce one score with which to rank building options (Dickie and Howard, 2000).

$$SM_{ratio} = Case\ 1/Case\ B \qquad (2)$$

Where:

SM ratio = summary measure ratio

Case 1 = summary measure value; retrofit under consideration (aka Case 1)

Case B = largest of the summary measure values being compared

Using Equation 2 each summary measure is converted into a SM ratio with a value equal to or less than one. These ratios show the relative environmental impact of the summary measure. A ratio of one means that that case is worse for that particular summary measure. A SM ratio of less than one indicates that that case is better from an environmental perspective. Specifically, the ratio shows what portion of pollution is released. For example, Case X has a ratio of 1 so 100% of the pollution is produced, but Case Y has a ratio of 0.80 so it produced only 80% of the pollution produced by Case X. These ratios are unitless and normalized and can be added together to produce one value. The smaller this number is for Case 1 the better Case 1 is in comparison with Case 2.

A straight summation of the summary measure ratios would assume that the units of each summary measure are equivalent to each other. Since this is not the case, all summary measures have unique units, this cannot be done. However, there is currently no way to say that one unit from the summary measures table has an equivalent environmental impact as another unit. Does 1kg of CO_2 equivalent harm the environment as much as 1 mole of H+? Or 1kg of NO_x equivalents? Determining the relative weighting of these units poses and interesting question and is a topic discussed below.

5.4.3.1 Weighting Factor

The difficulty with interpreting LCA results, such as those from the ATHENA Impact Estimator, is that rarely does one option outperform on all environmental impacts. This leaves a subjective decision to be made based on objective data (Gloria et al., 2007). Developing a weighting system that combines environmental effects into a single score simplifies the decision process; one option is ranked best. However, the weighting systems currently in use are all based on a consensus of subjective choices so the process is not objective.

Two weighting systems have been considered in this study. The first was developed by NIST (National Institute of Standards and Technology) in the United States in the late 1990s using the EPA's TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) categories (Bare et al., 2002). The weightings produced are used in LEED 2009 and BEES 4.0 (U.S. Green Building Council, 2010; Gloria et al., 2007). The second set of weightings was developed by BRE (Building Research Establishment) in 1997/98 (Anderson et al., 2002). These weightings have been incorporated into the UK Ecopoints rating system (Dickie & Howard, 2000).

The development of both sets of weightings followed a similar process. First, the LCA system, complete with its set of impact categories, was selected. Second, a panel of experts from a range of interest groups was assembled and asked to rank the relative importance of the impact categories. Third, the data from the panel was converted into a weighting factor for each impact category. Since these weightings rely on an expert panel's ranking of given impact categories, in a given region the resultant weighting factors are only applicable to the context in which they were created (U.S. Green Building Council, 2010; Gloria et al., 2007) and hence the weightings are not perfectly transferable.

Another reason the weightings are not directly transferable is that there is no global consensus on which impact categories and stressors to include in LCA analysis (Bare et al., 2002), so the impact categories used by the different systems are not all the same. The ATHENA Impact Estimator uses 8 summary measures, TRACI has 12 (Bare et al., 2002), LEED 2009 uses the 12 TRACI categories plus indoor air quality (U.S. Green Building Council, 2009), and BRE has developed 13 environmental impact categories (Dickie & Howard, 2000). There is a lot of overlap between each environmental rating system, for example all have categories for eutrophication, ozone depletion, and some form of global warming/climate change. Identical category names can be deceiving because sometimes the categories are not actually identical.

In the ATHENA Impact Estimator eutrophication is measured in kilograms of nitrogen equivalents while in BRE it is measured in kilograms of orthophosphate (PO_4) (Dickie & Howard, 2000). Furthermore, even when the units for the category are identical what is actually measured might not be. Some acknowledged difficulties of LCA methodology are defining boundaries for what is included, what point of the cause and effect chain to measure, and regional variation (Bare et al., 2002). While there is a fair amount of consensus on what is important to measure, as seen by the commonality in the categories, they are not identical and hence not transferable between systems.

Since the impact categories chosen for inclusion in each LCA method vary, the weightings developed for each system are not directly transferable to a different method. That is, LEED's

13 impact categories are not identical to the 8 summary measures produced by the ATHENA Impact Estimator and so the weightings cannot be transferred without adjustments. These adjustments, summations, simplifications, etc. would introduce assumptions and approximations into the process, thereby reducing accuracy.

Instead, much like earlier versions of BEES, this study begins with equally weighted environmental impact categories (Gloria et al., 2007). It is essential that future work will undertake the task of assessing weightings for each of the environmental impacts, or summary measures, as produced by the ATHENA Impact Estimator. The weighting system is expected to be developed specifically in the context of Athena's LCA system and applicable to Toronto's regional characteristics. Currently, the Athena Institute has not conducted work towards weighting their summary measures (J. Reed, personal communication, 2010).

The final equation in the retrofit ranking process is shown below. It includes the summary measure results for each of the eight summary measures multiplied by the weightings. After it is applied to the data each retrofit option will have one value, or score. The lower this score, the better the retrofit ranking and the better the retrofit is in comparison to the other retrofit options.

$$Retrofit\ Ranking = (W_1 \times SM_1 + W_2 \times SM_2 + W_3 \times SM_3 + W_4 \times SM_4 + W_5 \times SM_5 + W_6 \times SM_6 + W_7 \times SM_7 + W_8 \times SM_8)/8 \quad (3)$$

Where:

W_1 through W_8 = weighting factors assigned to each summary measure

SM_1 through SM_8 = summary measure ratios calculated with Equation 2.

6 RESULTS

6.1 HOT2000 Energy Modeling

6.1.1 Base Case Comparison

The Century house has an energy intensity of 408 kWh/m^2, the Wartime Bungalow 263/m^2, the 70s OBC 251 kWh/m^2, and the Modern 199 kWh/m^2. These results show a trend towards better energy efficiency as the age of the house decreases. Total Fuel Consumption shows a decreasing trend with age as well as a significant drop between the Century and other archetypes. The decreasing trend is skewed by the 70s OBC home for Heating & Cooling energy intensity. The downward trend with newer vintages is present, but the 70s OBC archetype is slightly out of line.

Table 6.1 - Summary of results and inputs for each archetype base case.

Fuel Consumption [kWh/m2]:		Century	Wartime	70s OBC	Modern
	Total	408	263	251	199
	Heating & Cooling	326	171	172	128
Parameter Heat Loss [%]:					
	Ceiling	3.52	6.35	3.61	3.68
	Walls	33.72	23.87	30.60	22.87
	Windows & Doors	15.98	22.81	27.85	27.89
	Foundation	16.90	27.96	19.96	21.61
	Ventilation	29.88	19.01	17.98	23.95
Component Inputs:					
	Ceiling [RSI]	2.74	3.66	4.18	5.76
	Main Walls [RSI]	1.11	1.41	1.71	2.79
	Doors [RSI]	0.39	0.39	0.39	1.14
	Windows [RSI]	0.39	0.39	0.39	1.14
	Foundation Walls [RSI]	0.52	0.74	1.16	2.01
	Slab [RSI]	0.00	0.00	0.00	0.00
	Ventilation [ACH]	11.24	7.50	5.75	3.42

6.1.2 Century

For the Century archetype, 23 retrofit cases plus the base case were modeled. All main parameters – ceilings, main walls, windows & doors, foundation, and ventilation – were changed in at least one case. The table below summarizes the results. Full descriptions of the modeled retrofit cases and a table with full results are attached as Appendix 6a and Appendix 6b, respectively. Please refer to these appendices for more information.

Table 6.2 - Changes to house elements for each retrofit case.

Name	Schedule of Retrofits
BASE - Century	base case, unisulated double-wythe brick
38X89 BATT	38x89 fiberglass batt insulation on main walls
38X89 BATT & ACH+	38x89 batt main walls + semi-invasive air sealing
ALL 38X89 BATT & ACH+	38x89 batt main walls + 3rd floor gable wall + semi-invasive
ACH, NON	base case + non-invasive air sealing
ACH+	base case + semi-invasive air sealing
CEILING, BLOWN-IN	base case + blown-in cellulose ceiling
FOUND., 38x89 BATT	base case + 38x89 batt-filled foundation wall insulation
FOUNDATION & ACH+	38x89 batt-filled foundaiton wall + semi-invasive air sealing
WINDOWS	base case + double-glazed windows
COMBO	FOUNDATION & ACH+ + double-glazed units, rafters fully insulated
COMBO+	COMBO + change all insulation to polyurethane, windows to heat mirror, 2.0 ACH
38x64 ICYNENE	base case + 38x64 Icynene on main and 2nd floor
38x64 ICYNENE + ACH	38x64 ICYNENE + semi-invasive air sealing
38X64 ICYNENE+ACH+3rd	38x64 ICYNENE + ACH + insulate 3rd floor gable wall
38x64 ICYNENE+	38x64 ICYNENE + ACH + 3rd + double-glazed windows
38x89 ICYNENE+	same as 38x64 ICYNENE+ but with 38x89 walls
38x140 ICYNENE+	same as 38x64 ICYNENE+ but with 38x140 walls and foundation
38x140 ICYNENE MAX	38x140 ICYNENE+ with heat mirror windows and upgraded doors
38x140 BLOWN-IN MAX	same as 38x140 ICYNENE MAX but with blown-in cellulose instead of ICYNENE
THERMAL BRIDGING	38x140 BLOWN-IN MAX with a 38x64 offset from foundational wall (38x140 equivalent, thermal briding reduced)
38X140 BATT MAX	38x140 BLOWN-IN MAX but with fibeglass batt instead
38X140 POLYUR. MAX	38x140 BLOWN-IN MAX but with polyurethane instead
COMBO+ CONT.	heat mirror windows, upgraded doors, rafters fully insulated, foundation wall and slab insulated, semi-invasive air sealing

Table 6.3 Results from Century archetype modeling in HOT2000.

Retrofit Case	Fuel Consumption [kWh/m2] Total	Heating & Cooling	Heat Loss through Parameters [%] Ceiling	Walls	Windows & Doors	Foundation	Ventilation
BASE - Century	408	326	3.5	33.7	16.0	16.9	29.9
2X4 BATT	338	256	4.3	23.1	19.6	20.7	32.3
2X4 BATT & ACH+	312	230	4.7	25.3	21.5	22.7	25.8
ALL 2X4 BATT & ACH+	305	223	4.9	23.3	22.0	23.3	26.5
ACH, NON	388	306	3.7	35.6	16.9	17.8	26.0
ACH+	368	286	3.9	37.7	17.9	18.9	21.6
CEILING, BLOWN-IN	398	316	2.8	34.6	16.4	17.3	28.9
FOUND., 2x4 BATT	364	281	4.0	36.8	18.1	11.3	29.9
FOUNDATION & ACH+	336	254	4.3	40.0	19.7	12.3	23.7
WINDOWS	383	301	3.8	36.6	11.8	18.3	29.5
COMBO	312	230	3.8	44.1	14.8	13.5	23.9
COMBO+	173	93	6.1	33.6	16.2	25.2	18.9
2x3 ICYNENE	314	232	4.7	24.0	21.3	22.6	27.5
2x3 ICYNENE + ACH	263	181	5.7	29.3	26.1	27.6	11.4
2X3 ICYNENE+ACH+3rd	256	174	5.9	26.9	26.9	28.5	11.7
2x3 ICYNENE+	216	135	7.4	33.6	22.8	22.7	13.5
2x4 ICYNENE+	203	122	8.0	31.2	24.6	21.7	14.5
2x6 ICYNENE+	185	104	9.0	25.3	27.8	21.5	16.4
2x6 ICYNENE MAX	170	90	10.8	30.5	13.5	25.6	19.6
2x6 BLOWN-IN MAX	177	97	10.2	27.6	12.7	24.0	25.6
THERMAL BRIDGING	176	95	10.3	28.0	12.9	22.8	26.0
2X6 BATT MAX	216	136	7.8	25.2	9.7	17.9	39.4
2X6 POLYUR. MAX	154	74	12.6	24.4	15.7	24.0	23.2
COMBO+ CONT.	226	145	4.3	59.4	9.2	13.6	13.5

The energy intensity of the Century house base case is 408kWh/m^2. The models ranged from 398kWh/m^2 to 154kWh/m^2. Considering solely the energy intensity of heating and cooling, the retrofit cases range from 316 to 74kWh/m^2, compared with a base case value of 326kWh/m^2. Of the 23 retrofit cases five had energy intensities below the 100kWh/m^2 target. The energy draw from domestic hot water systems and appliances was 82kWh/m^2. The DHW and appliance loads are held constant between cases. The difference is attributable to the different floor areas by which the loads are divided to obtain the energy intensity values.

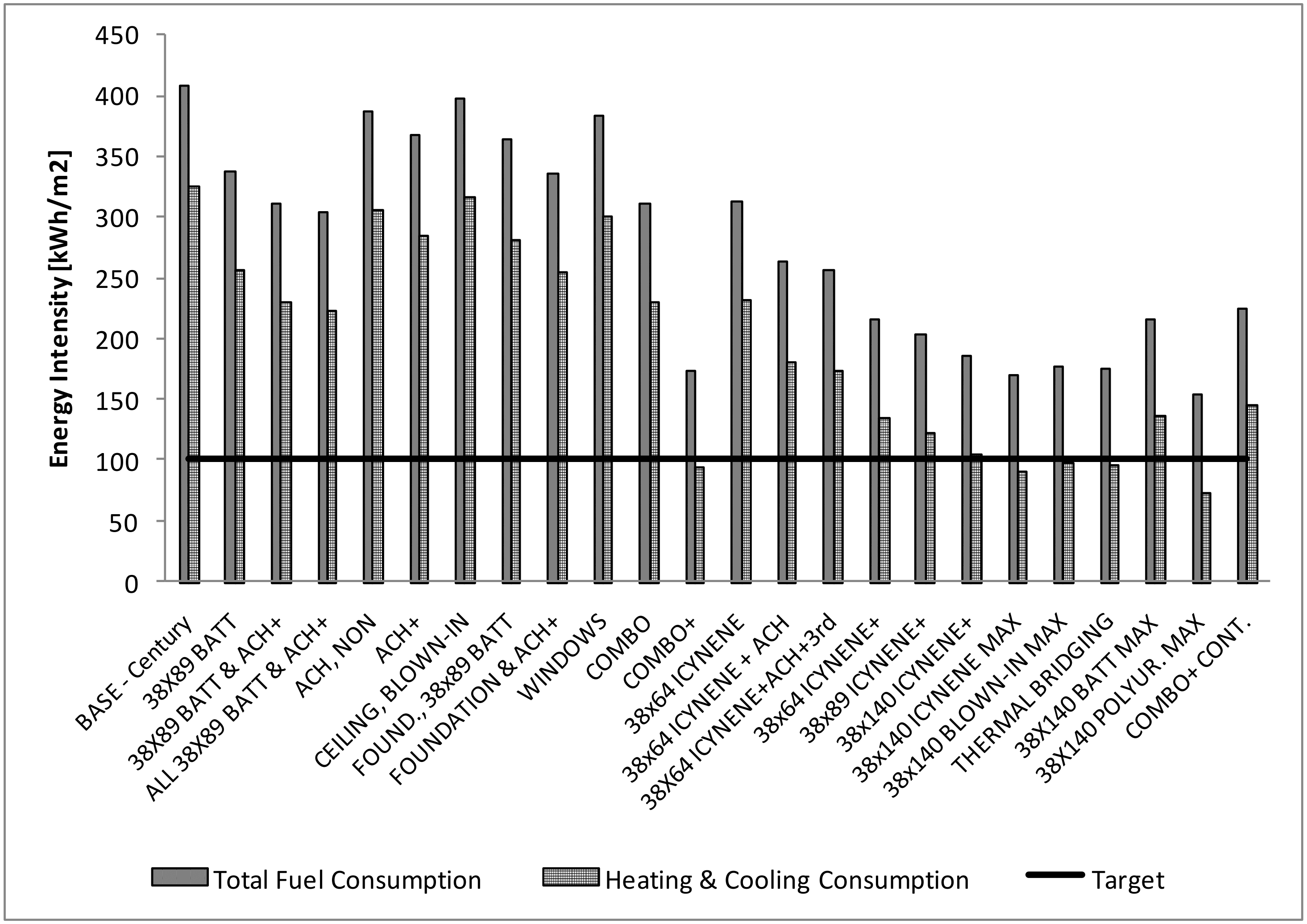


Figure 6.1 - Energy intensities from Century archetype modeling in HOT2000

In the base case the portion of heat lost through the main walls is the highest of the five parameters at 33.7%. Through the course of modeling the main walls continued to play a dominant role. Averaging all the retrofit cases shows the walls at 32% of heat loss compared with 23% for ventilation, 21% foundation, 18% windows & doors, and a slight 6% for ceilings. Looking further, the main walls are either the largest or second largest heat loss parameter in all retrofit cases. The ceiling parameter, however, is never a significant factor and is always the parameter with the lowest heat loss proportion. This curious result is discussed in Section 7.1.5.

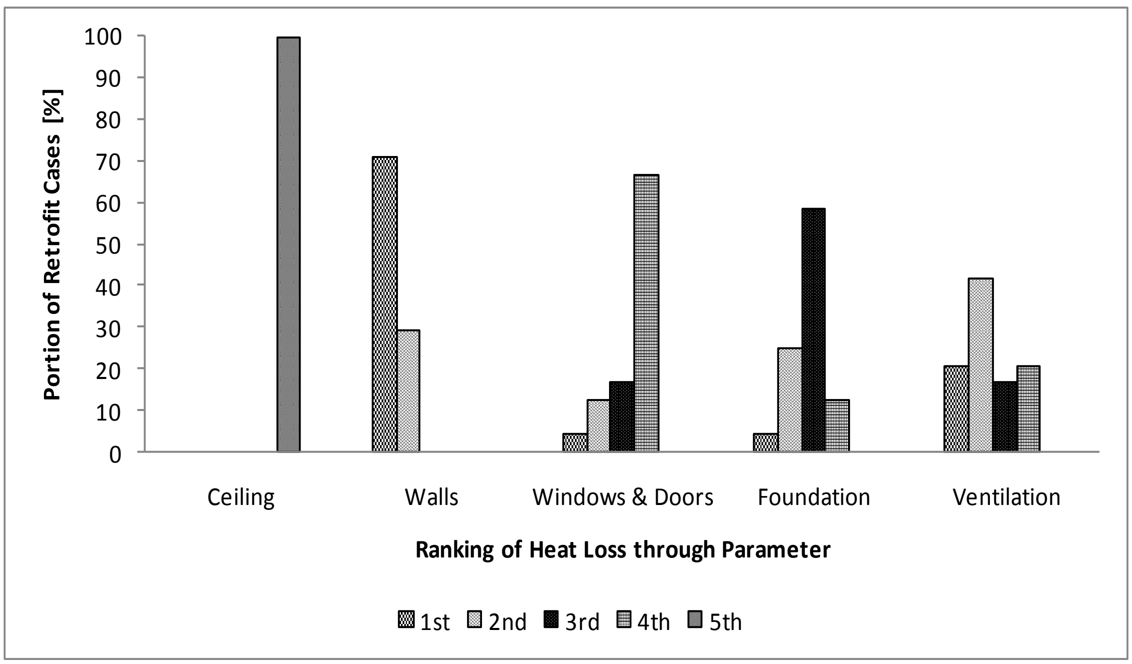


Figure 6.2 - Rankings of heat loss through parameters

The figure above shows the portion of time that a particular parameter has the 1st highest heat loss, 2nd, 3rd, and so on. For the Century archetype the walls parameter was consistently one of the top two in terms of heat loss. In contrast, the ceilings parameter has the lowest portion of heat loss for all modeled cases.

Of the 23 modeled retrofit cases, five were selected for further discussion. These five retrofit cases illustrate different relationships that became evident during the course of retrofit modeling. 38x89 BATT was selected to show the improvement possible when the homeowner is willing to sacrifice interior floor space and insulate their main walls. FOUNDATION & ACH+ was chosen to show the improvement attainable when a basement is conventionally finished along with full-home air sealing measures. WINDOWS was selected to show typical energy savings after window replacement, one of the most common house retrofits. COMBO+ CONT. was selected to show a maximized energy saving retrofit that does not involve insulating the main floors and thereby maintains the interior floor space. 38x64 ICYNENE+ was selected as a comparative retrofit to COMBO+ CONT. since it includes many of the same retrofits, but adds main wall insulation.

Table 6.4 - Summary of results and inputs for selected Century cases, 1-3

Fuel Consumption [kWh/m2]:	**BASE - Century**	**38x89 BATT**	**FOUND. & ACH+**
Total	408	338	336
Heating & Cooling	326	256	254
Parameter Heat Loss [%]:			
Ceiling	3.52	4.32	4.34
Walls	33.72	23.06	39.98
Windows & Doors	15.98	19.59	19.68
Foundation	16.90	20.71	12.29
Ventilation	29.88	32.31	23.71
Component Inputs:			
Ceiling [RSI]	2.74	2.74	2.74
Main Walls [RSI]	1.11	1.98	1.15
Doors [RSI]	0.39	0.39	0.39
Windows [RSI]	0.24	0.24	0.24
Foundation Walls [RSI]	0.52	0.52	1.84
Slab [RSI]	0.00	0.00	0.23
Ventilation [ACH]	11.24	9.74	6.74

Table 6.5 - Summary of results and inputs for selected Century cases, 4-6

Fuel Consumption [kWh/m2]:		**WINDOWS**	**COMBO+ CONT.**	**38x64 ICYNENE+**
	Total	383	226	216
	Heating & Cooling	301	145	135
Parameter Heat Loss [%]:				
	Ceiling	3.82	4.32	7.40
	Walls	36.56	59.42	33.58
	Windows & Doors	11.79	9.20	22.85
	Foundation	18.28	13.60	22.70
	Ventilation	29.54	13.46	13.47
Component Inputs:				
	Ceiling [RSI]	2.74	4.91	2.74
	Main Walls [RSI]	1.11	1.31	2.33
	Doors [RSI]	0.39	1.14	0.39
	Windows [RSI]	0.38	0.95	0.38
	Foundation Walls [RSI]	0.52	2.67	1.52
	Slab [RSI]	0.00	1.85	0.00
	Ventilation [ACH]	10.12	1.80	1.80

6.1.3 Wartime

For the Wartime archetype, 15 retrofit cases plus the base case were modeled. All main parameters – ceilings, main walls, windows & doors, foundation, and ventilation – were changed in at least one case. The table below summarizes the results. Full description of the modeled retrofit cases and a table with full results are attached as Appendix 7a and 7b – HOT2000 Input Notes – Retrofits – Wartime, respectively. Please refer to these appendices for further information.

Table 6.6 - Changes to house elements for each retrofit case.

Name	Schedule of Retrofits
BASE - Wartime	
BATT FOUNDATION	38x89 batt foundation wall
BATT WINDOWS	38x89 batt foundation wall + double-glazed windows
38X89 BLOWN-IN	38x89 blown-in cellulose main and foundation wall
38x89 B-IN WINDOWS	38x89 BLOWN-IN + double-glazed windows
38x140 B-IN FOUNDATION	38x140 thermal briding reduced blown-in foundation wall
38X140 POLYUR. FOUND.	38x140 polyurethane foundation walls, heat mirror windows, semi-invasive air sealing
38X89 B-IN SLAB	38x89 B-IN WINDOWS + 38x64 XPS slab insulation
38X89 B-IN SLAB+	38x89 B-IN WINDOWS + 38X76 XPS slab insulation
38x140 B-IN F/S/W	heat mirror windows, 38x140 blown-in foundation, 38x64 XPS slab insulation
38x140 B-IN CASE	heat mirror windows, 38x89 blown-in walls, 38x140 blown-in foundation, 38x64 XPS slab, upgraded doors, semi-invasive air sealing
38x140 ICYNENE CASE	38x140 B-IN CASE but with Icynene instead of blown-in
38X140 POLYUR. CASE	38x140 B-IN CASE but with polyurethane instead of blown-in
EXTERIOR INSULATION	heat mirror windows, 38x89 polyurethane walls, 38x140 polyurethane foundation wall, 38x64 XPS slab, 38x64 half height exterior XPS
EXT. INSUL. FULL	same as EXTERIOR INSULATION but full height
38x140 MAIN WALLS	38x140 polyurethane walls, heat mirror windows, upgraded doors, 38x140 polyurethane foundation, 38x64 XPS slab

Table 6.7 - Results from Wartime archetype modeling in HOT2000

	Fuel Consumption [kWh/m2]		Heat Loss through Parameters [%]				
Retofit Case	Total	Heating & Cooling	Ceiling	Walls	Windows & Doors	Foundation	Ventilation
BASE - Wartime	263	171	6.4	23.9	22.8	28.0	19.0
BATT FOUNDATION	237	146	7.2	23.7	25.9	23.9	19.3
BATT WINDOWS	230	139	7.5	24.8	20.1	25.0	22.5
2X4 BLOWN-IN	221	129	7.9	18.2	28.3	25.7	20.1
2x4 B-IN WINDOWS	209	118	8.6	19.8	22.8	27.9	21.0
2x6 B-IN FOUNDATION	202	111	9.0	20.7	23.9	24.4	22.0
2X6 POLYUR. FOUND.	183	92	10.8	23.8	15.4	26.0	24.0
2X4 B-IN SLAB	201	110	9.1	21.1	24.4	23.0	22.4
2X4 B-IN SLAB+	201	109	9.2	21.2	24.5	22.7	22.5
2x6 B-IN F/S/W	181	90	11.3	26.1	16.1	18.7	27.7
2x6 B-IN CASE	166	75	13.0	30.1	14.0	21.9	20.9
2x6 ICYNENE CASE	161	70	13.8	30.7	14.8	24.3	16.5
2X6 POLYUR. CASE	151	61	15.6	29.4	16.8	19.5	18.7
EXTERIOR INSULATION	152	62	15.2	28.6	16.3	21.7	18.2
EXT. INSUL. FULL	156	65	14.6	27.5	15.7	24.8	17.4
2x6 MAIN WALLS	141	51	18.1	18.1	19.5	22.6	21.6

The energy intensity of the Wartime house base case is 263kWh/m^2. The retrofit cases ranged from 237kWh/m^2 to 141kWh/m^2. Considering solely the energy intensity of heating and cooling, the retrofit cases range from 146 to 51kWh/m^2 compared with the base case value of 171kWh/m^2. Eight of the retrofitted cases had heating and cooling energy intensities below 100kWh/m^2. The energy draw from domestic hot water systems and appliances was 91kWh/m^2. The DHW and appliance loads are held constant between cases. The difference between the Wartime and Century case is attributable to the different floor areas by which the loads are divided to obtain the energy intensity values. For the Wartime archetype the floor area is smaller than for the Century home, explaining the 91 to 82kWh/m^2 difference.

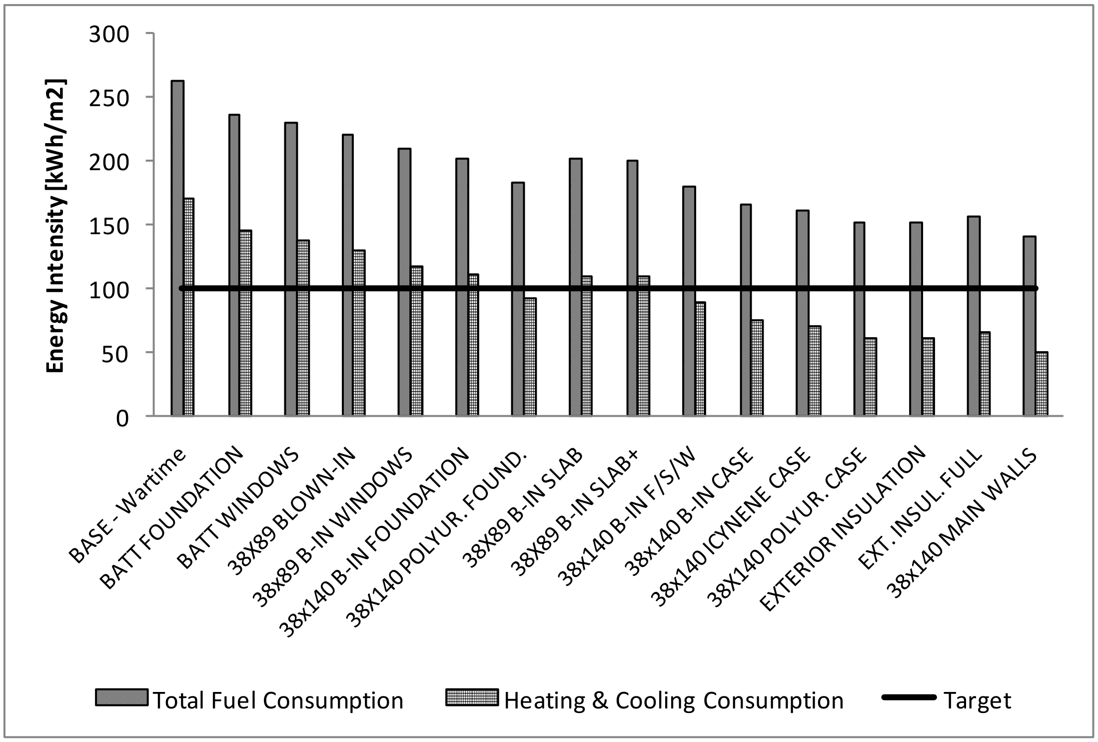


Figure 6.3 - Energy intensity results from Wartime archetype modeling in HOT2000

In the base case the portion of heat lost through the foundation is the highest of the five parameters at 28.0%. Three of the remaining four parameters are within 10% of this figure: walls 23.9%, windows & doors 23.9%, and ventilation 19.0%. The ceiling parameter consistently remains at the bottom of the list in terms of portion of heat loss. Through the course of modeling all five parameters begin to converge around the 20% mark. Averaging all the retrofit cases shows the walls at 24% of heat loss compared with 23% for foundation, 21% ventilation, 20% windows & doors, and 11% for ceilings.

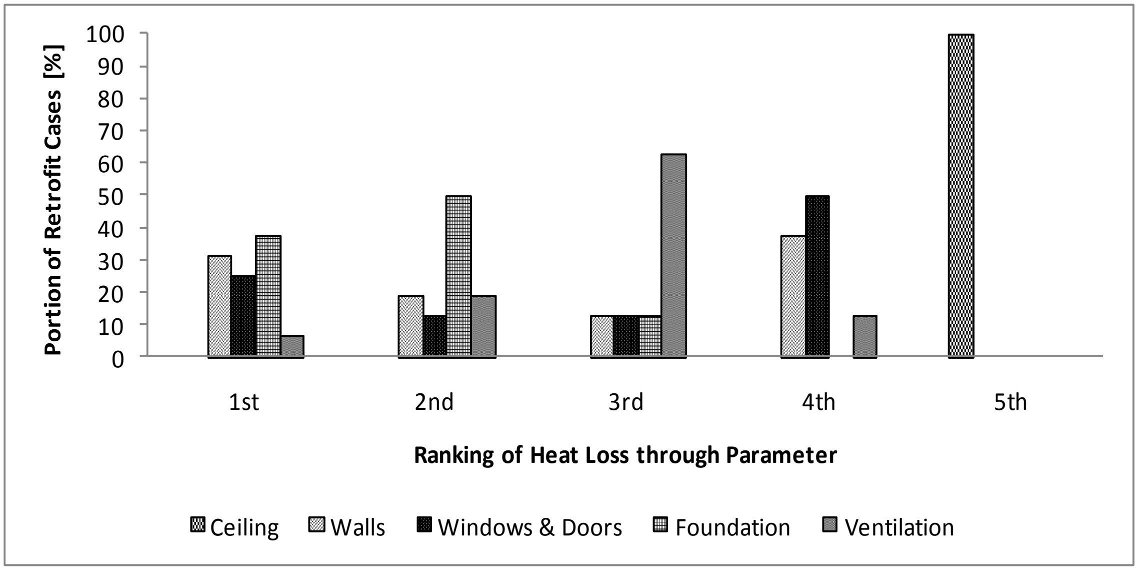


Figure 6.4 - Rankings of heat loss through parameters

Of the 15 modeled retrofit cases, five were selected for further discussion. These five retrofit cases illustrate different relationships that became evident during the course of retrofit modeling. BATT FOUNDATION was selected to show the improvement a conventional finished basement can obtain. To compare the effects of insulating the foundation slab 38x89 B-IN WINDOWS and 38x89 B-IN SLAB were chosen. 38x140 B-IN CASE was chosen because it exceeds the targeted 100kWh/m^2 in heating and cooling energy intensity without the need for polyurethane insulation or the loss of interior floor space. 38x140 MAIN WALLS was chosen to illustrate the convergence of the five parameters.

Table 6.8 - Summary of results and inputs for selected Wartime cases, 1-3

Fuel Consumption [kWh/m2]:	BASE - Wartime	BATT FOUNDATION	38x89 B-IN WIND.
Total	263	237	209
Heating & Cooling	171	146	118
Parameter Heat Loss [%]			
Ceiling	6.35	7.20	8.57
Walls	23.87	23.71	19.77
Windows & Doors	22.81	25.86	22.76
Foundation	27.96	23.89	27.94
Ventilation	19.01	19.34	20.96
Component Inputs:			
Ceiling [RSI]	3.66	3.66	3.66
Main Walls [RSI]	1.41	1.61	2.30
Doors [RSI]	0.39	0.39	0.39
Windows [RSI]	0.26	0.26	0.38
Foundation Walls [RSI]	0.74	1.84	1.93
Slab [RSI]	0.00	0.00	0.00
Ventilation [ACH]	7.50	6.75	4.99

Table 6.9 - Summary of results and inputs for selected Wartime cases, 4-6

Fuel Consumption [kWh/m2]:	38x89 B-IN SLAB	38x140 B-IN CASE	38x140 MAIN WALLS
Total	201	166	141
Heating & Cooling	110	75	51
Parameter Heat Loss [%]:			
Ceiling	9.14	13.05	18.11
Walls	21.10	30.11	18.15
Windows & Doors	24.35	14.04	19.54
Foundation	23.04	21.89	22.57
Ventilation	22.36	20.91	21.63
Component Inputs:			
Ceiling [RSI]	3.66	3.66	3.66
Main Walls [RSI]	2.30	2.30	5.29
Doors [RSI]	0.39	1.14	1.14
Windows [RSI]	0.38	0.95	0.83
Foundation Walls [RSI]	1.93	3.21	5.18
Slab [RSI]	1.85	1.85	5.18
Ventilation [ACH]	4.99	2.85	1.90

6.1.4 70s OBC

In addition to the base case, 15 retrofit cases were modeled for the 70s OBC house. Four of the main parameters – main walls, windows & doors, foundation, and ventilation – were varied in the retrofits. Due to its low contribution to heat loss no changes were modeled for the ceiling parameter. The table below summarizes the results. Full description of the modeled retrofit cases and a table with full results are attached as Appendix 8a and Appendix 8b – HOT2000 Input Notes – Retrofits – 70s OBC, respectively. Please refer to these appendices for further information.

Table 6.10 - Changes to house elements for each retrofit case

Name	Schedule of Retrofits
BASE - 70s OBC	
38x89 BATT WALLS	38x89 batt-filled walls
38x89 BATT & ACH	38x89 batt-filled walls, semi-invasive air sealing
38x89 BLOWN-IN WALLS	38x89 blown-in cellulose walls
38x89 BLOWN-IN + ACH	38x89 blown-in cellulose walls, semi-invasive air sealing
38x89 ICYNENE WALLS	38x89 Icynene walls
38x89 ICYNENE + ACH	38x89 Icynene walls, semi-invasive air sealing
38x89 POLYUR. WALLS	38x89 polyurethane walls
38x89 POLYUR. + ACH	38x89 polyurethane walls, semi-invasive air sealing
WINDOWS	38x89 ICYNENE + ACH, double-glazed windows
WINDOWS + FOUND.	38x89 ICYNENE + ACH, heat mirror windows, 38x89 Icynene foundation
38x140 ICYNENE	38x140 Icynene walls
38x140 FOUNDATION	38x140 Icynene foundation
38x64 SLAB	38x64 XPS slab
POLYURETHANE	38x140 polyurethane walls and foundation, heat mirror windows, upgraded doors
POLYURETHANE+	POLYURETHANE, 38x64 XPS slab

Table 6.11 - HOT2000 modeling results for the 70s OBC archetype

	Fuel Consumption [kWh/m2]		Heat Loss through Parameters [%]				
Retofit Case	Total	Heating & Cooling	Ceiling	Walls	Windows & Doors	Foundation	Ventilation
BASE - 70s OBC	251	172	3.6	30.6	27.9	20.0	18.0
2x4 BATT WALLS	234	156	3.9	25.0	29.9	21.5	19.8
2X4 BATT & ACH	229	150	4.0	25.7	30.9	22.1	17.2
2x4 BLOWN-IN WALLS	233	154	3.9	24.5	30.1	21.6	19.9
2x4 BLOWN-IN + ACH	222	144	4.1	26.0	32.0	22.9	15.0
2x4 ICYNENE WALLS	230	152	4.0	24.3	30.6	21.9	19.2
2x4 ICYNENE + ACH	215	136	4.3	26.6	33.5	24.0	11.4
2x4 POLYUR. WALLS	222	144	4.1	21.1	31.9	22.9	20.0
2x4 POLYUR. + ACH	207	128	4.6	23.2	35.1	25.2	12.0
WINDOWS	203	125	4.7	28.8	28.1	26.0	12.4
WINDOWS + FOUND.	179	103	5.8	35.7	17.3	25.8	15.3
2x6 ICYNENE	163	86	6.7	25.9	19.9	29.8	17.7
2x6 FOUNDATION	156	79	7.1	27.4	21.1	25.7	18.7
2x3 SLAB	156	79	7.2	27.5	21.2	25.2	18.8
POLYURETHANE	141	64	8.4	22.2	20.6	26.9	21.9
POLYURETHANE+	132	56	9.6	25.3	23.6	16.4	25.1

The base case energy intensity of the 70s OBC archetype is a total of 251kWh/m^2. The 15 retrofit cases ranged from 234kWh/m^2 to 132kWh/m^2. The heating and cooling energy intensity started at 172kWh/m^2 and ranged between 156 and 56kWh/m^2. Six of the 15 retrofit cases had energy intensities for heating and cooling below the targeted 100kWh/m^2. The energy load from domestic hot water systems and appliances comes out to 78kWh/m^2 for the 70s OBC case.

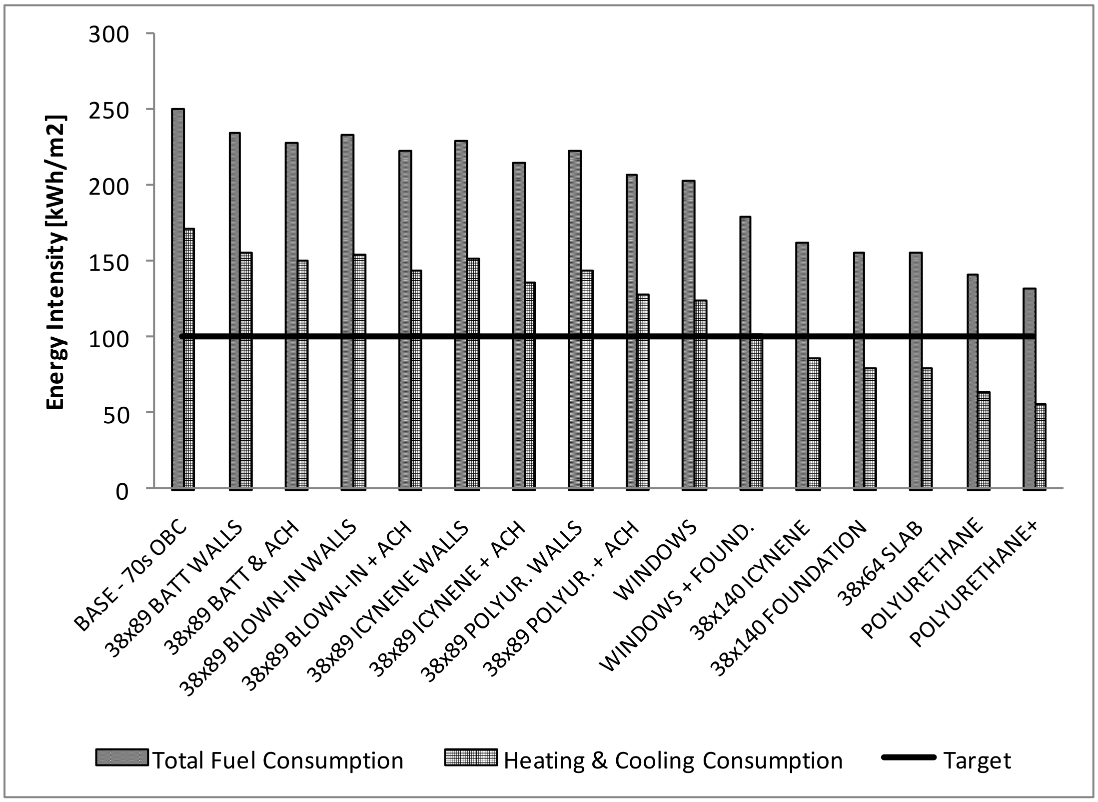


Figure 6.5 - Energy intensity results from 70s OBC archetype modeling in HOT2000

In the base case heat loss through the five parameters is as follows: walls 31%, window & doors 28%, foundation 20%, ventilation 18%, and ceiling 4%. Four of the five are reasonably similar in magnitude, with ceiling lagging behind. This is the first archetype where the windows & doors parameter contributes significantly to heat loss. In the base case it is only 3% behind the biggest heat loss parameter.

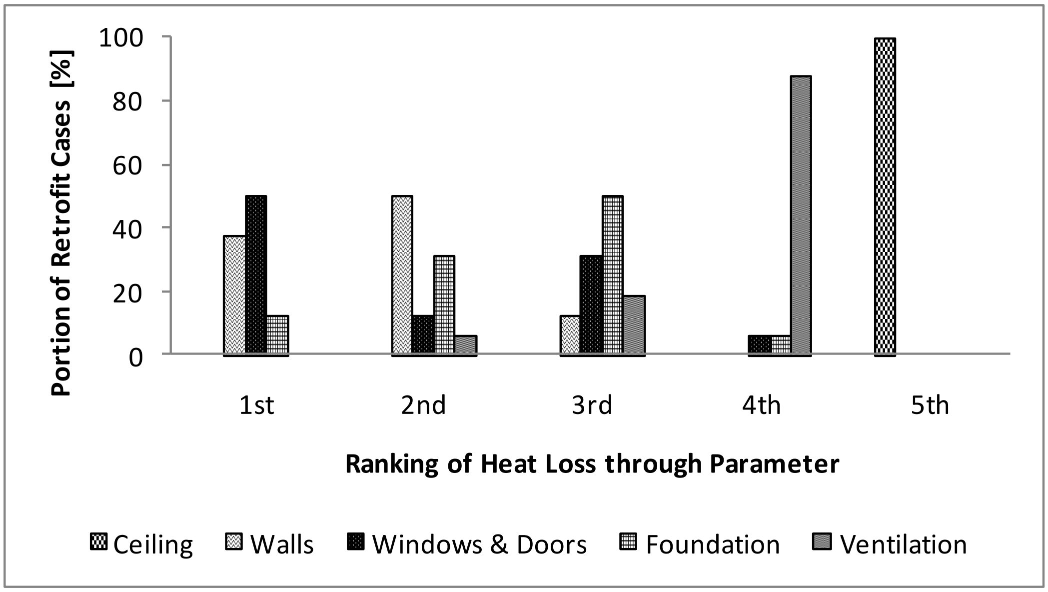


Figure 6.6 - Rankings of heat loss through parameters

Five retrofit cases were selected from the 15 because they are good examples of trends noticed during modeling the 70s OBC archetype. To show the difference in operational energy at different air leakage rates the 38x89 BATT + ACH and 38x89 ICYNENE + ACH cases were selected. 38x140 FOUNDATION and 38x140 SLAB are two cases that look to reducing foundation losses. They have been chosen to show the result when either foundation walls or slab is insulated. The final case selected for further discussion was POLYURETHANE+. With its 56kWh/m^2 heating and cooling energy intensity, it was chosen to show how much improvement can be made and the cost in terms of materials and space for that improvement.

Table 6.12 - Summary of results and inputs for selected 70s OBC cases, 1-3

Fuel Consumption [kWh/m2]:		BASE - 70s OBC	38x89 BATT & ACH	38x89 ICYNENE + ACH
	Total	251	229	215
	Heating & Cooling	172	150	136
Parameter Heat Loss:				
	Ceiling	3.61	4.01	4.35
	Walls	30.60	25.73	26.63
	Windows & Doors	27.85	30.89	33.54
	Foundation	19.96	22.13	24.04
	Ventilation	17.98	17.25	11.45
Component Inputs:				
	Ceiling [RSI]	4.18	4.18	4.18
	Main Walls [RSI]	1.71	2.25	2.36
	Doors [RSI]	0.39	0.39	0.39
	Windows [RSI]	0.28	0.28	0.28
	Foundation Walls [RSI]	1.16	1.16	1.16
	Slab [RSI]	0.00	0.00	0.00
	Ventilation [ACH]	5.75	3.74	2.00

Table 6.13 - Summary of results and inputs for selected 70s OBC cases, 4-6

Fuel Consumption [kWh/m2]:		38x140 FOUNDATION	38x64 SLAB	POLYURETHANE+
	Total	156	156	132
	Heating & Cooling	79	79	56
Parameter Heat Loss:				
	Ceiling	7.13	7.17	9.58
	Walls	27.37	27.53	25.34
	Windows & Doors	21.10	21.24	23.61
	Foundation	25.71	25.25	16.39
	Ventilation	18.69	18.80	25.09
Component Inputs:				
	Ceiling [RSI]	4.18	4.18	4.18
	Main Walls [RSI]	3.77	3.77	5.47
	Doors [RSI]	0.39	0.39	1.14
	Windows [RSI]	0.95	0.95	0.95
	Foundation Walls [RSI]	3.36	2.03	5.18
	Slab [RSI]	0.00	1.85	1.85
	Ventilation [ACH]	2.00	2.00	2.00

6.1.5 Modern

In total, 14 retrofit cases as well as the base case were modeled for the Modern archetype house. Four of the main parameters – main walls, windows & doors, foundation, and ventilation – were varied in the retrofits. Due to its low contribution to heat loss no changes were modeled for the ceiling parameter in this archetype. The table below summarizes the results. Full description of the modeled retrofit cases and a table with full results are attached as Appendix 9a and Appendix 9b – HOT2000 Input Notes – Retrofits – Modern, respectively. Please refer to these appendices for further information.

Table 6.14 - Changes to house elements for each retrofit case.

Name	Schedule of Retrofits
BASE - MODERN	
SLIDING GLASS	heat mirror sliding glass doors
DOORS & WINDOWS	all glazing heat mirror
GLAZING & VENT.	heat mirror glazing, semi-invasive air sealing
ALL + FOUNDATION	heat mirror glazing, upgraded doors, 38x140 blown-in foundation, semi-invasive air sealing
ALL + F. + SLAB	ALL + FOUNDATION, 38x64 XPS slab
38x140 BLOWN-IN	38x140 blown-in walls, semi-invasive air sealing
38x140 ICYNENE	38x140 Icynene walls, semi-invasive air sealing
38x140 POLYURETHANE	38x140 polyurethane, semi-invasive air sealing
BLOWN-IN+	38x140 BLOWN-IN, heat mirror glazing, 38x140 blown-in foundation
ICYNENE+	38x140 ICYNENE, heat mirror glazing, 38x140 Icynene foundation
POLYURETHANE+	38x140 POLYURETHANE, heat mirror glazing, 38x140 polyurethane foundation
ICYNENE+ & FOUND.	38X140 ICYNENE, 38x64 XPS slab
BEL. 100 BLOWN-IN	heat mirror glazing, semi-invasive air sealing, 38x184 blown-in cellulose walls and foundation, 38x64 XPS slab, ceiling insulation RSI value to match walls
WINDOW TEST	all TC88 heat mirror glazing

Table 6.15 - Results from Modern archetype modeling in HOT2000

	Fuel Consumption [kWh/m2]		Heat Loss through Parameters [%]				
Retofit Case	Total	Heating & Cooling	Ceiling	Walls	Windows & Doors	Foundation	Ventilation
BASE - MODERN	199	128	3.7	22.9	27.9	21.6	23.9
SLIDING GLASS	197	126	3.8	23.7	25.4	22.4	24.8
DOORS & WINDOWS	183	113	4.4	27.5	13.8	25.6	28.7
GLAZING & VENT.	179	109	4.6	28.4	14.3	26.4	26.3
ALL + FOUNDATION	174	105	4.7	29.2	14.7	24.3	27.1
ALL + F. + SLAB	166	96	5.0	31.4	15.9	18.7	29.1
38x140 BLOWN-IN	185	114	4.0	19.1	30.7	23.8	22.4
38x140 ICYNENE	177	105	4.3	19.1	32.6	25.3	18.8
38x140 POLYURETHANE	169	97	4.6	14.1	34.6	26.8	19.9
BLOWN-IN+	162	92	5.2	24.6	16.3	25.1	28.8
ICYNENE+	153	83	5.7	25.1	17.7	26.8	24.7
POLYURETHANE+	141	71	6.3	19.6	19.9	26.4	27.7
ICYNENE+ & FOUND.	143	73	6.3	27.8	19.8	18.8	27.4
BEL. 100 BLOWN-IN	143	73	6.3	22.3	19.9	16.9	34.7
WINDOW TEST	139	69	6.4	28.3	16.2	21.2	27.9

The base case of the Modern archetype has a total energy intensity of 199kWh/m^2 and a heating and cooling energy intensity of 128kWh/m^2. During retrofit modeling, the total energy intensity ranged from 197 to 139kWh/m^2 and the heating and cooling energy intensity varied from 126kWh/m^2 to 69kWh/m^2. Eight of the 14 retrofit cases exceed the 100kWh/m^2 target. The energy load from domestic hot water systems and appliances works out to 71kWh/m^2 for this archetype.

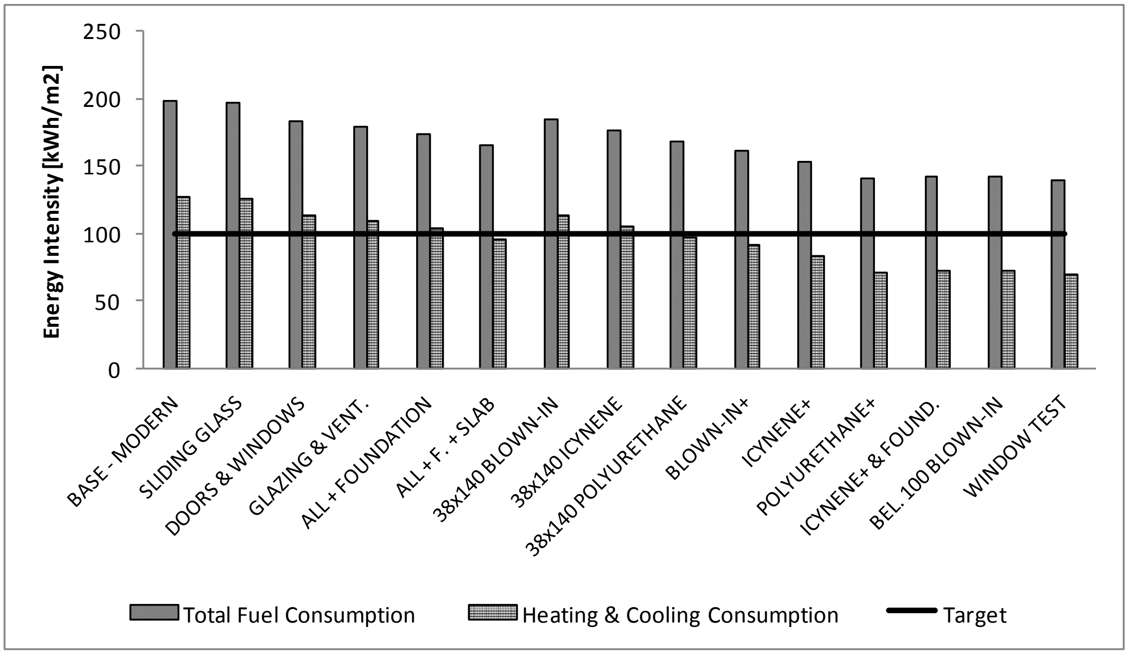


Figure 6.7 - Energy intensity results from Modern archetype modeling in HOT2000

In the base case four of the five retrofit parameters –windows & doors 28%, ventilation 24%, walls 23%, and foundation 22% – are within 10% of each other in terms of heat loss proportions. These parameters, therefore, are converging before retrofits are applied. This can be attributed to the better building code and construction standards to which the Modern house is built. However, the difficulty this presents is the lack of easy, minimally invasive retrofits to be applied to the house.

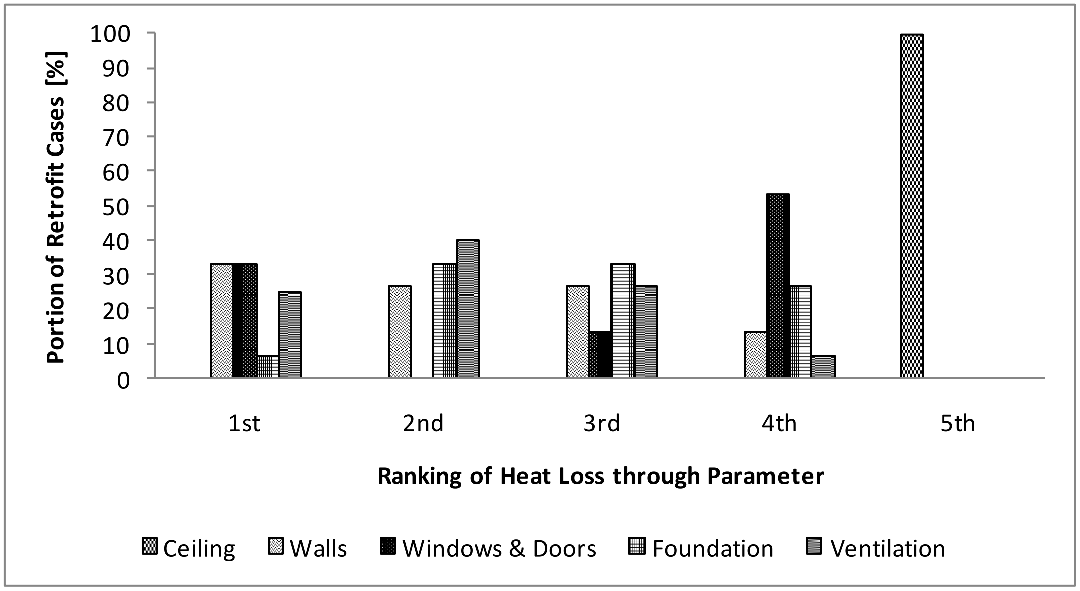


Figure 6.8 - Rankings of heat loss through parameters

Five retrofit cases were selected from the 14 to illustrate trends in the Modern archetype. The SLIDING GLASS case was chosen to demonstrate the relative contribution of sliding glass doors to heat loss. To show the level of energy performance that can be attained without losing floor area, the ALL + F. + SLAB case has been selected. Two cases, ICYNENE & FOUND. and BEL. 100 BLOWN-IN, were chosen because they exceed the $100kWh/m^2$ target. The final case, WINDOW TEST, was chosen because it tests the balance between thermal resistance and solar gains in the windows.

Table 6.16 - Summary of results and inputs for selected Modern cases, 1-3

Fuel Consumption [kWh/m2]:		BASE - MODERN	SLIDING GLASS	ALL + F. + SLAB
	Total	199	197	166
	Heating & Cooling	128	126	96
Parameter Heat Loss [%]:				
	Ceiling	3.68	3.80	5.04
	Walls	22.87	23.66	31.36
	Windows & Doors	27.89	25.43	15.85
	Foundation	21.61	22.35	18.69
	Ventilation	23.95	24.76	29.06
Component Inputs:				
	Ceiling [RSI]	5.76	5.76	5.76
	Main Walls [RSI]	2.79	2.79	2.79
	Doors [RSI]	1.14	1.14	1.14
	Windows [RSI]	0.36	0.46*	0.95
	Foundation Walls [RSI]	2.01	2.01	2.98
	Slab [RSI]	0.00	0.00	1.85
	Ventilation [ACH]	3.42	3.42	2.90

Table 6.17 - Summary of results and inputs for selected Modern cases, 4-6

Fuel Consumption [kWh/m2]:		ICYNENE+ & FOUND.	BEL. 100 BLOWN-IN	WINDOW TEST
	Total	143	143	139
	Heating & Cooling	73	73	69
Parameter Heat Loss [%]:				
	Ceiling	6.26	6.29	6.39
	Walls	27.83	22.25	28.27
	Windows & Doors	19.78	19.89	16.21
	Foundation	18.77	16.87	21.21
	Ventilation	27.37	34.71	27.92
Component Inputs:				
	Ceiling [RSI]	5.76	5.76	5.76
	Main Walls [RSI]	3.79	4.80	3.79
	Doors [RSI]	1.14	1.14	1.14
	Windows [RSI]	0.95	0.95	1.15
	Foundation Walls [RSI]	3.36	4.41	4.41
	Slab [RSI]	1.85	1.85	1.85
	Ventilation [ACH]	2.00	2.75	2.00

* the window RSI value given is a weighted average of the retrofitted sliding door glazing and the base case windows.

6.2 ATHENA Impact Estimator: Ranking Retrofits

6.2.1 Beyond Energy

To briefly show that materials have independent environmental effects four insulation materials – fiberglass batt, blown-in cellulose, extruded polystyrene, and polyisocyanurate foam (using the polyisocyanurate proxy) – were selected. Environmental effects were modeled for the amount of insulation yielding an identical RSI-value of 2.11 for each material. With some simplifying assumptions, most significantly that the insulation does not affect the air leakage characteristics of the house, keeping the RSI-value constant ensures equal operational energy performance for the house. These results, therefore, show the difference in environmental effects attributable to material choice. For a full account of the development of the summary table below please see Appendix 10 – Operationally Equal Insulation.

Table 6.18 – Insulation summary measures standardized to an equivalent RSI-value

	Unit	Insulation [RSI-2.11 eq.]			
		Batt	Blown-in	XPS	Polyiso.
Primary Energy Consumption	[MJ]	34.75	4.34	100.28	61.77
Weighted Resource Use	[kg]	3.59	1.94	2.79	2.16
Global Warming Potential	[kg CO2 eq.]	2.06	0.19	4.92	6.14
Acidification Potential	[moles H+ eq.]	0.78	0.07	1.51	1.06
HH Respiratory Effects Potential	[kg PM2.5 eq.]	0.0203	0.0003	0.0018	0.0031
Eutrophication Potential	[kg N eq.]	3.48539E-06	1.96801E-07	4.27571E-06	2.84104E-06
Ozone Depletion Potential	[kg CFC-11 eq.]	3.78156E-10	8.81065E-10	7.12551E-11	1.07271E-09
Smog Potential	[kg NOx eq.]	0.0035	0.0002	0.0997	0.0087

6.2.2 Operationally Equal

During HOT2000 modeling of the retrofit cases it became apparent that there are different retrofit options that result in the same operational energy performance. To show these cases, and explore the variation in embodied effects when operational effects were held constant, two pair of retrofit cases were chosen.

Wartime - 38x140 B-IN FOUND. vs. 38x89 B-IN + SLAB:

The first pair of operationally equal retrofit options tested was the 38x140 B-IN FOUND. and 38x89 B-IN + SLAB cases of the Wartime archetype. After these retrofits the Wartime house has an energy intensity of 202kWh/m^2. 38x140 B-IN FOUND. includes a 38x140 equivalent, blown-in cellulose filled, double-stud foundation wall. To compare the 38x89 B-IN + SLAB case uses a 38x89 equivalent, blown-in cellulose filled, double-stud foundation wall and XPS insulation over the slab. The XPS insulation is not a walking surface so the elements required, wood framing and sheathing, are included in the Athena inputs as well. Please refer to Appendix 11 – ATHENA Input Notes – Operationally Equal – Wartime for a full description of the Athena inputs and results.

These two cases were chosen to determine which is less detrimental to the environment, using a larger volume of blown-in cellulose (by approximately a factor of 1.5) or using a smaller volume of cellulose in conjunction with XPS, wood framing and sheathing. The table below shows results obtained from the Athena program for the retrofit inputs described above.

Table 6.19 - Environmental effects resulting from Wartime retrofit options.

Summary Measures	Units	38x89 B-IN FOUND.	38x89 B-IN + SLAB
Primary Energy Consumption	MJ	2168	28980
Weighted Resource Use	kg	1260	4760
Global Warming Potential	kg CO2 eq	91	1272
Acidification Potential	moles H+ eq.	29	412
HH Respiratory Effects Potential	kg PM2.5 eq.	0.17	1.06
Eutrophication Potential	kg N eq.	0.001588081	0.003799388
Ozone Depletion Potential	kg CFC-11 eq.	9.4881E-07	2.35175E-05
Smog Potential	kg NOx eq.	0.09	18.07

70s OBS - 38x89 B-IN + ACH vs. 38x89 POLYURETHANE:

The second pair of operationally equal retrofits to be modeled in the Athena program belong to the 70s OBC archetype. The 38x89 B-IN + ACH case uses blown-in cellulose wall insulation combined with semi-invasive air sealing to obtain a total energy intensity of 222kWh/m^2. In contrast, the 38x89 POLYURETHANE case depends solely on the high RSI-value of the insulation in the main walls to achieve the same energy intensity. Please refer to Appendix 12 – ATHENA Input Notes – Operationally Equal – 70s OBC for a full description of the Athena inputs and results.

With these two cases the environmental effect of equal volumes of different types of insulation, one with the addition of air sealing materials, was compared.

Table 6.20 - Environmental effects resulting from 70s OBC retrofit options.

Summary Measures	Units	38x89 B-IN + ACH	38x89 POLYUR.
Primary Energy Consumption	MJ	34287	58386
Weighted Resource Use	kg	6623	7396
Global Warming Potential	kg CO2 eq	1683	4896
Acidification Potential	moles H+ eq.	608	984
HH Respiratory Effects Potential	kg PM2.5 eq.	3.75	4.58
Eutrophication Potential	kg N eq.	0.006011482	0.007104816
Ozone Depletion Potential	kg CFC-11 eq.	3.15021E-06	3.39175E-06
Smog Potential	kg NOx eq.	3.12	6.43

6.2.3 Operationally Unequal

The retrofit cases compared in Athena up to this point have been modeled and presented in order of increasing complexity. The first comparison pairs had equal operating energy, however, the majority of the retrofit cases do not have constant operational energy. It is these cases that make ideal test cases for the retrofit ranking equation and for this purpose four pairs of retrofits were chosen. The first pair was chosen to compare two different insulation materials. The second pair compared the impact of window replacement. The third tests a wide energy intensity spread and the final compares cases with an intermediate spread. Please refer to Appendix 13a – 13d – ATHENA Input Notes – Operationally Unequal for input notes.

Century - COMBO + CONT. and 38x140 BATT MAX:

The first two cases used to test the functioning of the formula are the Century archetype's COMBO+ CONT. and 38x140 BATT MAX retrofit cases. COMBO+ CONT. maxed out the energy intensity reduction that can be achieved without insulating the main walls. Polyurethane is used to fill the cathedral ceiling, flat ceiling, and a 38x89 foundation wall cavity. The slab is insulated with XPS. The comparison case, 38x140 BATT MAX, reduces energy intensity by insulating the main and foundation walls with fiberglass batt. The two have similar, but not identical, energy intensities with COMBO+ CONT. at 226 and 38x140 BATT MAX at 216kWh/m^2. This pair is used to model a slight difference in energy intensity and variation in insulation material.

The table below shows the retrofit ranking of the two options for a selection of life cycle. Since the lower ranking number is the preferred retrofit option the 38x140 BATT MAX case is preferred for all life cycles considered.

Table 6.21 – Results from the retrofit ranking equation for the Century archetype

Life Cycle	COMBO+ CONT.	38x140 BATT MAX
Years: 1	0.95	0.77
10	0.99	0.83
20	1	0.84
60	1	0.85
80	1	0.86
100	1	0.86

Wartime – 38x89 BLOWN-IN vs. 38x89 BLOWN-IN WINDOWS:

Retrofit cases from the Wartime archetype were modeled next. The first was 38x89 BLOWN-IN and the second was 38x89 BLOWN-IN WINDOWS. The only difference between the two cases is that 38x89 BLOWN-IN WINDOWS case replaces the original windows with sealed, double-glazed units. Their energy intensities are 221 and 209kWh/m^2 respectively.

Table 6.22 – Results from the retrofit ranking equation for the Wartime archetype

Life Cycle	38x89 BLOWN-IN	38x89 B-IN WIND.
Years: 1	0.31	1
10	0.72	1
20	0.8	1
60	0.86	0.99
80	0.87	0.98
100	0.88	0.98

In this comparison the 38x89 BLOWN-IN WINDOW case is the better option environmentally through the range of life expectancies.

70s OBC – 38x89 BLOWN-IN + ACH vs. POLYURETHANE:

The next pair of retrofits to be compared are 38x89 BLOWN-IN + ACH and POLYURETHANE from the 70s OBC archetype. The first has an energy intensity of 222kWh/m^2 and the second is at 141kWh/m^2. At a difference of 81kWh/m^2 this is the case with the largest spread in operating energy.

The first case, 38x89 BLOWN-IN + ACH, has 38x89, batt-filled walls on the main floor combined with semi-invasion air sealing around the house. To account for the air sealing a quantity of polyethylene sheet and polyisocyanurate foam were input into Athena. The second case, POLYURETHANE, has more marked reductions. Its retrofit includes a thermally broken 38x140 polyurethane foundation wall, 38x140 polyurethane main wall, and XPS slab insulation.

Table 6.23 – Results from the retrofit ranking equation for the 70s OBC archetype

Life Cycle	38x89 B-IN +ACH	POLYURETHANE
Years: 1	0.33	1
10	0.8	0.91
20	0.84	0.83
60	0.89	0.77
80	0.9	0.76
100	0.9	0.75

In this case, the environmentally superior option changes with the length of the life cycle. For life cycles under 20 years it appears to be better to use the 38x89 B-IN +ACH case. For expected life cycles of 20 years or more the POLYURETHANE case is superior.

Modern – BEL. 100 BLOWN-IN vs. 38x140 POLYURETHANE:

The last pair of retrofits to be tested are the Modern BEL. 100 BLOWN-IN at 162kWh/m^2 and 38x140 POLYURETHANE at 189kWh/m^2. The energy intensity spread between the two cases is 24kWh/m^2. The first case, BEL. 100 BLOWN-IN, attempts to reach the targeted 100kWh/m^2 for heating and cooling without using polyurethane. As previously mentioned, during modeling attention was paid to ensure polyurethane and non-polyurethane options were modeled to provide choices for homeowners. The main and foundation walls are thermally broken, batt-filled 38x184 walls. The slab is insulated with XPS filled, 38x64 framed flooring and the windows have been replaced with heat mirror units. The second case, 38x140 POLYURETHANE, includes only thermally broken, polyurethane-filled 38x140 main walls.

Table 6.24 – Results from the retrofit ranking equation for the Modern archetype

Life Cycle	BEL. 100 B-IN	38x140 POLYUR.
Years: 1	0.28	1
10	0.55	1
20	0.61	1
60	0.69	1
80	0.70	1
100	0.71	1

In this retrofit comparison the BEL. 100 B-IN option is superior for all life cycles. The 38x140 POLYURETHANE case has the higher environmental effect throughout the life cycle as demonstrated by the constant value of one from the ranking equation.

7 DISCUSSION

7.1 The Four Archetypes

The four archetypes modeled represent different vintages and construction practices. As such, it is expected that they will perform differently from an operational energy perspective.

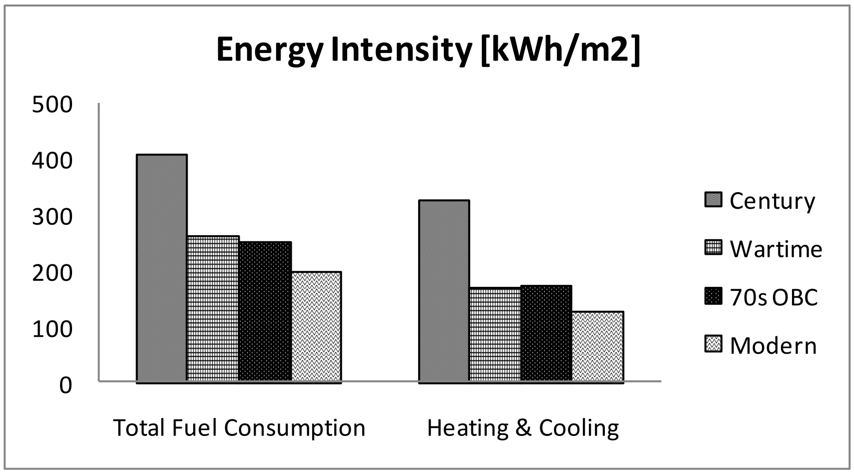


Figure 7.1 - Base case energy intensity for each of the archetype houses.

Looking at the two most extreme results, the Modern home uses only 48% as much energy per unit area as the Century home. This is in line with expectations because the RSI-value difference between the two cases is approximately a factor of 2. However, the energy intensity of the Wartime and 70s OBC archetypes are also much lower than the Century home. Partially, this is attributable to the differences in thermal resistance. The Wartime and 70s OBC have RSI values of 1.41 and 1.71 respectively, compared with 1.11 in the Century house. The second major parameter of heat loss in the Century case is ventilation. At 11.24 the ACH rate for the Century house is 1.5 times that of the Wartime home (7.50 ACH) and 1.95 times that of the 70s OBC (5.75 ACH). The heat loss from these two parameters, walls and ventilation, is two to three times larger in the Century home than in the other two archetypes.

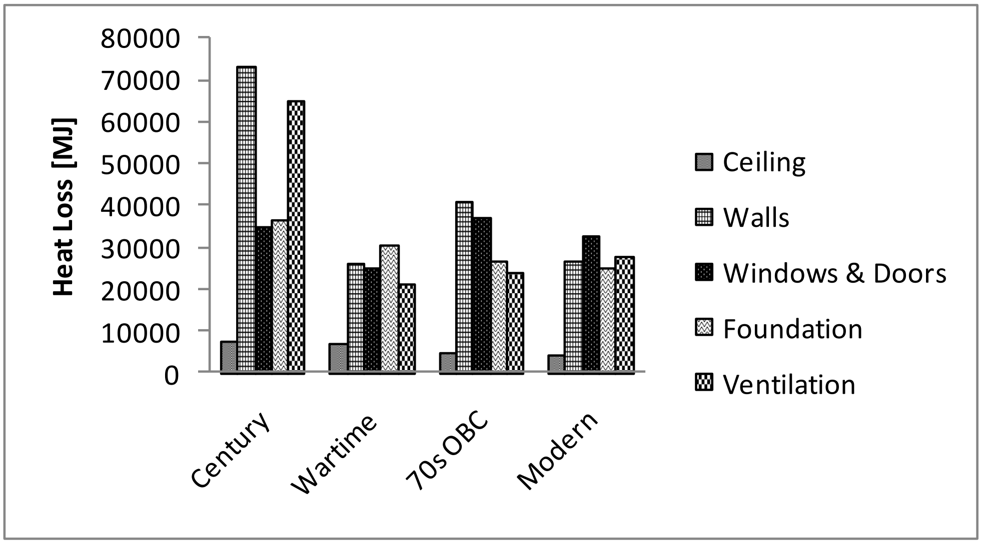


Figure 7.2 - Base case heat loss through the five parameters - ceiling, walls, windows & doors, foundation, and ventilation - for each archetype.

HOT2000 heat loss results are easily divided into five main building envelope parameters: ceiling, walls, windows & doors, foundation, and ventilation. As can be seen from the figure above, the majority of heat loss occurs through the walls and ventilation in the Century home. The Wartime, 70s OBC, and Modern homes have more closely clustered parameters. One parameter, the ceiling, is consistently low. At 3-6% of heat loss, the ceiling is a minor component in all archetypes.

7.1.1 Century

The Century archetype is a tall, narrow home with uninsulated, double-wythe brick walls. Heat loss through the envelope is dominated by the main walls. The reason for this is the geometry of the home. The main walls have an area approximately 1.5 times greater than the foundation, 4 times greater than the ceiling and 11 times greater than the windows. Despite the much lower thermal resistance of the windows, 0.24RSI compared with 1.11RSI, the order of magnitude difference in their surface area ensures the main walls dominate.

The one parameter without a comparable surface area, ventilation, is the second largest cause of heat loss. The Century house is modeled as an old, leaky building with an ACH rate of 11.24. At this rate, 3-4 times a common modern rate (ecoENERGY, 2010), a lot of heat is lost through air leakage as can be seen in the magnitude of the heat loss numbers. For the base case this is at 64,754MJ compared with 73,062MJ for the dominant main walls and around half as much each for the foundation and windows & doors.

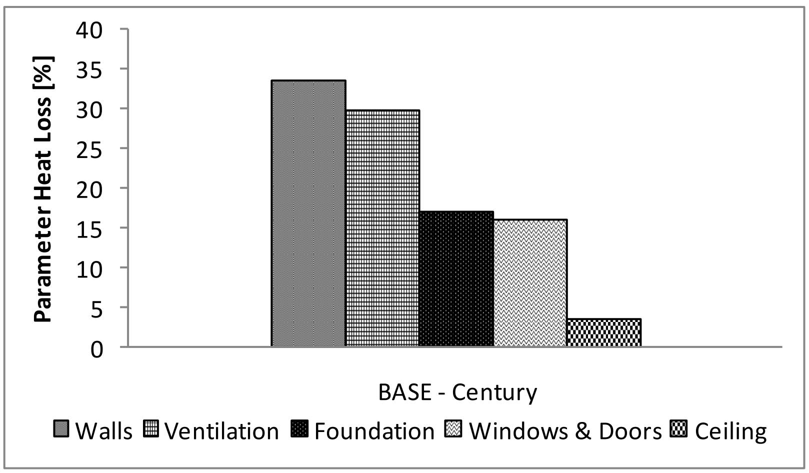


Figure 7.3 - Century base case heat loss through the five parameters

These results clearly show that the priorities for an owner of the Century home should be main wall insulation and air sealing. However, due to the nature of the main walls, insulation would need to be added to either the interior or exterior of the walls. Due to the Torontonian's ongoing preference for brick (Maclean-Hunter, 1945) homeowners are reluctant to cover up this material. This shifts the location of the insulation to the interior space. Here, too, homeowners are reluctant to add insulation since every inch added is an inch of interior space lost. In larger homes and/or larger rooms the homeowners may still choose to sacrifice some interior space for better energy performance, but this is not feasible in all cases. Hallways and stairwells in particular are often narrow in Century homes and cannot afford to lose 102 to 152mm of space to insulation. One possible solution would be to move the stairs, allowing room for the insulation.

To demonstrate the operational performance differences that can be obtained when main walls are specifically included or excluded as part of conventional, common retrofits, two of the modeled cases were chosen. The first case, 38x89 BATT, assumes the homeowner is willing and able to lose 102mm of interior space to improve energy performance. The second case, FOUND. + ACH+ assumes the homeowner is not willing or cannot insulate the main walls and instead shifts focus to the ventilation and foundation parameters. This case involves finishing the basement, including a batt-filled 38x89 wall, and professional air sealing in conjunction with blower door verification.

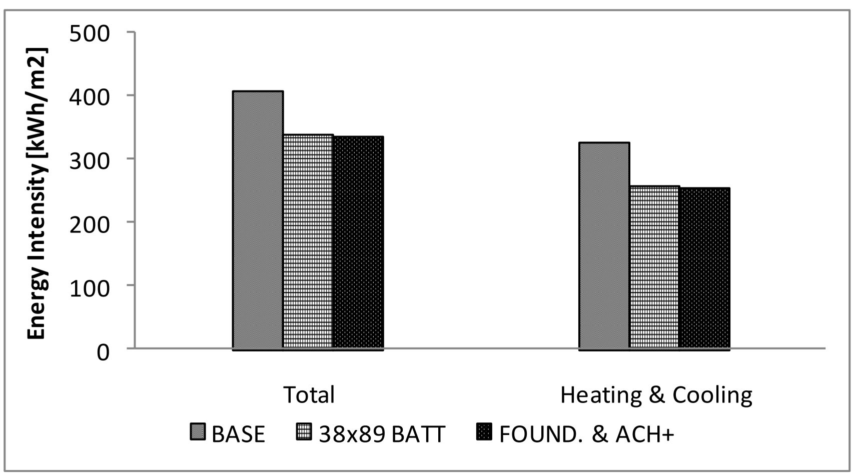


Figure 7.4 - Energy intensity comparison of the Century base case, 38x89 BATT, and FOUND. & ACH+ cases.

As can be seen in the figure above, the two retrofit options result in approximately the same energy performance, a reduction of about 20% from the base case. This result illustrates the idea that there are many ways to reach the same energy intensity level. Providing information to homeowners on effects associated with the myriad of options with the same energy intensity will allow them to identify the best option from an environmental standpoint. This can then be combined with other decision criteria such the feasibility of the retrofit, cost, disruption time and any other factors the homeowner chooses to consider, to give a more comprehensive result from the retrofit.

The next retrofit case for consideration is WINDOWS. This retrofit was chosen due to its prevalence in mass media and popularity with homeowners. The retrofit involves nothing more than replacing the existing windows, assumed to be old and leaky, with conventional modern double-glazed, argon-filled units.

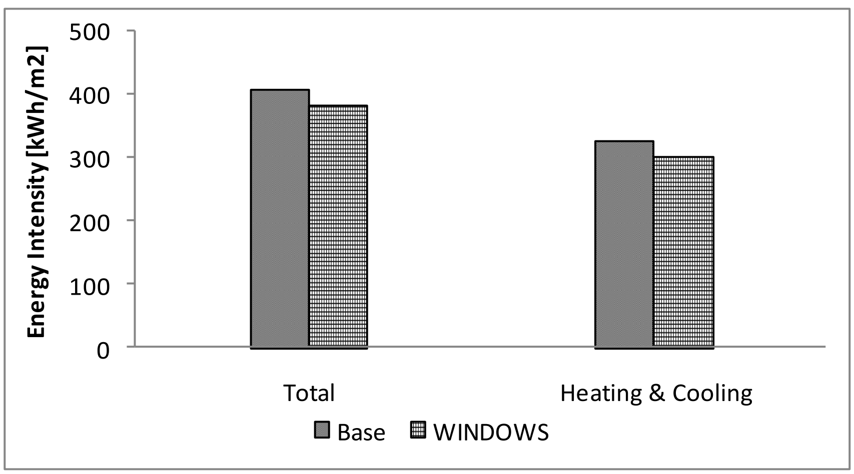


Figure 7.5 - Energy intensity comparison of the Century base and WINDOWS cases

Window replacement reduced energy intensity by 6%. If the windows are replaced with the better performing heat mirror units a further improvement is made, from 383 to 373kWh/m^2, but this is also not a significant reduction. As mentioned previously, the main walls and ventilation parameters are overwhelmingly dominant in the Century archetype. Therefore, making improvements to parameters with a small contribution to heat loss will have an equally small contribution on overall energy performance. At times it is possible to insulate a portion of the wall during widow replacements. Any such effort would result in a further improvement to energy intensity.

The above cases are examples of conventional retrofit cases. 38x89 walls filled with batt insulation are an industry standard, as are sealed, double-glazed windows. Comprehensive air sealing, while not the most common retrofit, is simply an expansion of draftproofing, with which homeowners are familiar. To reduce energy intensity to at or near the 100kWh/m^2 target, more complete retrofits will need to be undertaken. The next two retrofit cases discussed do not reach the 100kWh/m^2 target, but do approach it. The reductions in energy intensity over the base case are slightly larger than 50%.

The next case, COMBO+ CONT., assumes that the homeowner is unwilling or unable to insulate the main walls. All other parameters are exhausted, within the limits of the scope of this work, to achieve the best energy performance possible without insulating the main walls and thereby losing interior floor space. Insulation is added to the ceiling, the doors are replaced with polyurethane core doors, the windows are replaced with heat mirror windows, the foundation wall and slab are insulated, and air sealing measure are undertaken. The second case, 38x64 ICYNENE+, assumes the homeowner is able to sacrifice 64mm of interior space. The main walls are spray foamed with Icynene, windows are replaced with conventional sealed, double-glazed units, the foundation wall is insulated, but the slab is left uninsulated.

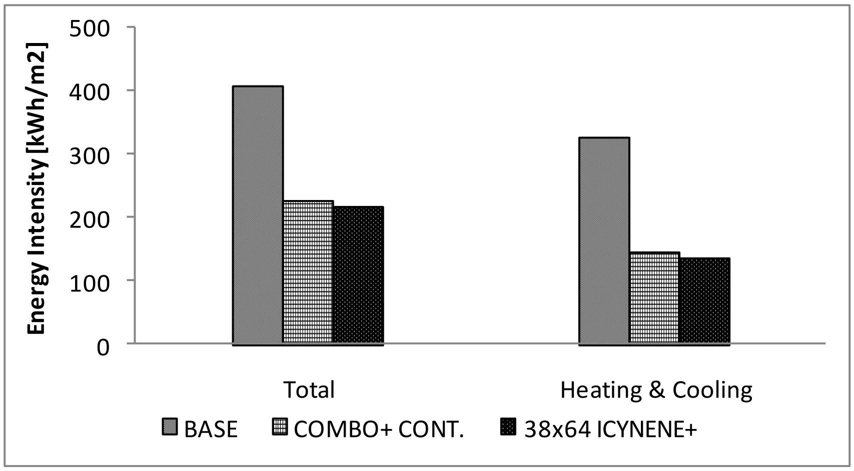


Figure 7.6 - Energy intensity comparison of the Century base case, COMBO + CONT., and 38x64 ICYNENE + cases

Both of these retrofit options reduce the total energy intensity by at least 45%. When domestic hot water systems and appliances are excluded and only the heating and cooling loads are considered, the reduction in energy intensity is 55%. These cases serve to illustrate two points. The first, as previously mentioned, is that there are many different ways to get to the same operating energy performance. In such cases the embodied effects of the retrofit should be considered when choosing between options. This is analyzed in Section 6.2.2 – Operationally Equal.

The second is that without insulating the main walls, the Century archetype will not reasonably meet the 100kWh/m^2 target. The COMBO+ CONT. case is exhausted with few exceptions. The ceiling spaces are filled with polyurethane insulation. Since polyurethane has the best RSI-value per inch, no further improvements will be made within the ceiling space. The windows are high performance, heat mirror units. There are slightly better units available, but the difference is small enough so as to be negligible when considering the 100kWh/m^2 target. Air leakage is at 1.8ACH. This low value is difficult to achieve in retrofit situations and it is not reasonable to expect much further gain. There is some flexibility in how much insulation is added to the basement walls and slab, but ranked third at 20% of heat loss, the gains here would be small as well.

The 38x64 ICYNENE+ case, in contrast, has only one exhausted parameter: ventilation. There is no additional insulation in either the ceiling or the slab. The windows are sealed, double-glazed units and switching to a heat mirror window with a better performance would cut their losses roughly in half. Also, if the homeowner is willing and able, more than 64mm of insulation can be added to the main and basement walls. Or, if space is at a premium beyond 64mm, the insulation material can be switched to polyurethane which has a higher RSI-value per inch than Icynene. Continuing to retrofit the 38x64 ICYNENE+ case can and does result in heating & cooling energy intensity values at and below the targeted 100kWh/m^2.

7.1.2 Wartime

The Wartime archetype house is a small, one-storey rectangle with a hip roof and full basement. It is the only single-storey home in the four archetypes, making its geometry unique. It is compact and has only about half of the exposed main wall surface area as the other archetypes. The foundation, which includes the foundation walls and slab, is the largest surface area. It is almost twice as large as the main walls and slightly more than twice as large as the ceiling area. This geometry suggests that the foundation parameter will dominate heat loss and the modeled cases bear this out. A second reason to expect the foundation to account for the greatest portion of heat loss is the fact that the foundation walls and slabs are lightly or not at all insulated, compared with the main walls and ceiling. The modeled cases bear out this expectation, with the base case foundation accounting for 28% of heat loss and foundations remaining either the first, second, or third largest parameters for heat loss in all the retrofit cases.

The main walls and ceiling are nearly comparable in surface area, with the main walls approximately 25% larger than the ceiling. Even though the surface areas are roughly similar they have very different contributions to heat loss. The ceiling, with an RSI value of 3.66, has a much smaller role than the 1.41–2.30RSI walls. In early stage retrofit cases, the ceiling plays an almost insignificant part in the overall heat loss equation. However, once heat loss via the other parameters is addressed to some extent, the ceiling begins to be noticeable. While it never becomes even the fourth highest heat loss parameter, it ranges between 13 and 18%, approaching the 20% mark at which all five parameters break even. Of the four archetypes it is with the Wartime home that the parameters converge most.

Another point to consider is that due to its small, conservative design, total energy use is the lowest of all the archetypes. The house itself is listed as a compact 100m^2 home. Including the basement, which is generally finished and used as living space its total heated floor space is 182m^2. There are not many windows and those that are present are not particularly large. In fact, this archetype has the smallest glazing percentages – 20% for the front, 8% for the sides, and 15% for the rear – of all the archetypes. All these factors give the home an advantage in terms of energy performance. Comparing its energy intensity across the four archetypes – Century 408, Wartime 263, 70s OBC 251, Modern 199kWh/m^2 – shows that these conservative factors have an effect. The Wartime home has an energy intensity that is only 14% worse than the archetype home built to the 2006 OBC.

To follow the stated methodology of addressing the parameter with the highest proportion of heat loss, the foundation walls were chosen. The BATT FOUNDATION case is the first retrofit applied to the base case and adds a 38x89, batt-filled wall in the basement. The header space from the main floor, generally accessible from the basement, is filled with fiberglass batt as well. Lastly, a small adjustment is made to the ACH rate, lowering it from 7.50 to 6.75, to account for the slight air sealing benefit of insulating the basement and header.

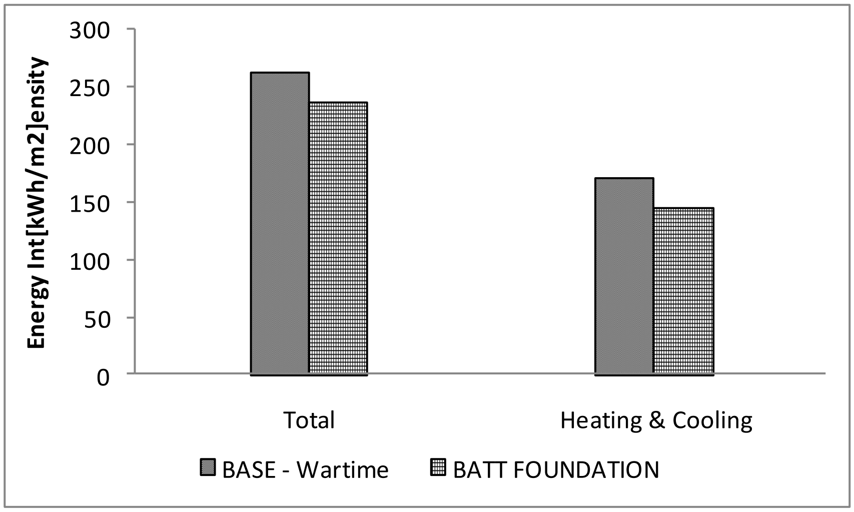


Figure 7.7 - Energy intensity comparison of the Wartime base and BATT FOUNDATION cases.

The resulting energy intensity was 237kWh/m^2, or an improvement of 10%. It is convenient that this retrofit closely resembles a Wartime home with a conventional finished basement because these homes almost exclusively have had their basements finished (I. Teodorescu, personal communication, May 18, 2010). Whether insulation was included in the finished basements is up to debate, but it is safe to say that the operational performance of a typical Toronto Wartime home would fall between the base case 263 and the BATT FOUNDATION 237kWh/m^2.

The next two cases have been chosen to illustrate the difference between an uninsulated and insulated slab. In the 38x89 B-IN WINDOW case, the main wall cavities are filled with blown-in cellulose, the windows are replaced with conventional sealed double-glazed units, and the basement is finished with a 38x89, blown-in cellulose filled wall. Adjustments are made to the air leakage characteristics to reflect these changes as per the air sealing chart developed. The foundation slab remains uninsulated. This case is meant to show the level of energy intensity that can be reached with a thorough, but conventional retrofit.

To contrast the 38x89 B-IN WINDOW case the 38x89 B-IN SLAB retrofit case has been selected. These cases are identical except for the floor slab. In the 38x89 B-IN SLAB case the foundation slab is insulated with XPS set in a framed, 38x64 floor.

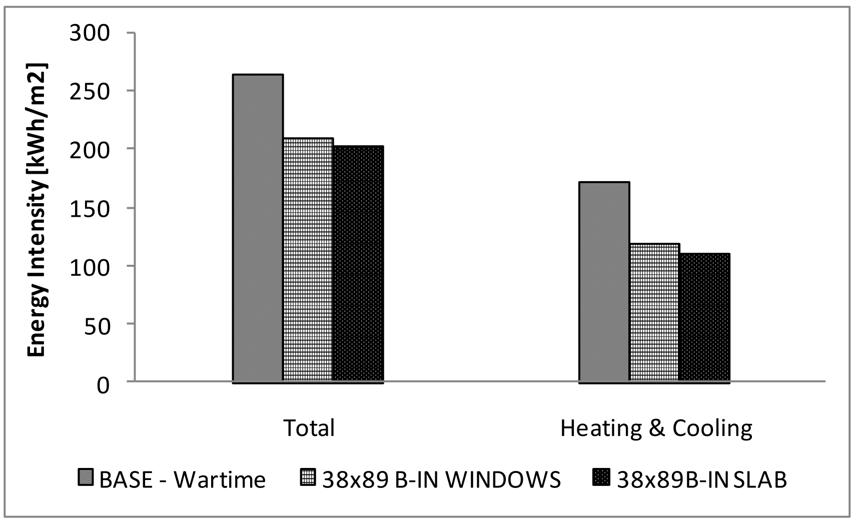


Figure 7.8 - Energy intensity comparison of the Wartime base case, 38x89 B-IN WINDOWS, and 38x89 B-IN SLAB cases.

The energy intensity of the 38x89 B-IN WINDOWS case changes from 209 to 201kWh/m^2 when the slab is insulated. The heat loss through the foundation drops 23%, which is a good result considering the foundation parameter includes the surface area of the walls as well as the slab.

The 38x140 B-IN CASE is meant to illustrate potential retrofit savings without resorting to polyurethane insulation or losing interior floor space. Both the 38x89 main and 38x140 foundation wall cavities have been insulated with blown-in cellulose, the windows have been replaced with heat mirror units and the doors with steel polyurethane doors. Also, semi-invasive air sealing was undertaken during the retrofit dropping the ACH rate, as per the air sealing chart, to 2.85.

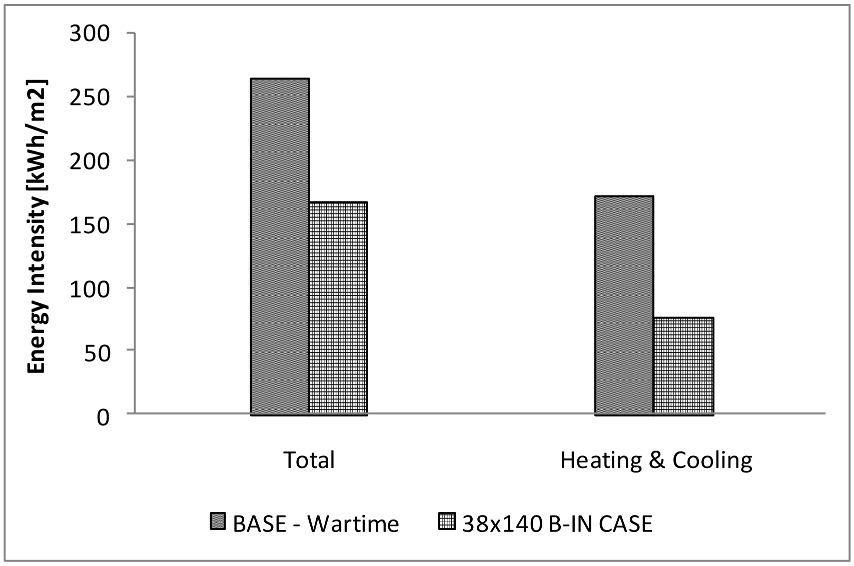


Figure 7.9 - Energy intensity comparison of Wartime base and 38x140 B-IN CASE.

38x140 B-IN CASE shows that you can achieve an energy intensity of 166kWh/m^2, or an improvement of 37% over the base case, without losing any interior space on the main floor or using polyurethane foam. If only heating and cooling are considered, the energy intensity is 75kWh/m^2 and well below the targeted 100kWh/m^2. Approximately half of the retrofit models from the Wartime case have heating and cooling energy intensities of below 100kWh/m^2, showing that for this home it is not unreasonably difficult to achieve good energy performance.

The final case highlighted for consideration is 38x140 MAIN WALLS. In this case many of the parameters have been exhausted and the homeowner has used 51mm of interior floor space to allow for additional insulation. The windows have been replaced with heat mirror units and the doors with steel polyurethane core doors. Both the main and foundation walls are polyurethane-filled 38x140 walls and the foundation slab is insulated with XPS boards set in a 38x64 flooring frame. The air leakage rate, at 1.9ACH, reflects the widespread use of spray foam as an air barrier and also replacement of the windows.

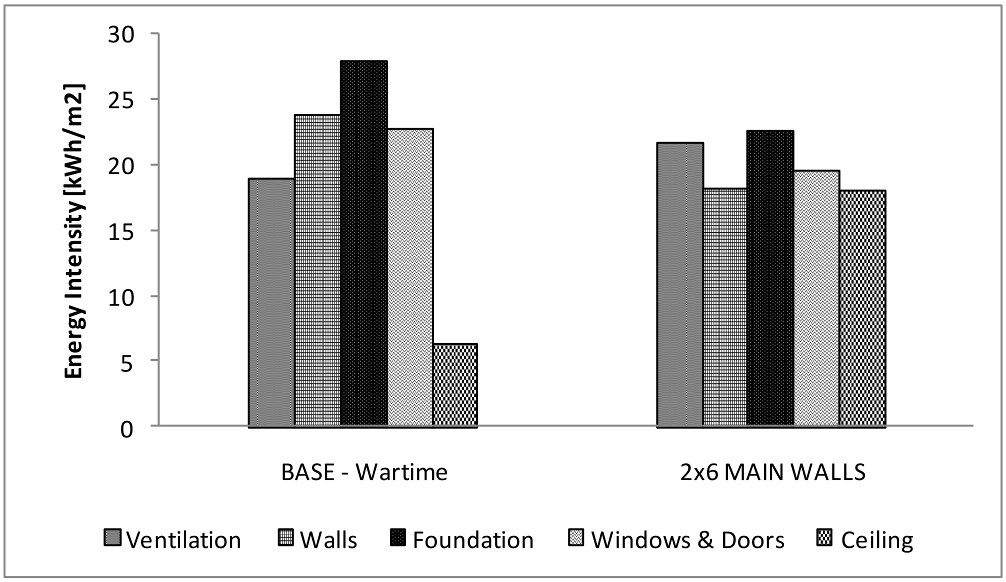


Figure 7.10 - Heat loss through parameters in the Wartime base and 38x140 MAIN WALLS cases.

This case was chosen to show that in the Wartime archetype all five parameters can be made to converge. They range from 18 to 23%, meaning that they all contribute roughly equally to heat loss and at this point there is no obvious parameter to target for further reductions. The parameter with the highest portion of heat loss is the foundation, second highest is ventilation. This is understandable due to the high surface area of the foundation and to the fact that ventilation cannot be further improved as per the air sealing chart.

7.1.3 70s OBC

The 70s OBC house is a two-storey rectangle with geometry similar to the Century house. The surface area of the main walls is greater than that of the foundation by a factor of 4:3 and the ceiling by a factor of 3:1. Once again, these geometry effects are helpful in explaining the order of heat loss parameters. Main walls, with the greatest surface area and low RSI-value are the biggest component in heat loss at 31%, followed closely by windows & doors at 29%. Foundation and ventilation are a step down at 20% and 18% respectively and, predictably, ceilings are last at 4%.

The 70s OBC archetype is the only one where windows & doors play a top role in heat loss. The parameter stays within the top three for all modeled cases. As previously discussed in the section on archetype development, this construction period was one of ever larger glazing areas. The 70s OBC house has the largest glazing surface area as a percentage of all the archetypes. The 22m^2 of glazing provide the house with a "modern, open feel" (Maclean-Hunter, 1945), but at a cost to the homeowner of lost energy. For this reason, of the four archetypes, 70s OBC homeowners should consider window replacement most seriously.

During this construction period building standards and particularly levels of insulation increased. One of the effects that can be seen during modeling is the diminishing returns from insulating the main wall cavity. Since this cavity starts at RSI-1.71 as per the ecoENERGY database, not much improvement is seen when bringing the cavity space up to an equivalent 38x89 batt-filled wall because the wall RSI-value is only altered to around RSI-2.25. The starting thermal resistance was higher, therefore there is less room for improvement before the thickness of the walls needs to be increased.

Two cases were selected for discussion about air sealing and the resulting changes to heat loss to the ventilation parameter. The first is 38x89 BATT + ACH, the second 38x89 ICYNENE + ACH. The only retrofit made in both cases is the insulation of 38x89 main walls, with fiberglass batt for the first case and Icynene for the second, and the associated changes in air leakage rates.

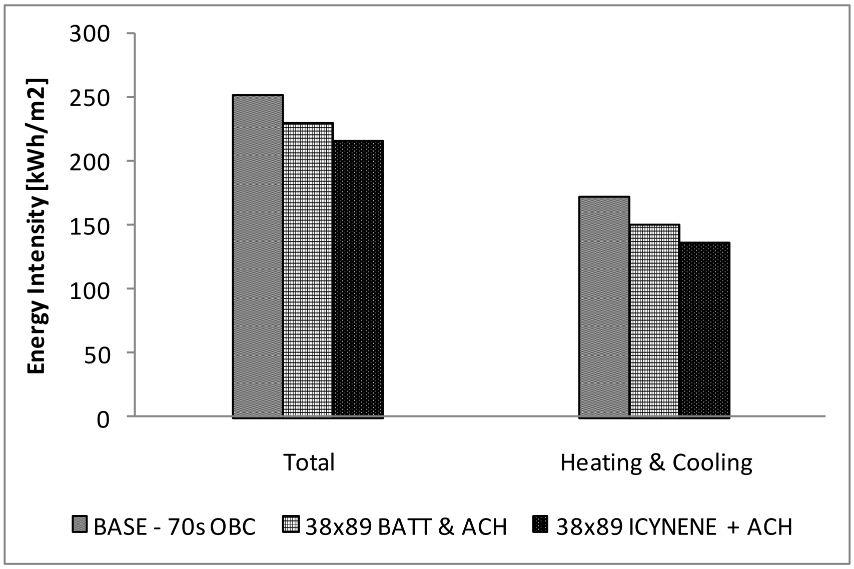


Figure 7.11 - Energy intensity comparison of 70s OBC base, 38x89 BATT & ACH, and 38x89 ICYNENE + ACH cases.

The 38x89 BATT + ACH and 38x89 ICYNENE + ACH have similar RSI-values, R-3.5 for fiberglass batt and R-3.6 for Icynene, but different air leakage rates. With semi-invasive air sealing measures the fiberglass batt case has an ACH of 3.74. If Icynene is used instead, the air leakage rate drops to 2ACH. In other respects these cases are equal. Therefore the difference in energy intensity, between 229 and 215kWh/m^2, 6%, is attributable to the tightness of the building envelope. Looking at heat loss due to ventilation the difference is 20,680MJ compared with 12,644MJ for the Icynene case. This is an improvement of almost 40%.

The next two cases compared the effect of insulating the foundation walls with insulating the foundation slab. Both the 38x140 FOUNDATION and 38x64 SLAB cases have 38x140 Icynene walls and headers, heat mirror windows, and identical air leakage rates of 2ACH. Where they differ is foundation insulation. Both cases start at 38x89 Icynene walls. The 38x140 FOUNDATION case adds 51mm more Icynene to get a thermally broken, double-stud equivalent 38x140 wall. The 38x64 SLAB case, on the other hand, adds 64mm of XPS over the floor slab. In both cases the amount of insulation added is roughly the same, 51mm to 64mm, and the heat loss surface areas are similar, 95m^2 for the walls and 70m^2 for the slab.

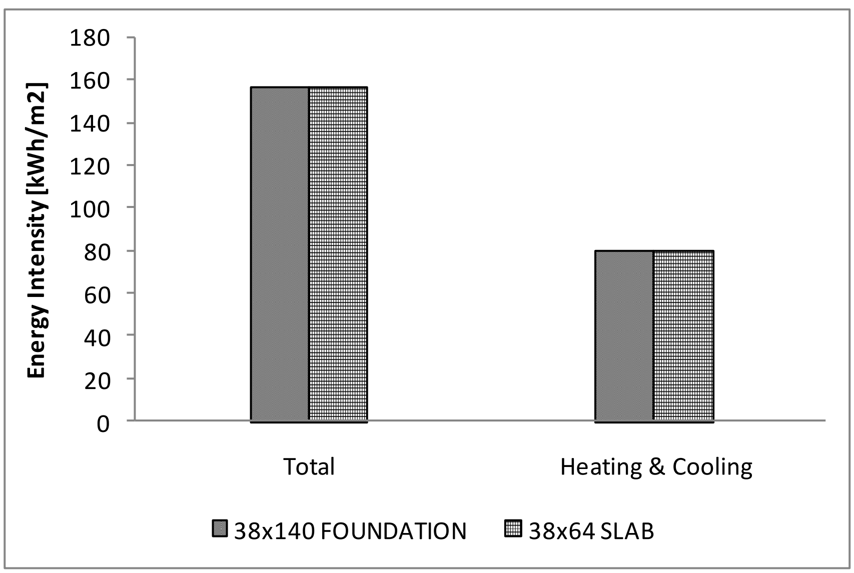


Figure 7.12 - Energy intensity comparison of 38x140 FOUNDATION and 38x64 SLAB cases.

While basement wall insulation is common and typically part of finishing a basement, fewer basement renovations involve slab insulation. From the results it would appear that there is not a strong argument from an energy performance perspective to select one over the other. A homeowner can choose whether they would prefer to lose a few inches in floor area or from overhead height. Another thing to note is that since each of the insulation retrofits – walls and slabs – reduces heat loss by approximately 4,000MJ, by insulating both the homeowner receives the cumulative effect.

The final case in the discussion is the POLYURETHANE+ case. The intention of this case was to push the energy intensity down dramatically, but still within the general retrofit guidelines of this report. To this end the windows were replaced with heat mirror units, steel polyurethane-core doors are retrofitted, the main walls, foundation walls and headers are thermally broken, 38x140 polyurethane walls, the 38x64 XPS slab has been added, and the air leakage rate was set to a tight 2ACH.

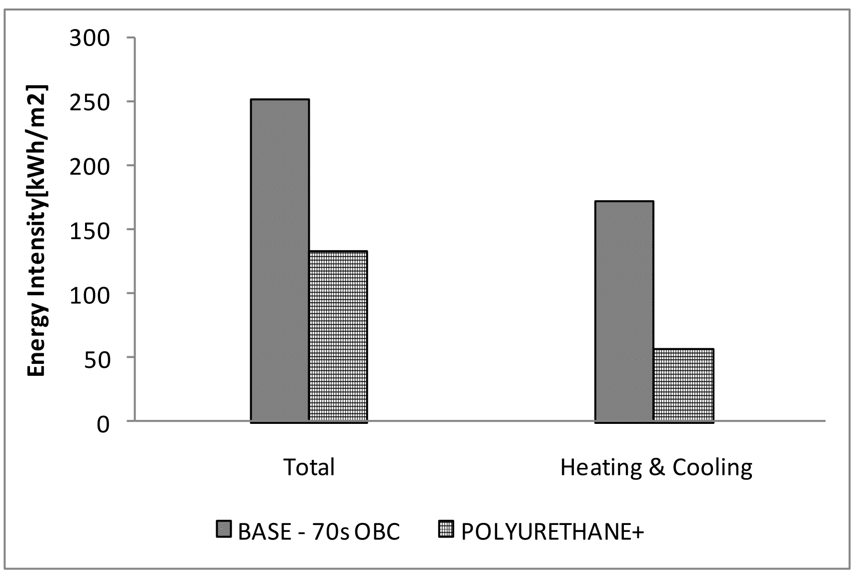


Figure 7.13 - Energy intensity comparison of 70s OBC base and POLYURETHANE+ cases.

As expected, the energy intensity dropped significantly after these intensive retrofits. This case has a total energy intensity of almost half the base case. When the heating and cooling alone is considered, the savings are more dramatic; this case uses only one-third of the energy required in the base case. This difference, between one-half and one-third, serves to illustrate an important point. While the intent of this report is to show a thorough and comprehensive whole-home energy intensity, it is useful at consider only heating and cooling energy intensity when dealing with building envelope retrofits that affect, quite specifically, heating and cooling.

7.1.4 Modern

The Modern archetype house is a 2-storey, brick veneer, L-shaped structure. It is the largest of the archetype homes, with a total heated floor area of 239m^2. A unique element for this archetype is the ground-level, attached garage and resulting partly submerged basement.

Modeling of the main walls begins at RSI-2.9 in the Modern archetype. Taken on its own, an RSI-2.9 wall has more thermal resistance than a standard batt-filled 38x89 stud wall. Compared with the other archetypes, a wall RSI of 2.9 was considered an intermediate retrofit. This limits the retrofit potential of the main walls. Either the existing 38x89 cavity can be insulated with polyurethane, which has a higher RSI/mm, or the wall thickness will need to be increased for the thermal performance of the main walls to be improved.

Another parameter that starts the base case near its best attainable level is air leakage. The Modern base case has an ACH rate of 3.42, which was near the optimal attainable, the improvements to be expected from retrofits are smaller. The improvements attainable in ACH rates, for example, are minimal and require intensive retrofits due to the fact that an air barrier is installed during construction.

For homeowners this means that there is no "low-hanging fruit" available for retrofits. Retrofits that will have a material impact on a Modern home will be more invasive and intensive on average than for the other archetypes. The diminishing returns that the 70s OBC was starting to see have become more pronounced. However, as the results of the retrofit modeling shows, there are still many ways to reduce the energy intensity of the Modern home to the $100kWh/m^2$ target.

Whereas older homes tend to have a single or double door (S. Yeates, personal communication, June 1, 2010) the Modern archetype house includes sliding glass doors wherever possible. It is not uncommon to find two sliding glass doors, one from a walk-out basement and the second from the main floor onto a deck, or one on the main floor plus one on the second floor opening onto a deck, as has been modeled in the Modern archetype. Sliding glass doors have a very different energy performance to a conventional hinged door. They essentially act like large, leaky windows.

To test the contribution two sliding glass doors make to overall energy performance of the Modern house the SLIDING GLASS retrofit case was developed. It is identical to the base case in all but the sliding glass doors at the rear of the building. These have been replaced with heat mirror units.

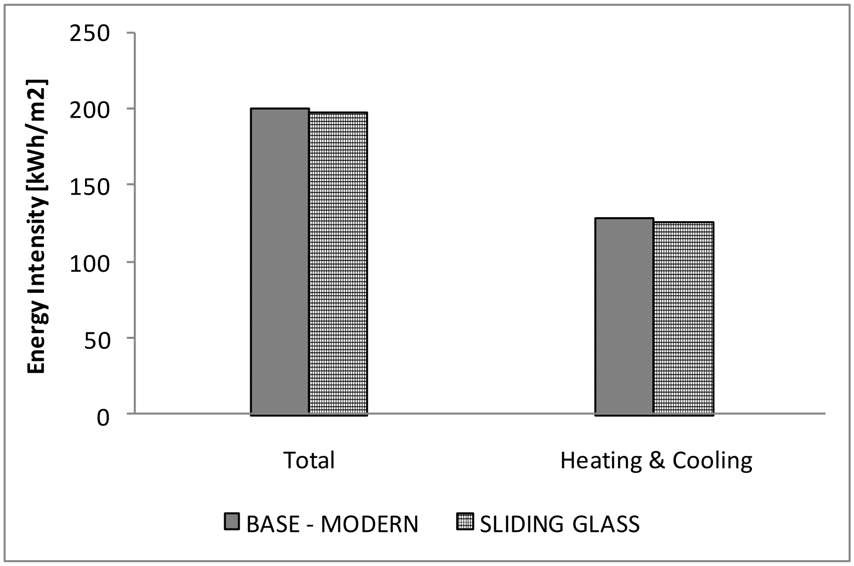


Figure 7.14 - Energy intensity comparison of Modern base and SLIDING GLASS cases.

Switching to heat mirror sliding doors saved 2kWh/m^2, or 3,848MJ. Considering that these doors are only 22% of the total glazing area, a heat loss reduction of 12% is a good result. One effect that was not readily quantifiable was the effect on air leakage rates with the installation of a new, better sealed sliding glass door. It may be presumed that the ACH reductions will fall somewhere in the vicinity of the 5-10% that was also used for replacements of old and/or leaky windows in the Century and Wartime archetypes. With a lower ACH rate, the energy intensity will drop further, resulting in this retrofit having a savings of 2kWh/m^2 or more. Alternatively, sliding glass doors can be replaced with a pair of hinged doors or one large hinged door and a side lite, etc. for even better energy performance.

The main heat loss components were windows & doors at 28% followed by ventilation, walls, and foundation walls all at 22-24%. Since the main walls of the base case already exceed a standard 38x89, batt-filled wall, the first sets of retrofits modeled worked with the other parameters. The ALL + F. + SLAB case has heat mirror windows and sliding doors, steel polyurethane-core doors, a 38x64 XPS insulated slab, 38x140 foundation walls insulated with blown-in cellulose, and an air leakage rate of 2.9ACH.

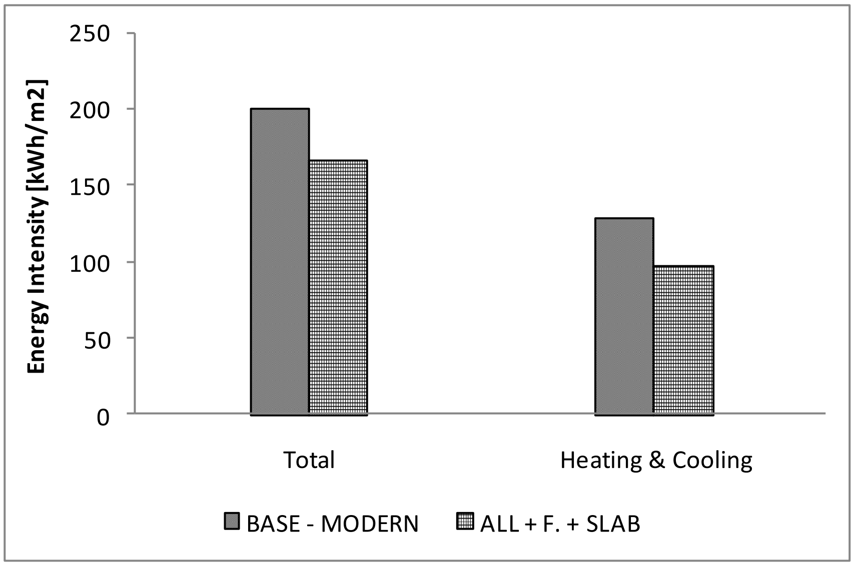


Figure 7.15 - Energy intensity comparison of Modern base and ALL +F. + SLAB cases

This retrofit case has a total energy intensity of 166kWh/m^2, compared with 199kWh/m^2 for the base case. It is a good proxy for a modern home retrofit option. The main walls are loosely equivalent to the 38x89 batt-filled wall that is the standard of Canadian construction in the Toronto area. The retrofits chosen by the homeowner are window and door replacements and a finished, insulated basement.

While this retrofit is fairly comprehensive, the window & door and foundation parameter heat loss in particular drops just over and just under half respectively, it just reaches the targeted intensity at 96kWh/m^2. To further reduce energy intensity, the heat loss through the main walls, 32%, and ventilation, 29%, would have to be tackled. Since the air leakage rate is already set to a low 2.9ACH, the onus falls on the main wall parameter. With such a large main wall surface area to surpass the 100kWh/m^2 target the main walls the Modern home would need more thermal resistance than a 38x89 batt-filled wall can provide.

This case is also a good example of the diminishing returns. Here these retrofits resulted in a 17% improvement in energy intensity. In the Century or Wartime archetypes this type of retrofit would reduce energy intensity on the order of 20-40%, because the starting point in those archetypes is lower so the difference between start and finish is larger.

The next two retrofit cases to be discussed are ICYNENE & FOUND. and BEL. 100 BLOWN-IN. Both exceed the heating and cooling energy intensity target of 100kWh/m^2. ICYNENE & FOUND. has thermally broken, 38x140 Icynene main and foundation walls, 38x64 XPS slab insulation, steel polyurethane-core doors, all heat mirror glazing units and an air leakage rate of 2ACH. To drop below 100kWh/m^2 the BEL. 100 BLOWN-IN case has all the retrofits of the previous case, but the 38x140 walls are upgraded to 38x1889mm walls to compensate for the difference in ACH rates. Since Icynene, at 2ACH, has better air sealing properties than dense-pack, blown-in cellulose, at 2.75ACH, the blown-in cellulose case needs more thermal insulation to be comparable.

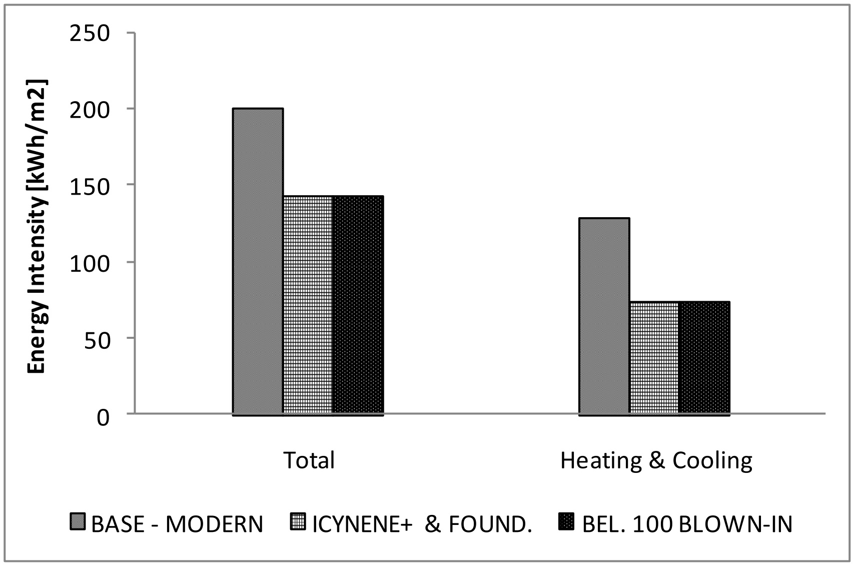


Figure 7.16 - Energy intensity comparison of Modern base, ICYNENE+ & FOUND., and BEL. 100 BLOWN-IN cases.

WINDOW TEST is the final retrofit case to be discussed. During modeling, two types of heat mirror windows were used. The glazing with a lower SHGC, HM66, was used on the sunny elevations while the higher RSI-value, higher SHGC glazing, TC88, was reserved for the north elevation. To test if this resulted in an optimal balance between solar gains and heat loss, the ICYNENE & FOUND. case described above was edited to have all TC88 glazed units.

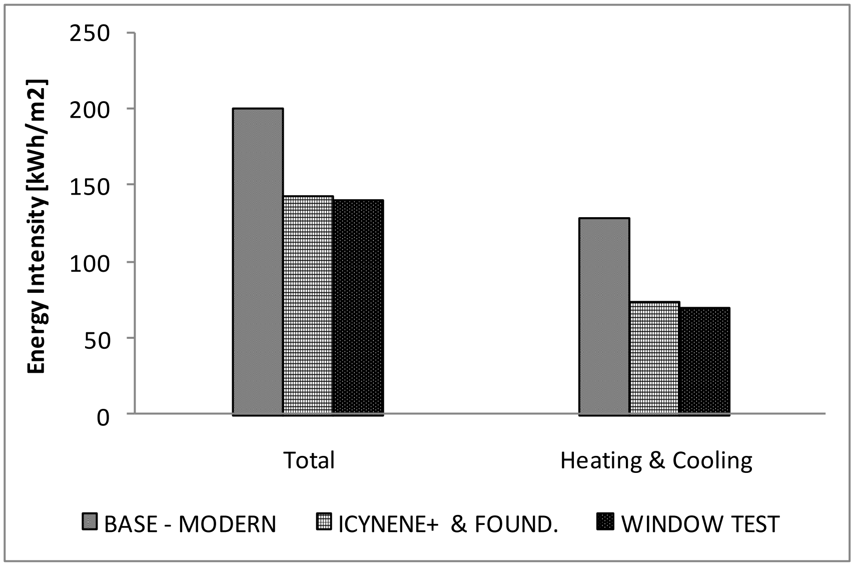


Figure 7.17 - Energy intensity comparison of Modern base, ICYNENE+ & FOUND., and WINDOWS TEST cases.

The results show better operational energy performance when all the glazing units are set to TC88 heat mirror. The difference in energy intensity is minor, 4kWh/m^2, but the edited glazing has a very small surface area so this is neither unexpected nor insignificant. It would appear that for this orientation at least, it would be better to use all TC88 glazing. The difference is small and orientation plays a big role in solar gains versus thermal losses, so further modeling would need to be conducted to verify this generalization.

7.1.5 Heat Loss through the Ceiling Parameter

The results consistently showed that ceilings are a minor component of heat loss through the building envelope in all four house archetypes. Since this is somewhat contrary to conventional wisdom additional modeling was done using the Wartime house; the archetype expected to have the highest ceiling contribution based on its geometry.

To start, the surface area ratios between the ceiling and main walls were 1:1.3 and between the foundation were 1:2.3. Based on geometry alone it would be expected that the heat loss through the main walls was approximately 30% higher than through the ceiling and approximately twice that of the ceiling through the foundation. For the base case the heat loss contributions were 6.3% for the ceiling, 23.8% for the walls, and 28.0% for the foundation, but the base case had a ceiling RSI of 3.7 compared with 1.4 for the main walls. When the RSI values are equalized, i.e. both ceiling and main walls are set to 1.4RSI, the heat loss proportions change to 13.2% and 21.5% respectively. At this point, the heat loss through the walls is 60% higher than through the ceilings instead of the 30% expected from geometry alone.

HOT2000 also uses a factor for buffer spaces such as attached garages and enclosed porches. This same principle, a semi-protected buffer space, applies in the case of ceilings as well. After removing the insulation factor (using 1.4 from the HOT2000 chart) from the ceiling's insulation value to equalize it to the walls the relative heat loss proportions change to 16.7 and 20.7%. The heat loss through the ceiling is 21,100MJ compared with 26,100MJ, well within the 1:1.3 surface area ratio.

The conclusion that can be drawn from this is that the assumptions on buffer characteristics associated with ceiling spaces in HOT2000 have a material effect on the results. These assumptions are embedded in the program and the results should be viewed with their effects in mind. It is not unreasonable to expect the ceiling component heat loss to be lessened by this buffer space for two main reasons. One, the ceiling space is slower moving and warmer than exterior air, both of which reduce rates of heat loss. Two, the ceiling surface is mostly sheltered from wind effects, which would also reduce the rate of heat loss.

7.1.6 HOT2000 Modeling Considerations

There are three inherent sensitivities in the HOT2000 modeling: house geometry, building envelope construction, and air leakage rates. House geometry was a guiding factor in showing which building components had the most heat loss. It had a pronounced effect on energy performance so it is important that the input values be reasonably accurate.

Building envelope construction defined levels of thermal insulation and so was integrally connected to the energy performance of the house. These inputs were taken from the ecoENERGY database and are considered very reliable.

Air leakage rates also had a significant effect on the energy performance of the archetype houses. The air leakage reductions modeled for the retrofit cases were taken from the air sealing table developed in this thesis specifically for this purpose. Due to the lack of published data on sequential air tightening the chart, as discussed in Section 5.1.2, had to be developed from interviews with industry experts. The combination of modeling sensitivity and a lack of tested and verified data on the effectiveness of air sealing measures suggests that there may have been some error introduced into the modeling. The approach employed in this research, using a panel of experts to develop expected reductions in air leakage, is reasonable and a first step towards further work. Future work should focus on sequential air tightening data for building envelopes, therefore removing the subjective element from the air leakage reduction expectations.

7.2 Ranking Retrofit Options

7.2.1 Beyond Energy

Up to this point much work has been done on quantifying energy use and performance. Operational energy, whether site or source, quantifies the amount of energy required to power a house and all of its systems. Embodied energy quantifies the equivalent energy that went into making a material, product or system. While both of these are good environmental metrics they are not comprehensive enough to show the full environmental effect of a house.

As previously discussed, there are a myriad of environmental effects from acid rain to eutrophication. While somewhat related to the concept of energy, these effects are not perfectly quantifiable by energy usage. This concept was illustrated by showing the environmental effects associated with an equivalent (from an operational energy standpoint) amount of four insulation materials.

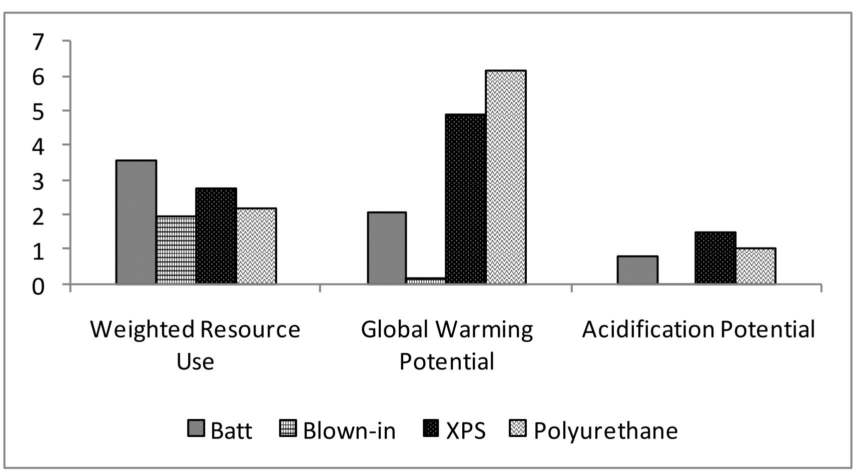


Figure 7.18 - A selection of environmental effects of the four insulation materials.

As can be seen in the figure above materials that result in the same operational energy performance can have very different environmental performance when other environmental effects are considered. Choosing to use polyurethane foam insulation instead of blown-in cellulose to achieve the same RSI-value uses 14 times the Primary Energy, produces 32 times the Global Warming Potential, 15 times the Acidification Potential, 10 times the HH Respiratory Effects Potential, 14 times the Eutrophication Potential, and 44 times the Smog Potential. The remaining effects, Weighted Resource Use and Ozone Depletion Potential, are similar in magnitude. This illustrates the importance of material selection from an environmental effects perspective.

7.2.2 Operationally Equal

This follows from the thought above that when operational energy is held constant the embodied effects should be used to sway a retrofit decision. When deciding on a retrofit the homeowner has several decisions to make. What end result they want to obtain, what materials they will use, where these materials will be placed, and in what quantity. There are any number of combinations that will meet an energy intensity target. From that point looking at the embodied effects can determine which retrofit is better from an environmental perspective.

Looking at the two operationally equal Wartime archetypes compared the figure below shows the relative portion of pollution that results from one of two retrofit options. For example, if the 38x140 B-IN FOUND. case is selected only 4% of the pollution that would have been released had the 38x89 B-IN + SLAB been chosen would be released.

Smog potential is measures in kg NO_x eq., ozone depletion in kg CFC-11 eq., eutrophication in kg N eq., human health respiratory effects in kg PM2.5 eq., acidification in moles H+ eq., global warming in kg CO_2 eq., weighted resource use in kg, and primary energy use in MJ.

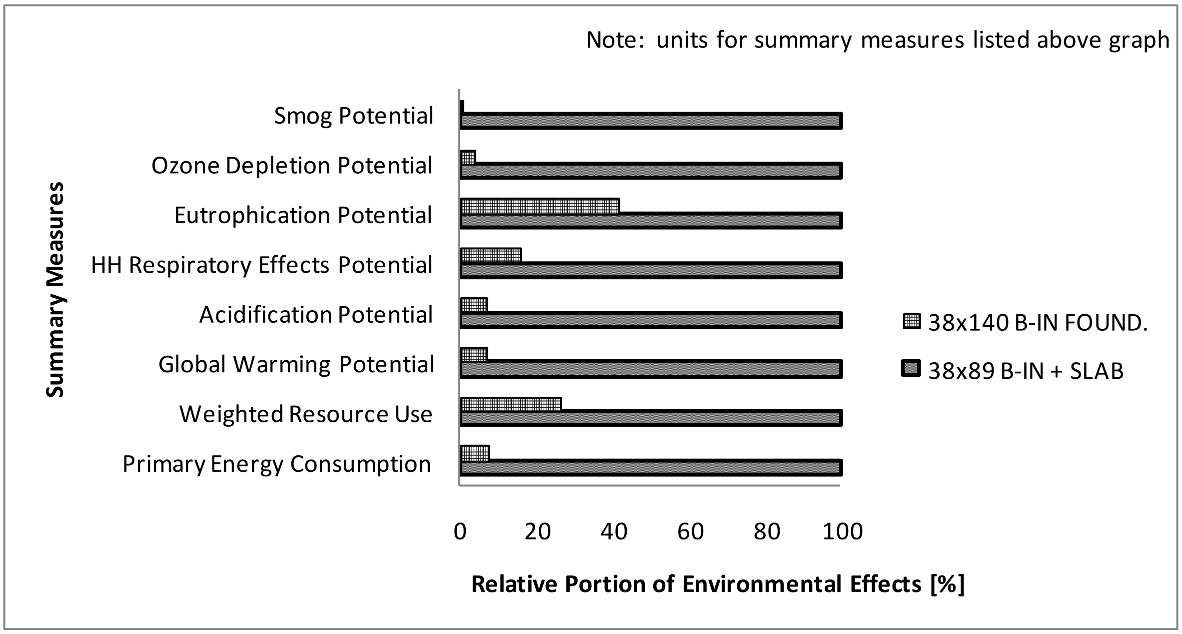


Figure 7.19 - The environmental effects resulting from choosing one or the other option plotted relative to one another. The negative environmental effects from the 38x140 B-IN FOUND. options range between one-tenth and one-half of those produced by 38x89 B-IN + SLAB

From the results it is evident that the 38x89 B-IN + SLAB case has a worse effect on the environment. It creates more pollution on every summary measure used by the Athena program. It is roughly 15 times worse than the 38x140 B-IN FOUND. case in terms of acidification, global warming potential, and primary energy consumption. The biggest difference is smog potential where the 38x140 B-IN + SLAB case produces only 0.5% of the kilograms of CFC-11 equivalents. Even thought the total volume of material used in the 38x89 B-IN + SLAB case is less, the negative environmental effects are significantly bigger.

The next figure compares the 70s OBC operationally equal cases discussed previously. In the figure smog potential is measures in kg NO_x eq., ozone depletion in kg CFC-11 eq., eutrophication in kg N eq., human health respiratory effects in kg PM2.5 eq., acidification in moles H+ eq., global warming in kg CO_2 eq., weighted resource use in kg, and primary energy use in MJ.

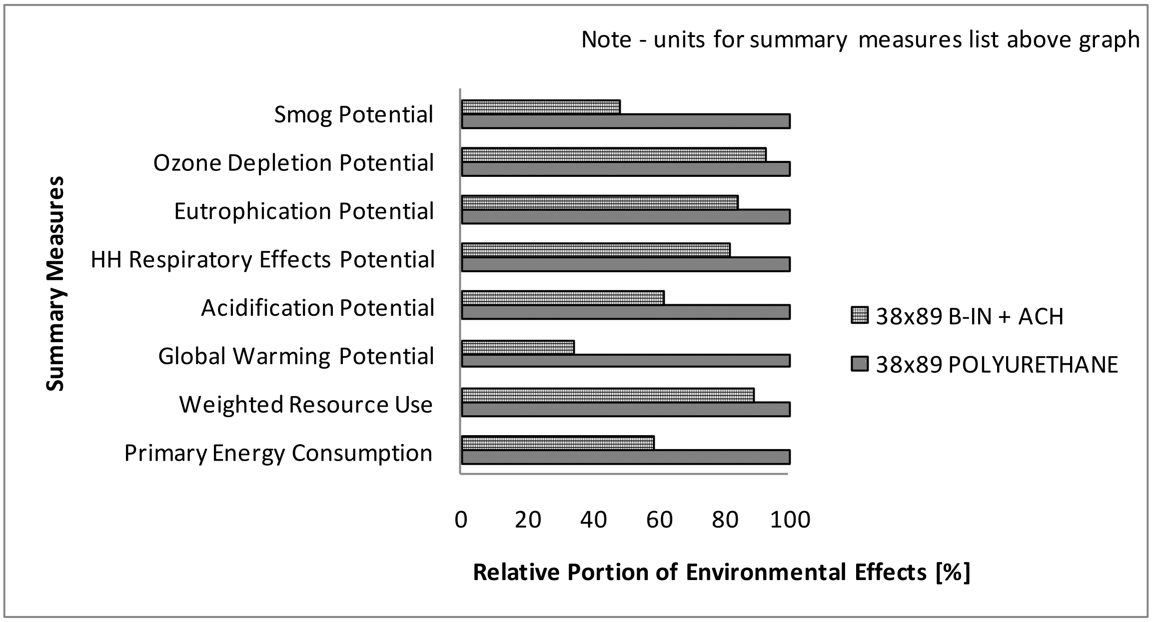


Figure 7.20 - The environmental effects resulting from choosing one or the other option plotted relative to one another. The negative environmental effects from the 38x89 B-IN +ACH option range between one-third and nine-tenths of those produced by 38x89 POLYURETHANE.

The 38x89 POLYURETHANE retrofit case is worse than the 38x89 B-IN + ACH on every environmental metric measured by the ATHENA Impact Estimator. If a homeowner were to select this option more pollutants would be released into the environment than if they had chosen 38x89 B-IN + ACH.

Comparing the two pairs of cases, for the Wartime and 70s OBC archetypes, one can see that each of the four retrofit cases has a unique environmental footprint. Some are worse from an acidification perspective, others are worse in terms of weighted resource use. An interesting question is how would a homeowner choose between such cases? A homeowner could look at an individual summary measure, eutrophication for example, to compare the retrofit cases, but there are eight summary measures and it is conceivable that there are retrofit cases where the results will be mixed; on some measures one option will be better, on other the other option will be better. It is for such cases that the retrofit ranking equation is most useful since it combines the environmental effects into one score.

7.2.3 Operationally Unequal

Using the retrofit ranking equation developed, the four pairs of retrofit options were assessed and used to test the function of the equation.

Century - COMBO + CONT. and 38x140 BATT MAX:

The Century archetype test pair of retrofit option environmental effects have been graphed in the figure below to provide a visual representation of the relative amounts of pollution release with each option.

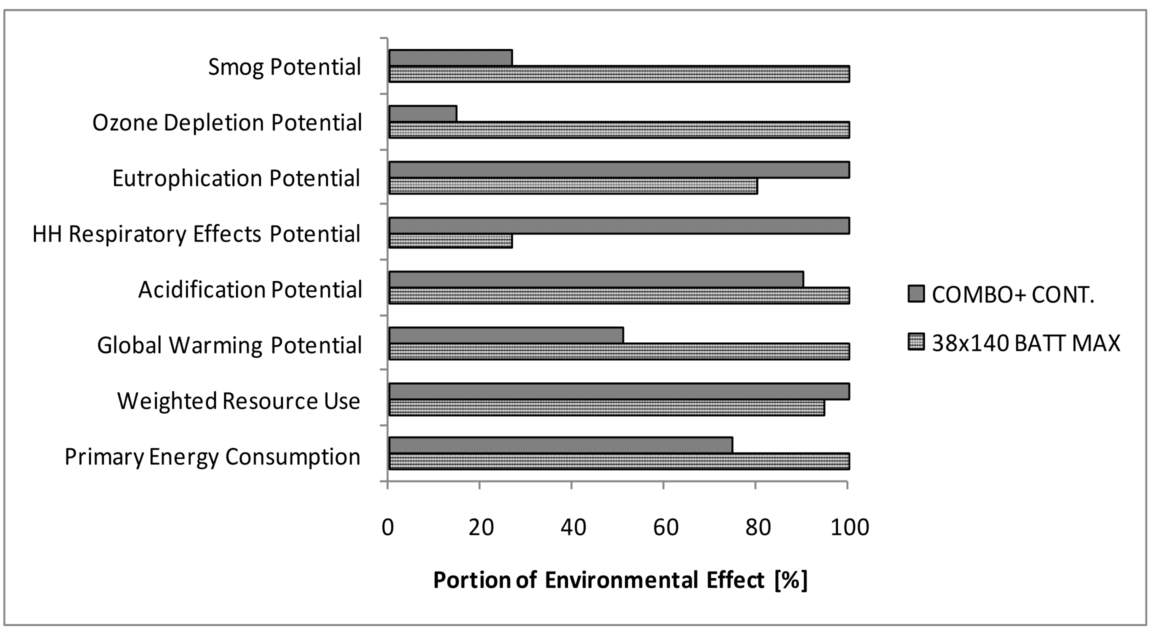


Figure 7.21 - Two Century archetype cases plotted based on their relative environmental effects.

The COMBO + CONT. case produces only a portion of the smog potential, ozone depletion potential, acidification potential, global warming potential, and primary energy consumption than does the 38x140 BATT MAX case. It is the better choice for five out of the eight summary measures. The 38x140 BATT MAX retrofit case, however, is the better option for the other three summary measures.

Table 7.1 - Retrofit ranking equation results - Century

Life Cycle	COMBO+ CONT.	38x140 BATT MAX
Years: 1	0.95	0.77
10	0.99	0.83
20	1	0.84
60	1	0.85
80	1	0.86
100	1	0.86

The standard retrofit ranking, or score, for the COMBO+ CONT. case is 1. In comparison, the standard retrofit ranking for the 38x140 BATT MAX case is 0.85. By this metric the 38x140 BATT MAX is the better retrofit case from an environmental perspective. It so happens that in this case the better overall retrofit was also the retrofit with the better energy intensity as would be expected.

Wartime – 38x89 BLOWN-IN vs. 38x89 BLOWN-IN WINDOWS:

Table 7.2 – Retrofit ranking equation results - Wartime

Life Cycle	38x89 BLOWN-IN	38x89 B-IN WIND.
Years: 1	0.31	1
10	0.72	1
20	0.8	1
60	0.86	0.99
80	0.87	0.98
100	0.88	0.98

These ranking equation results are unexpected because operational energy, due to the fact that it repeats every year for the duration of the life expectancy, normally dominates (Fix, 2010).

Following this idea, it would be expected that the option with the lower energy intensity, 38x89 B-IN WINDOWS, would be the better option environmentally and hence have the lower ranking equation score. The equation, however, shows the embodied effects that result from the life cycle of the new windows outweighing the operational energy savings. Furthermore, it would appear that the new windows do not break even from an environmental perspective within the 100 year life cycle length considered.

Table 7.3 - Relative difference between operational and embodied contributions to summary measures

	Operational Effects [50yrs]		**Difference**	
	38x89 BLOWN-IN	38x89 B-IN WIND.	**Operational**	**Embodied**
Primary Energy Consumption	1.00E+07	9.58E+06	**4.33E+05**	1.90E+05
Weighted Resource Use	4.28E+05	4.12E+05	**1.62E+04**	1.38E+04
Global Warming Potential	4.56E+05	4.34E+05	**2.21E+04**	1.43E+04
Acidification Potential	1.86E+05	1.77E+05	**9.26E+03**	6.09E+03
HH Respiratory Effects Potential	9.26E+02	8.81E+02	4.42E+01	**6.46E+01**
Eutrophication Potential	7.49E-01	7.02E-01	4.71E-02	**2.75E-02**
Ozone Depletion Potential	1.79E-07	1.78E-07	1.02E-09	**9.93E-06**
Smog Potential	1.43E+02	1.37E+02	6.16E+00	**5.73E+01**

> order of magnitude difference | **less than an order of magitude difference**

Looking more closely at the contribution from operational versus embodied effects to the summary measures over a 50 year period shows a possible explanation. The summary measures are split about half and half between favouring operational versus embodied effects. Only two of these summary measures are different by an order of magnitude or more and both favour the embodied contribution. Since all eight summary measures are weighted evenly it takes many years for the operational energy benefits to match and surpass the losses suffered at the initial embodied stage. When the weighting factors for these two parameters, ozone depletion potential and smog potential, are reduced or eliminated the retrofit ranking switches to favouring the 38x89 B-IN WINDOWS case. This suggest that the retrofit rankings are very sensitive to individual summary measures that have an order of magnitude or more difference between operational and embodied contributions.

70s OBC – 38x89 BLOWN-IN + ACH vs. POLYURETHANE:

Table 7.4 – Retrofit ranking results - 70s OBC

Life Cycle	38x89 B-IN +ACH	POLYURETHANE
Years: 1	0.33	1
10	0.8	0.91
20	0.84	0.83
60	0.89	0.77
80	0.9	0.76
100	0.9	0.75

This is an interesting case to compare because defining which retrofit is better retrofit depends on what life expectancy is chosen. For shorter life expectancies the 38x89 B-IN + ACH case is expected to have a more positive environmental impact. However, at approximately 20 years a balance point is reached beyond which the POLYURETHANE case is better. This in and of itself is not unexpected; the retrofit cases being compared are different and their effects vary over time and relative to each other. What is unexpected, at first glance, is the length of time to reach the balance point.

The difference in operational energy between the two cases, their energy intensity is 81kWh/m^2 in favour of POLYURETHANE. With such an overwhelmingly better operational energy value it was expected that this case would rank better from an early stage. The explanation lies in the proportion of electricity to natural gas in the cases. Almost all of the 81kWh/m^2 energy intensity comes from an increase in natural gas use; the electricity usage difference between the cases is minimal. The environmental effects resulting from using natural gas instead of electricity are approximately an order of magnitude smaller. This is the reason the POLYURETHANE case takes so long to catch up to the 38x89 B-IN + ACH case; the incremental difference added every year from operational energy is small. It takes almost 20 years for that small incremental difference to offset the much higher embodied effects of the POLYURETHANE case.

Modern – BEL. 100 BLOWN-IN vs. 38x140 POLYURETHANE:

Table 7.5 – Retrofit ranking results – Modern.

Life Cycle	BEL. 100 B-IN	38x140 POLYUR.
Years: 1	0.28	1
10	0.55	1
20	0.61	1
60	0.69	1
80	0.70	1
100	0.71	1

The BEL. 100 B-IN case has the lower operating energy so it makes sense that as time passes it should look like a better and better option because the savings occur every year. The table above, however, does not reflect this. From the table it appears that the shorter the life expectance used the better an option BEL. 100 B-IN becomes.

The reason for this is the difference between absolute values and ratios. In terms of absolute values, the actual amount of a polluting substance released, BEL. 100 B-IN gets better every year because it increases its lead on 38x140 POLYUR. The graph, however, shows ratios between the two cases and not absolute values.

The embodied effects of the BEL. 100 B-IN are much better than those of 38x140 POLYUR. while their operation energies are much more similar. The ratio between the cases is much wider while embodied effects play a significant role, reflecting the wide ratio between the two cases' embodied effects. Over time, the overall contribution from embodied effects drops off, and the ratio between the cases shifts to reflect the operating energy ratio.

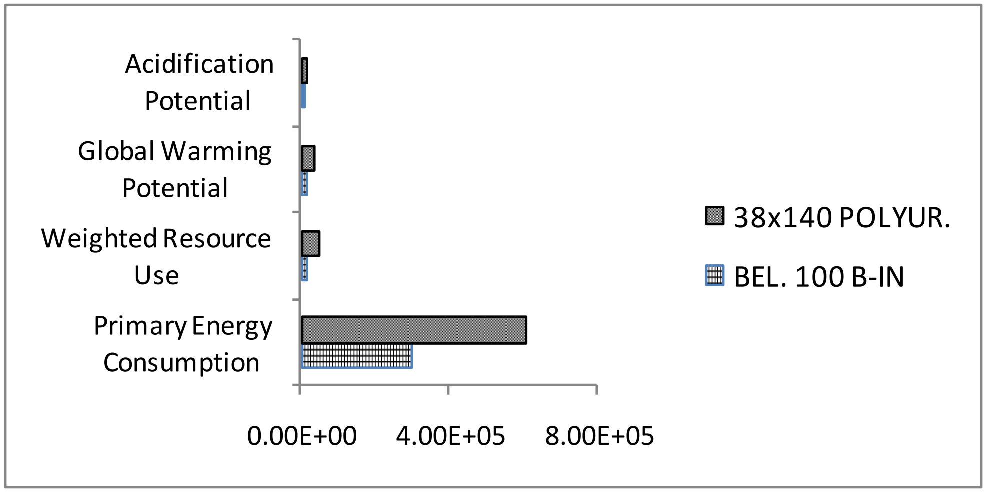


Figure 7.22 - A selection of summary measure results for a Modern home with a 1 year life expectancy

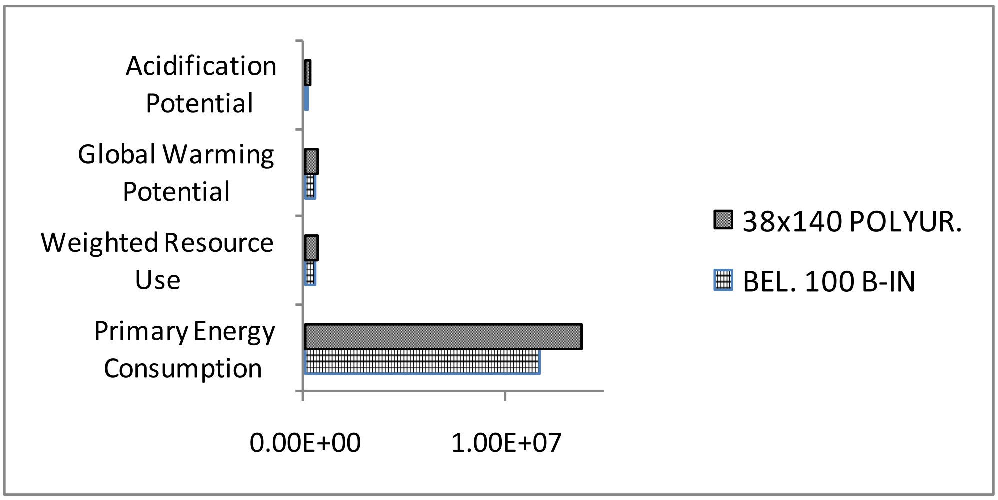


Figure 7.23 - A selection of summary measures for the Modern home with a 60 year life expectancy

The figures above show the same two pairs of cases, 38x140 POLYUR. and BEL. 100 B-IN, with different life expectancies. The 38x140 POLYUR. case produces a larger quantity of summary measures in both the embodied and operational stages. The first figure uses a 1 year life expectancy. In this case the embodied and operational contributions towards a summary measure are roughly equal in scale: 101,000MJ vs. 175,000MJ for the 38x140 POLYUR. case Primary Energy Consumption. In the second figure the life expectancy is changed to 60 years and the ratio of embodied to operations changes to 101,000MJ vs. 10,500,000MJ. Over time the embodied component becomes less and less significant and operational energy dominates.

This explains why the ratio between 38x140 POLYUR. and BEL. 100 B-IN is roughly half in the first figure, but over the longer life expectancy this ratio has shrunk.

7.2.4 Limitations and Sensitivities

During testing of the developed ranking equation some factors that materially affect the resultant ranking were identified. Specifically there are three sensitivities that must be addressed in future work: weighting factors, fuel source sensitivity, and order of magnitude differences.

7.2.4.1 Weighting Factors

The combination of the eight individual summary measures, each with their unique unit of measurement, is complex. There is not enough data available to objectively determine that one kilogram of nitrogen equivalents is just as bad from an environmental perspective as one kilogram of solid waste or one kilogram of CO_2 equivalents or any of the other summary measures. Previous attempts to assign weightings to environmental effects have been based on subjective rankings.

Test case modeling has shown the proposed ranking equation is sensitive to changes in the weightings of the various summary measures. Changing the rankings between summary effects to a factor of two or three, both well within the current range of subjective rankings (U.S. Green Building Council, 2010; Gloria et al., 2007; Anderson et al., 2002; Dickie & Howard, 2000), materially affects the ranking outcome. In many cases the summary measure assigned a weighting factor of 3 or more dominates the equation and the retrofit option with the better performance on that particular factor, rather than any of the other factors, is selected as the better option. Given the weighting, that summary measure is three times more important than any other, that is the expected and intended result, however it does highlight the need for accuracy in the weighting factors. As more research is conducted on this topic the accuracy of the weightings will improve, thereby increasing the accuracy of the ranking equation.

7.2.4.2 Fuel Source Sensitivity

Secondly, the equation is very sensitive to the difference between fuel sources. As previously mentioned, natural gas and electricity result in very different amounts of pollutant being released into the environment with electricity being the bigger polluter. In test cases where the operational energy difference was due mostly to an increase in natural gas consumption the ranking of one retrofit option to another is not very different. In test cases where electricity comprised the bulk of the operational energy difference the retrofit ranking were very different.

There is nothing inherently wrong with this result; electricity does have the worse environmental effect. The sensitivity of the equation to this difference does demand that the input for natural gas to electricity consumption be accurate. Small inaccuracies may be enough to skew the retrofit ranking between the retrofit options under consideration.

7.2.4.3 Magnitude Differences in Summary Measures

The last caveat also deals with sensitivity, but in this case it is to the magnitude of the summary measures. In most cases the difference between one retrofit's summary measure result and the other retrofit option's result is small. When the difference between the two cases reaches an order of magnitude or more that summary measure begins to dominate the equation. Whichever retrofit has the better performance on that particular summary measure ranked better.

Once again, this result is not unexpected, but does emphasize the need for accurate data. If a retrofit option is 100 times worse at one summary measure and roughly comparable on the rest it is reasonable for it to be ranked worse.

8 CONCLUSIONS

8.1 Energy Performance

The energy modeling conducted as a part of this thesis was dependant on the archetype houses developed. The archetype houses span over 100 years of Toronto's construction history and single out the most common and ubiquitous house styles in the city for analysis. All four archetypes have the necessary characteristics defined and were successfully used as the basis for both HOT2000 and ATHENA Impact Estimator modeling.

8.1.1 Target 100kWh/m^2

In total, 71 retrofit cases were modeled using the four Toronto house archetypes and of these 26 were successfully renovated to below the 100kWh/m^2 target. These results show the possibility of retrofitting the existing housing stock in Toronto to low-energy levels.

All four archetypes were successfully retrofitted to meet or exceed the 100kWh/m^2 heating and cooling energy intensity, however, the intensity of retrofits required to meet this target varied. Two archetypes, Wartime and Modern, were successfully retrofitted to meet the target within the first circle bounds, that is, with no loss of interior space on the main floor and little or no use of polyurethane foam.

The Wartime house has several energy performance advantages that help explain the relative ease of modeling to the 100kWh/m^2 target:

- Rectangular shape minimize surface area for a given volume
- lowest glazing area of the four archetypes
- single-storey has a small exposed wall area

It can be retrofitted to meet the target when the full main floor wall cavity is filled with insulation, an insulated 38x140 foundation wall is added, the floor slab is insulated with 64mm of XPS or an equivalent, the windows are replaced, and air sealing measures undertaken.

The Modern house requires approximately the same level of retrofit measures to meet the energy intensity target: the main floor walls have the existing 2.9RSI insulation, a 38x140 insulated wall in added to the basement floor, the floor slab is insulated with 64mm of XPS, windows and doors are replaced, and air sealing measures are undertaken. One advantage the Modern archetype has from a thermal resistance perspective is the attached garage which provides a buffer zone for a portion of the envelope. The downside is that this walkout basement configuration exposes more of the foundation wall, which is insulation to a RSI-value than the main walls, to the exterior.

The 70s OBC archetype is somewhat more difficult to retrofit to the target. Like the Wartime home it also has an efficient shape, but its energy performance is hampered by large glazing areas and main walls. Within the first circle boundaries, the 70s OBC house approaches the energy intensity target; one retrofit case has an energy intensity of 103kWh/m^2, but does not meet 100kWh/m^2. To fall below the target the main floor walls need to have an insulated 38x140 cavity which reduces the interior floor space by 51mm at each exterior wall.

The Century archetype appears to be the most difficult to retrofit to meet the target because it is the only archetype that falls into the third circle boundaries. To model cases with energy intensities of 100kWh/m^2 or lower, the main floor needs to have an insulated 38x140 wall installed. Because the existing walls are double-wythe brick, all 140mm of the new wall is subtracted from the interior floor space, sending the Century archetype into the third circle boundaries.

8.1.2 High Heat Loss Parameters

The energy modeling showed that each archetype had a parameter or parameters which dominated heat loss through the building envelope. Furthermore, the heat loss parameter mix was different for each archetype indicating the need to select retrofit priorities for each archetype individually rather than for single-family homes as a group.

Two conclusions can be drawn about retrofit prioritization from the ranking of heat loss through parameters for each archetype house. First, retrofit effort should be focused on the highest heat loss parameters. There are the parameters where the largest energy savings can be found simply because they are responsible for the largest absolute value of energy loss. Second, retrofits to parameters that play a minor role in heat loss should not be a priority because their energy load reduction potential is small.

Geometry being a good indicator of parameter heat loss was a trend observed in the results. Broadly speaking, the building parameter with the highest surface area dominated heat loss. This conclusion assumes, and the archetype models developed support, that the difference in RSI-value between the competing parameters is small enough to allow the geometry to dominate.

One noted exception to this general observation is the windows parameter. If the glazing area is greater than or in the range of 20-25% of the wall area at the front and back of the house it is fair to assume they are a significant heat loss factor as well, despite only being one-quarter of the surface area. Around this glazing to wall ratio the difference in RSI-values between parameters is significant enough to move the windows & doors parameter into the two top spots.

The only parameter that is not easily estimated by house geometry is ventilation. Here, however, the age of the building can be used to make assumptions, with older buildings being leakier than newer buildings.

8.1.3 Retrofit Priorities for the Four Archetypes

From the HOT2000 energy modeling conclusions can be drawn about where to focus retrofits for each archetype.

Table 8.1 - Retrofit prioritization listed by archetype.

	1st Priority	2nd Priority
Century	walls	ventilation
Wartime	foundation	walls
70s OBC	walls	windows & doors
Modern	windows & doors	ventilation, walls or foundation

The Century archetype, with its large, uninsulated double-wythe walls and very high ACH rate, has two obvious areas of concern for homeowners. Good energy performance cannot be reached without insulating the main walls and air sealing the home. To reach the 100kWh/m^2 target the homeowner must be willing to either lose some interior floor space or cover the brick exterior.

The weakness in the Wartime archetype is the foundation. The single-storey, rectangular geometry of the home means that the foundation walls and slab together make up the largest surface area and without insulating the slab it is difficult to reach low energy intensities. To reach the 100kWh/m^2 target the Wartime homeowner should focus on insulating the foundation and main walls.

As in the other archetypes, heat loss in the 70s OBC house is dominated by a couple parameters. In its case the high surface area of the main walls and the high relative proportion of glazing ensures that these two parameters dominate most retrofit cases. The prudent 70s OBC homeowner will focus primarily on insulating the main walls and replacing the windows with high performance units to reduce the energy intensity of the house.

The Modern archetype is more balanced, with four of the five parameters contributing a more equal share to heat loss than in the previous archetypes. The window & doors, which includes two large sliding doors, are responsible for most of the heat loss. This is the case despite the fact that the base case windows for the Modern archetype are equivalent to a sealed, double-glazed unit. This suggests that if the owner of a Modern home chose to reduce their energy intensity through the windows & doors parameter they would need to look beyond conventional windows to something like a heat mirror unit. However, if that course is not desirable ventilation, main walls, and foundation are all good choices as well.

8.1.4 Popular Retrofits with Limited Effectiveness

Equally important to knowing what to prioritize is knowing what to avoid. Parameters that start with low heat loss values have little potential for energy savings. Halving the heat loss though a minor parameter has little effect on total energy intensity because the value that was halved was small to begin with.

The ceiling parameter is by far the smallest contributor to heat loss in all four archetypes. There are several reasons for this including the relatively small surface area of the ceiling compared with other parameters, the presence of a reasonable level of insulation, and the buffering effect of the attic space on heat loss. Based on the modeled retrofit cases the ceiling, assuming it has insulation to being with, should not be the first renovation performed if the homeowner is seeking to maximize energy savings.

Window replacement is another popular and often mentioned retrofit option. There is a lot of information in the mass media about the energy savings potential of window replacements. While it is true that replacing windows with better performing units will improve energy performance, it will only be a significant overall improvement in cases where windows contributed significantly to a home's heat loss. Of the archetype houses modeled in this thesis only the Modern and to a lesser extent 70s OBC exhibit this characteristic. Also, for the savings to be significant, both retrofit cases needed to be upgraded to heat mirror units rather than sealed, double glazed units that are commonly used in retrofits today.

8.1.5 Considering Energy Intensity vs. Total Energy

This thesis uses energy intensity, either total or for heating and cooling alone, to compare the energy performance of the four archetypes. The main advantage to using energy intensity is that it normalizes energy usage to floor area. By using energy intensity one can distinguish between homes with good and bad energy performance independent of their size. This metric is useful, but not without limitations.

Comparing the four archetypes based on total annual heat loss the Wartime home has the best absolute value at 110GJ. Two newer homes, built years later and to more taxing building codes, trail slightly behind at 133GJ for the 70s OBC home and 116GJ for the Modern house. In terms of overall energy use the Wartime archetype is better than the two newer homes. When total energy is considered along with energy intensity, the case is made for smaller homes built to exacting standards.

8.1.6 Choosing Materials for Performance

During energy modeling some very effective retrofit options came out of using a material that has more than one purpose. Specifically, insulation provides thermal resistance, thereby lowering the energy requirement for the house. Insulation can also contribute to the tightness of a building envelope, thereby lowering air leakage.

Icynene foam, fiberglass batt, and dense-pack, blown-in cellulose all have roughly the same RSI-value per inch, but they behave very differently as air barriers. Of the three, Icynene is the most effective and dense-pack, blown-in cellulose is nearly comparable whereas fiberglass batt has no noticeable effect on air tightness. By choosing an insulation material that also improves the air tightness of the envelope two heat loss parameters are reduced with one retrofit.

8.2 Rankings for Retrofits

An equation capable of combining the operational and embodied effects of home retrofits reported as the ATHENA Impact Estimator's eight summary measures into an overall rating was successfully developed. In its current form the ranking equation can produce ranked results, subject to its limitation. When changes to the weighting factors are made the retrofit rankings change as well, often materially, emphasizing the need for further research to establish reasonable weighting and building science factors.

This equation is an initial effort and has sensitivities that must be addressed prior to being used on a full scale basis for retrofit comparison. It is intended to be used as part of the first steps towards the development of a Sustainable Renovation Index (Richman, 2010). This index, when complete, could be used to comprehensively evaluate retrofit options for residential buildings and help determine what to target for retrofit and with what materials.

8.2.1 Ranking Equation in Context

The retrofit ranking equation produces deceptively simple results. Just looking at the rankings, for example 0.33 vs. 0.95 or 0.74 versus 0.75, makes it appear that the retrofits are easily and effectively rated. These retrofit ranking fractions do not effectively convey how sensitive they are to their equation inputs. This sensitivity was seen clearly in the 70s OBC case where, because of the fuel type embodied effects play a dominant role far longer than would be expected and in the Wartime case where the operational and embodied contributions from two summary measures controlled the ranking.

The retrofit ranking results must be taken in context with thought given to accuracy in the fuel mix, differences in operational and embodied contributions to the summary measures, weighting factors, and building science factors assigned to each summary measure.

9 FUTURE RESEARCH

There are several important avenues for additional research stemming from this work including:

- Weightings for environmental effects
- Development of the Building Science Factor
- Testing and validation of the retrofit ranking equation
- Expansion of study to include more archetypes, retrofit options and locations
- Sequential air tightness testing of air sealing retrofits

As has been previously mentioned, weighting the environmental effect of the eight summary measures is a complex, but necessary task for the ranking equation. Wherever possible, quantitative data should be substituted for or used to support the subjective weighting processes currently used. The weightings to be developed must also be regionally-specific, and specific to the environmental effects used in calculations, namely the eight summary measures of the ATHENA Impact Estimator.

The Building Science Factor is also an integral component of this equation that requires further research. Initially, the BSF for different retrofit cases needs to be determined and the scale by which it can increase or decrease the environmental effects needs to be studied. Subsequently, the BSF can be validated with experimental data as it becomes available.

The retrofit ranking equation, being a first step towards a fully functional retrofit ranking system, requires further research, testing, and validation. Part of this process is an exploration of the sensitivities, for example to fuel types, of the ranking equation. Strategies to reduce these sensitivities should be considered. As well, since more accurate inputs produce more accurate results, the inputs used in the equation, namely environmental effects resulting from retrofits and building operation need to be studied thoroughly.

Other further avenues for research stem from modeling the operational performance of the buildings. The archetypes could be modeled to different energy intensity targets, new retrofit materials could be introduced, and changes could be made to the mechanical system. Other retrofit decision criteria such as cost and disruption time could be studied in combination with the environmental effect optimization introduced in this work. More archetypes could be developed and more retrofit options analyzed to give more breadth to the study.

Sequential air tightening is another area that deserves attention. The sensitivity of energy performance to the rate of air leakage through the building envelope makes this data an important step towards improving the accuracy of energy models.

10 REFERENCES

Abel, E. (1994). Low-energy buildings. *Energy and Buildings, 21*(1994) 169-174.

Anderson, J., Shiers, D., & Sinclair, M. (2002). *The green guide to specification*. Osney Mead, Oxford: Blackwell Science Ltd.

Athena Institute. (2006). *Service life considerations in relation to green building rating systems: An exploratory study.* Retrieved October 12, 2010 from http://www.athenasmi.ca/publications/docs/Service_Life_Expl_Study_Report.pdf.

Athena Institute. (2010). *Athena Institute*. Retrieved August 30, 2010 from http://www.athenasmi.org/index.html

Bare, J., Norris, G., Pennington, D., & McKone, T. (2002) TRACI: the tool for the reduction and assessment of chemical and other environmental impacts. *Journal of Industrial Ecology,* 6(3-4), 49-78.

Berge, B. (2009). *The ecology of building materials*. Elsevier/Architectural Press. London.

Bowick, M., Richman, R., & Meil, J. (2010, June). *Towards an innovative method to quantify the impact of residential building stocks.* Paper presented at ICBEST 2010, Vancouver

Building Research Establishment Ltd. (2008). *PassivHausUK: basic principles.* Retrieved September 19, 2010 from http://www.passivhaus.org.uk/index.jsp?id=668.

C40 Cities. (2010). *Buildings: Freiburg, Germany*. Retrieved September 17, 2010 from http://www.c40cities.org/bestpractices/buildings/freiburg_housing.jsp

City of Toronto. (2010). *Toronto neighbourhood profiles*. Retrieved July 4, 2010 from http://www.toronto.ca/demographics/neighbourhoods.htm

CMHC. (1947). *67 homes for Canadians.* Central Mortgage and Housing, Ottawa, Canada

CMHC. (2010). *History of the CMHC*. Retrieved July 4, 2010 from http://www.cmhc-schl.gc.ca/en/corp/about/hi/index.cfm

Coon, B.R. (1942). Wartime housing. *Royal Architectural Institute of Canada Journal*, 19 (1), 3-8.

Demerse, C., & Bramley, M. (2008). Choosing Greenhouse Gas Emission Reduction Policies in Canada. *The Pembina Foundation*. Retrieved from http://pubs.pembina.org/reports/pembina-td-final.pdf

Dickie, I. and Howard, N. (2000). *Assessing environmental impacts of construction industry: consensus, BREEAM and UK Ecopoints*. BRE Digest 446. BRE, Garston.

Dong, B. (2005). Comparing life cycle implications of building retrofit and replacement options. *Canadian Journal of Civil Engineering*, 32 (6), 1051-1063.

ecoENERGY (2010). ecoENERGY housing database. Natural Resources Canada, Ottawa

ENERGY STAR. (2009). *Methodology for incorporating source energy use*. Retrieved August 27, 2010 from http://www.energystar.gov/ia/business/evaluate_performance/site_source.pdf

Environment Canada. (2009) *Clean air online: fossil fuels*. Retrieved November 9, 2009 from http://www.ec.gc.ca/cleanair-airpur/Pollution_Sources/Fossil_Fuels-WS0E66B313-1_En.htm

European Commission. (2008). *The Kyoto protocol*. Retrieved September 27, 2009 from http://ec.europa.eu/environment/climat/kyoto.htm

Fix, S. (2010). *Towards the removal of uncertainty in sustainable building design through full scale optimization* (Unpublished master's thesis). Ryerson University, Toronto.

Fadi, C., Husaunndee, A., Inard, C. and Riederer, P. (2009). A new method for the design of low energy buildings. *Energy and Building, 41*(2009) 982-990.

Gloria, T., Lippiatt, B., & Cooper, J. (2007). Life cycle impact assessment weights to support environmentally preferable purchasing in the United States. *Environmental Science & Technology, 41*(21), 7551-7557.

Grady, W. (1993). *Greenhome: Planning and building the environmentally advanced house*. Camden House, Ontario.

Harris, J.F. (2008) *The early family businesses*. Retrieved August 29, 2010 from http://harris-history.com/wharrisco/wharrisco-p1.html

Horvat, M., M. Gorgolewski, and A. Cuciureanu. (2009). Operational and Embodied Impact Placed in Context, *Energy Efficiency and New Approaches,* Ed. N.T. Bayazit, G. Manioglu, G.K. Oral, Z. Yilmaz, 4th International Building Physics Conference – proceedings, May 15th – 18th, 2009, Istanbul, Turkey.

Kalen & Associates Inc. and the Centre for Studies in Construction, University of Western Ontario. (1993). The state of demolition waste recycling in Canada. *Forintek Canada Corp*., Ontario.

Kapelos, G.T . (2009). The small house in print: promoting the modern home to post-war Canadians through pattern books, journals, and magazines. *Journal for the Society for the Study of Architecture in Canada*, 34 (1), 33-60

Karlsson, J.F., Moshfegh, B. (2007). A comprehensive investigation of a low-energy building in Sweden. *Renewable Energy, 32*(2007) 1830-1841.

Kovarik, W. (n.d.). *Environmental history timeline*. Retrieved September 27, 2009 from http://www.runet.edu/~wkovarik/envhist/

Livegreen Toronto (2010). *Home Energy Assistance Toronto – Insulate your Home and your Wallet*. Retrieved August 30, 2010 from http://www.toronto.ca/livegreen/greenlife_saveenergy_rebates_heat.htm

Lstiburek, J., (2006). Increasing the durability of building construction. *Building Science Digest 144*, Building Science Corporation, Westford, MA

MacDonald, I. (2008) Infiltration, ventilation and indoor air quality in Canadian residential buildings. *NRC-IRC Building Science Insight 2008/09.*

Maclean-Hunter. (1945) The housing plans of Canadians. *Maclean-Hunter Publishing Company Limited*, Toronto, ON.

Natural Resources Canada, Office of Energy Efficiency. (2000). 1997 survey of household energy use: summary report. *Natural Resources Canada*, Ottawa, Canada.

Natural Resources Canada. (2005). *Survey of household energy use (SHEU) summary report*. Retrieved October 23, 2009 from http://oee.nrcan.gc.ca/publications/statistics/sheu-summary/pdf/sheu-summary.pdf

Natural Resources Canada. (2007). *Community energy planning guide*. Retrieved on July 20, 2010 from http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/fichier/79100/CommunityEnergyPlanningGuide_en.pdf

Natural Resources Canada. (2009). *Energy-efficient residential windows, doors and skylights.* Retrieved June 20, 2010 from http://oee.nrcan.gc.ca/residential/personal/windows-doors/wds/wds-considerations.cfm?attr=4

Natural Resources Canada. (2010). *ecoENERGY Retrofit – Homes Program*. Retrieved August 30, 2010 from http://oee.nrcan.gc.ca/residential/personal/grants.cfm

Natural Resrouces Canada. (2010). ecoENERGY database (excerpt). Obtained July 18, 2010.

Natural Resources Canada – CanmetENERGY. (2009). *The urban archetypes project: the city of Ottawa*. Retrieved on July 22, 2010 from http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/buildings_communities/communities/urban_archetypes_project.html

NRCan. (2001). EnerGuide for Homes Database. *Database of homes participating in the EnerGuide for Houses program (1998-2007) and the ecoENERGY Retrofits - Homes (2007 to current)*. Housing Division, Office of Energy Efficiency, Ottawa. ['EnerGuide for Houses Database' is protected under Canada's Privacy Act.]

Ontario. (2008). *Ontario's climate change action plan.* Retrieved October 12, 2010 from http://www.ene.gov.on.ca/publications/6874e.pdf

Ontario Ministry of Energy. (2010). *Home Energy Savings*. Retrieved August 30, 2010 from http://www.mei.gov.on.ca/en/energy/conservation/ohesp2/?page=ohesp2-intro

Parekh, A. & Roux, L. (2007). Thermal and air leakage characteristics of Canadian housing, *Proceedings of the 11th Canadian Conference on Building Science and Technology*, Banff, Alberta, 2007.

Parker, D. (2009). Very low energy homes in the United States: perspectives on performance from measured data. *Energy and Buildings, 41*(2009) 512-520.

PPHP. (2007). Passive house planning package manual. *Passive House Institute*, Germany.

Richman, R. (2010). *Sustainable buildings group – current research*. Retrieved August 31, 2010 from http://www.ryerson.ca/richman/research/sustainable_buildings_group/current_research/

ROM. (1984). *Mapping Toronto's first century 1787 - 1884*. Retrieved July 18, 2010 from http://prod.library.utoronto.ca:8090/maplib/gta/mapping.html

Straube, J. & Schumacher, C. (2007). Interior insulation retrofits of load-bearing masonry walls in cold climates. *Building Science Digest 144*, Building Science Corporation, Westford, MA

Somerville, W.L. (1942). Site planning for wartime housing. *Royal Architectural Institute of Canada Journal*, 19 (6), 129-131

The Canadian Real Estate Association. (2010). *Welcome to Realtor.ca: property search*. Retrieved June 3-20, 2010 from http://www.realtor.ca/index.aspx?cul=1

Thomsen, K.E., Schultz, J.M., and Poel, B. (2005). Measured performance of 12 demonstration projects – IEA Task 12 "advanced solar low energy buildings". *Energy and Buildings, 37*(2005) 111-119.

Toronto. (2007). *Energy efficiency beyond: Toronto's sustainable energy plan*. Retrieved November 10, 2009 from http://www.toronto.ca/legdocs/mmis/2007/pe/bgrd/backgroundfile-4989.pdf

Toronto (2010). *Toronto Neighbourhood Maps*. Retrieved May 15, 2010 from http://www.toronto.ca/demographics/profiles_map_and_index.htm

Toronto Neighbourhood Guide. (2010). *The "megacity".* Retrieved August 29, 2010 from http://www.torontoneighbourhoods.net/search/search.html

U.S. Green Building Council. (2009). *Introduction to the LEED 2009 credit weighting tool.* Retrieved September 14, 2010 from http://www.clu-in.org/conf/tio/lcia_092309/LEED-2009-Weightings-Tool-Overview.pdf

U.S. Green Building Council. (2010). *Credit weightings tool.* Retrieved September 13, 2010 from http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1971#weightings.

VandeWeghe, J.R., & Kennedy, C. (2007). A spatial analysis of residential greenhouse gas emissions in the Toronto census metropolitan area. *Journal of Industrial Ecology, 11*(2), 133-144.

Wade, J. (1986). Wartime housing limited, 1941-1947: Canadian housing policy at the crossroads. *Urban History Review*, 15 (1), 41-60

Appendix 1 - Neighbourhood Profiles Tabulated

No.	Neighbourhood	Structure Type (#) Detached	Semi	Row	Duplex Apt.	Total
62	East End-Danforth	1735	1880	350	480	4445
63	The Beaches	2580	1455	260	465	4760
64	Woodbine Corridor	850	1500	215	180	2745
65	Greenwood-Coxwell	925	1415	295	345	2980
66	Danforth Village	665	1220	25	190	2100
67	Playter Estates-Danforth	660	600	60	160	1480
68	North Riverdale	785	1205	135	215	2340
69	Blake-Jones	445	615	320	135	1515
70	South Riverdale	835	2205	1180	370	4590
71	Cabbagetown-South St. James Town	150	425	610	40	1225
72	Regent Park	5	45	655	0	705
73	Moss Park	75	95	625	50	845
74	North St. James Town	5	0	60	5	70
75	Church-Yonge Corridor	15	25	220	10	270
76	Bay Street Corridor	0	5	15	5	25
77	Waterfront Communities-The Island	255	30	565	5	855
78	Kensington-Chinatown	85	185	675	65	1010
79	University	115	210	325	80	730
80	Palmerston-Little Italy	315	855	255	145	1570
81	Trinity-Bellwoods	320	720	1000	175	2215
82	Niagara	5	0	520	5	530
83	Durrerin Grove	300	510	90	205	1105
84	Little Portugal	260	480	600	180	1520
85	South Parkdale	185	150	130	265	730
86	Roncesvalles	630	995	360	545	2530
87	High Park-Swansea	2620	495	165	605	3885
88	High Park North	1375	580	110	455	2520
89	Runnymede-Bloor West Village	1980	765	50	265	3060
90	Junction Area	750	965	540	600	2855
91	Weston-Pellam Park	535	1305	325	225	2390
92	Corso Italia-Davenport	1280	1225	110	455	3070
93	Dovercourt-Wallace Emerson-Junction	1590	2145	745	845	5325
94	Wychwood	945	920	255	300	2420
95	Annex	630	1120	620	240	2610
96	Casa Loma	875	230	195	170	1470
97	Yonge-St. Clair	540	390	210	145	1285
98	Rosedale-Moore Park	2450	445	245	330	3470
99	Mount Pleasant East	2155	1570	150	150	4025
100	Yonge-Eglinton	1410	460	25	320	2215
101	Forest Hill South	1740	50	50	70	1910
102	Forest Hill North	1450	10	10	115	1585
103	Lawrence Park South	3415	110	25	250	3800
104	Mount Pleasant West	475	200	170	95	940
105	Lawrence Park North	3110	865	20	185	4180

Appendix 1 - Neighbourhood Profiles Tabulated

No.	Neighbourhood	Period of Construction (year)						
		<1946	46-60	61-70	71-80	81-90	91-00	2001-06
62	East End-Danforth	4305	1280	820	930	555	405	455
63	The Beaches	5760	1085	515	385	160	575	630
64	Woodbine Corridor	3080	795	315	205	425	285	135
65	Greenwood-Coxwell	3125	1055	410	525	645	230	60
66	Danforth Village	2620	505	270	280	180	20	40
67	Playter Estates-Danforth	2050	400	595	300	110	85	20
68	North Riverdale	3600	500	445	190	130	40	30
69	Blake-Jones	1800	400	445	290	140	50	20
70	South Riverdale	5995	935	640	605	695	600	255
71	Cabbagetown-South St. James Town	2185	490	450	1110	1405	200	215
72	Regent Park	740	1170	635	515	425	100	50
73	Moss Park	1330	495	445	555	340	990	1155
74	North St. James Town	740	1270	3345	1825	795	205	160
75	Church-Yonge Corridor	1690	1945	2350	2725	2825	2240	1825
76	Bay Street Corridor	450	275	1030	1370	2920	1950	760
77	Waterfront Communities-The Island	565	205	350	1830	3555	3725	5460
78	Kensington-Chinatown	2085	700	1060	1500	1475	510	305
79	University	1635	180	230	255	135	75	25
80	Palmerston-Little Italy	4420	880	240	205	215	75	10
81	Trinity-Bellwoods	4405	840	415	250	200	125	160
82	Niagara	90	10	60	60	630	385	865
83	Durrerin Grove	2520	735	660	480	155	205	215
84	Little Portugal	2955	595	475	300	260	105	120
85	South Parkdale	3050	2443	1910	1245	845	340	85
86	Roncesvalles	4285	795	690	370	155	70	85
87	High Park-Swansea	80	320	1870	1090	240	120	115
88	High Park North	165	1195	1615	1005	415	170	20
89	Runnymede-Bloor West Village	135	1075	675	295	325	280	140
90	Junction Area	255	620	2795	2660	665	85	0
91	Weston-Pellam Park	1700	820	620	410	220	140	380
92	Corso Italia-Davenport	2800	1100	500	325	200	150	50
93	Dovercourt-Wallace Emerson-Junction	6600	2000	1200	900	800	800	800
94	Wychwood	2700	800	400	490	900	275	100
95	Annex	5785	1905	2285	1330	1640	850	930
96	Casa Loma	1935	1130	915	425	215	290	25
97	Yonge-St. Clair	1975	1710	850	720	465	390	415
98	Rosedale-Moore Park	3570	1465	1735	1040	715	505	870
99	Mount Pleasant East	3355	1080	920	745	575	335	150
100	Yonge-Eglinton	2550	670	620	775	345	110	140
101	Forest Hill South	2075	905	580	405	615	125	75
102	Forest Hill North	940	2205	1080	515	395	195	40
103	Lawrence Park South	3650	885	180	125	145	190	395
104	Mount Pleasant West	1445	1740	4690	2865	1270	1740	970
105	Lawrence Park North	3580	755	165	95	295	325	215

Appendix 2 - House Dimensions

Archetype Geometry

Century | Source: MLS | Search Criteria: $400-1,000K
detached or semi
2 or more bedrooms

		Lot [ft]		House [m]		Floor Usage				
		frontage	depth	width	length	basement	separate entrance	1st	2nd	attic
East End/Riverdale										
	E1899645	18	120	8	12	in-law suite		y	y	n
	E1899759	25	120	5.2	10	rec room		y	y	n
	E1870318	20	100	4.8	10	?		y	y	bedroom
	E1904229	26	86	6.1	10	in-law suite	y	y	y	2 bdrms
	E1867194	24	100	6	11	in-law suite	y	y	y	bdrm, ensuite
	E1869205	20	109	5	10.4	?		y	y	n
	E1897084	20	100	5	10	finished		y	y	bdrm, ensuite
	E1804686	25	95	4	10	in-law suite	y	y	y	loft
	E1840998	20	136	4.5	10	finished	y	y	y	n
	E1870732	20	115	5.6	13	unfinished	y	y	y	n
	E1897080	18.6	109	4.6	12	?	y	y	y	n
	E1892495	19.8	110	4.6	10	unfinished	y	y	y	bedroom
Parkdale/High Park										
	W1895752	28	125	6.75	16	in-law suite	y	y	y	bdrm
	W1877747	30	126	7	10	in-law suite	y	y	y	bdrms
	W1886464	25	120	6	12	in-law suite	y	y	y	kitchen
	W1884481	17.6	115	4.5	11	partially finished	y	y	y	n
	W1857290	22.5	102	6.2	14	finished	n	y	y	loft
	C1904118	20	117	7	15	n	n	y	y	bdrms
	C1865879	25	91	5.8	11	in-law suite	y	y	y	loft
	W1899333	23.7	156	5.5	10	unfinished	?	y	y	bdrm
	C1885451	25	120	6	12	finished	y	y	y	bdrms
	W1893221	20	80	4.2	11	finished	n	y	y	n
	C1865009	25.7	92	5.3	10	in-law suite	y	y	y	n
	C1861891	26	130	6.5	12	in-law suite	n	y	y	aptmt

Appendix 2 - House Dimensions

Archetype Features

Century | Source: MLS | Search Criteria: $400-1,000K
detached or semi
2 or more bedrooms

		Features			
		roof	porch	overhang	windows
East End/Riverdale					
	E1899645	gable front + ?	y	deep porch	1 on 1st, bay on 2nd
	E1899759	gable front + ?	enclosed	deep porch	1 on 1st, 2 on 2nd
	E1870318	gable + flat	n	1' regular	2 big + 1 half size triangle on 3rd floor
	E1904229	gable front + ?	y	deep porch	2 big gable + small stair + med attic window on front
	E1867194	gable front + ?	y	deep porch	1 on 1st, bay on 2nd, stair on 2nd, small on attic
	E1869205	gable front + ?	walk-up	awning instead	1 extra wide on 1st, 2 tall and narrow on 2nd
	E1897084	gable front + ?	y	deep porch	1 on 1st, bay on 2nd, can't see attic
	E1804686	gable + flat	y	deep porch	1 on 1st, bay on 2nd, small on attic
	E1840998	gable front + ?	y	deep porch	1 on 1st, bay on 2nd, small on attic
	E1870732	gable front + ?	y	deep porch	1 on 1st, bay on 2nd, small on attic
	E1897080	gable front + ?	y	?	1 on 1st, bay on 2nd
	E1892495	gable front + ?	y	?	1 on 1st, bay on 2nd, small on attic
Parkdale/High Park					
	W1895752	gable front + ?	enclosed	deep porch	? On main, 2 med on 2nd, 1 med on attic
	W1877747	gable front + ?	half-width	deep porch	1 on main, bay and walkout on 2nd, reg on attic
	W1886464	gable w window	enclosed	enclosed	2 lrg on porch, 2 tall and narrow + 1 small on 2nd, 1 reg on attic dormer
	W1884481	gable w window	half-width	deep porch	1 reg on main, 1 reg + 1 narrow on 2nd, small on attic
	W1857290	gable + flat	n	deep porch	3 tall and narrow on 1st, 2 tall and narrow on 2nd, small on attic
	C1904118	mansard?	y	deep porch	1 reg on main, 1 + walkout on 2nd, reg on attic
	C1865879	gable + flat	y	deep porch	1 lrg on main, 2 tall and narrow + small on 2nd, small round on attic
	W1899333	gable w window	y	deep porch	1 reg on main, bay + small on 2nd, reg on attic
	C1885451	gable w window	y	deep porch	1 reg on main, bay on 2nd, short reg on attic
	W1893221	gable, front	y	deep porch	1 reg on main, 1 reg on 2nd + small square, none on attic
	C1865009	gable + flat	half-width	deep half, 3' rest	1 reg on main, 1 reg + 1 narrow on 2nd
	C1861891	gable, front	half-width	deep porch	1 bay on main, 1 bay + small on 2nd, small on attic

Appendix 2 - House Dimensions

Calculating House Dimensions
Century

WIDTH

Method 1: starting with lot dimensions then subtracting space between houses

vs.

Method 2: averaging width and length estimates

Method 1:

	Lot [ft]	
	frontage	depth
AVG. WIDTH [FT]	20.95769	n/a
-	3	subtract 1.5' on each side
	17.96	

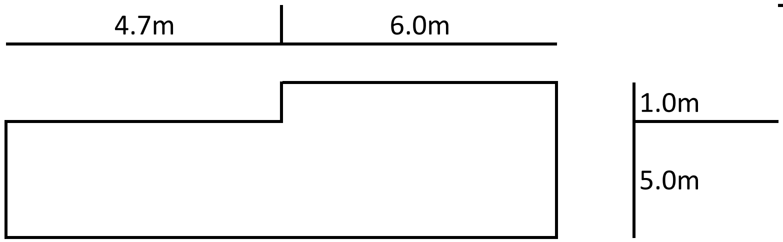
Method 2:

House [m]		
width	length	
5.159615	10.47692	AVG. [M]
15.47885	31.43077	AVG. WIDTH [FT]
15.50		

Depth:

1) Start with ecoENERGY database value for average floor area then
2) use a width that fits within the bounds set above to
3) calculate a depth then
4) adjust depth to account for 'L' floorplan shape

208	ecoENERGY average heated floor area
208	fits within 75-306m2 CMHC range for Century homes
208	fits within 10% of Riverdale House @ 231m2
6	try an 18' width
3.5	heated floor = 3 floors + 1/2 attic
9.90	AVERAGE DEPTH
10.7	with 'L' at 6m,
	need to account for ~14m2 in additional length



Notes:

assume:
- 1/2 floor area on attic floor
- full basement heated
- gable front, flat rear roof
- L' shaped floor plan

observations:
- attic often a bedroom
- sometimes attic has an ensuite
- sometimes attic has a walk-out to a deck on flat roof
- 7m seems common gable, pre-flat, length

		A files				B files			
		25th %	Mean	75th %	Avg.	25th %	Mean	75th %	Avg.
1945 or older	ACH (@50Pa)	**7.56**	**10.05**	**13.60**	**11.24**	**5.66**	**7.48**	**9.76**	**8.10**
1946 - 1960	ACH (@50Pa)	**4.90**	**6.65**	**8.95**	**7.50**	**4.10**	**5.42**	**7.11**	**5.91**
1961 - 1970	ACH (@50Pa)	**3.76**	**5.12**	**7.33**	**6.03**	**3.30**	**4.35**	**6.04**	**4.97**
1971 - 1980	ACH (@50Pa)	**3.66**	**4.95**	**6.97**	**5.75**	**3.19**	**4.27**	**5.83**	**4.80**
1981 - 1990	ACH (@50Pa)	**3.40**	**4.40**	**5.90**	**5.02**	**3.06**	**3.93**	**5.06**	**4.32**
1991 - 2000	ACH (@50Pa)	**2.76**	**3.72**	**5.00**	**4.31**	**2.52**	**3.38**	**4.44**	**3.73**
2001-2009	ACH (@50Pa)	**2.10**	**3.22**	**4.81**	**3.42**	**1.91**	**2.83**	**4.12**	**3.52**
1945 or older	ELA (cm2)	**1,332**	**1,938**	**2,803**	**2,204**	**984**	**1,367**	**1,903**	**1,532**
1946 - 1960	ELA (cm2)	**839**	**1,168**	**1,656**	**1,356**	**670**	**929**	**1,278**	**1,038**
1961 - 1970	ELA (cm2)	**686**	**1,002**	**1,486**	**1,196**	**576**	**830**	**1,186**	**956**
1971 - 1980	ELA (cm2)	**697**	**988**	**1,392**	**1,145**	**576**	**819**	**1,143**	**934**
1981 - 1990	ELA (cm2)	**742**	**1,050**	**1,418**	**1,176**	**641**	**904**	**1,204**	**980**
1991 - 2000	ELA (cm2)	**665**	**937**	**1,275**	**1,066**	**591**	**846**	**1,115**	**906**
2001-2009	ELA (cm2)	**620**	**876**	**1,140**	**985**	**532**	**821**	**1,014**	**874**
1945 or older	Ceiling insulation (RSI)	**1.51**	**2.46**	**3.74**	**2.74**	**2.86**	**4.41**	**6.00**	**4.36**
1946 - 1960	Ceiling insulation (RSI)	**2.08**	**3.37**	**5.03**	**3.66**	**3.45**	**5.23**	**6.50**	**5.08**
1961 - 1970	Ceiling insulation (RSI)	**2.20**	**3.80**	**5.46**	**3.99**	**3.76**	**5.57**	**6.50**	**5.24**
1971 - 1980	Ceiling insulation (RSI)	**3.03**	**3.97**	**5.52**	**4.18**	**4.13**	**5.64**	**6.50**	**5.40**
1981 - 1990	Ceiling insulation (RSI)	**4.34**	**5.18**	**6.16**	**5.08**	**4.72**	**5.47**	**6.50**	**5.65**
1991 - 2000	Ceiling insulation (RSI)	**4.72**	**5.37**	**6.50**	**5.47**	**4.89**	**6.07**	**6.52**	**5.89**
2001-2009	Ceiling insulation (RSI)	**5.22**	**5.65**	**7.72**	**5.76**	**5.87**	**6.90**	**8.30**	**6.97**
1945 or older	Wall insulation (RSI)	**0.79**	**1.15**	**1.69**	**1.27**	**1.15**	**1.72**	**2.06**	**1.69**
1946 - 1960	Wall insulation (RSI)	**1.16**	**1.66**	**1.83**	**1.54**	**1.53**	**1.71**	**1.99**	**1.78**
1961 - 1970	Wall insulation (RSI)	**1.67**	**1.80**	**1.91**	**1.78**	**1.69**	**1.85**	**1.98**	**1.93**
1971 - 1980	Wall insulation (RSI)	**1.80**	**1.90**	**1.96**	**1.95**	**1.83**	**1.91**	**2.15**	**2.08**
1981 - 1990	Wall insulation (RSI)	**1.91**	**2.16**	**2.67**	**2.31**	**1.92**	**2.19**	**2.69**	**2.35**
1991 - 2000	Wall insulation (RSI)	**2.13**	**2.61**	**2.73**	**2.52**	**2.15**	**2.61**	**2.74**	**2.55**
2001-2009	Wall insulation (RSI)	**2.45**	**3.00**	**3.14**	**2.90**	**2.47**	**3.00**	**3.15**	**2.93**
1945 or older	Windows (RSI)	**0.12**	**0.22**	**0.35**	**0.24**	**0.27**	**0.42**	**0.57**	**0.47**
1946 - 1960	Windows (RSI)	**0.17**	**0.24**	**0.37**	**0.26**	**0.28**	**0.42**	**0.57**	**0.47**
1961 - 1970	Windows (RSI)	**0.17**	**0.23**	**0.38**	**0.25**	**0.26**	**0.42**	**0.57**	**0.47**
1971 - 1980	Windows (RSI)	**0.22**	**0.27**	**0.38**	**0.28**	**0.25**	**0.42**	**0.57**	**0.47**
1981 - 1990	Windows (RSI)	**0.23**	**0.28**	**0.37**	**0.30**	**0.40**	**0.42**	**0.57**	**0.47**
1991 - 2000	Windows (RSI)	**0.30**	**0.32**	**0.38**	**0.34**	**0.35**	**0.42**	**0.57**	**0.47**
2001-2009	Windows (RSI)	**0.35**	**0.35**	**0.52**	**0.35**	**0.35**	**0.42**	**0.57**	**0.47**
1945 or older	Foundation insulation (RSI)	**0.06**	**0.25**	**0.66**	**0.52**	**0.27**	**0.92**	**1.83**	**1.20**
1946 - 1960	Foundation insulation (RSI)	**0.20**	**0.49**	**1.28**	**0.74**	**0.47**	**1.37**	**1.84**	**1.33**
1961 - 1970	Foundation insulation (RSI)	**0.28**	**0.72**	**1.50**	**0.89**	**0.57**	**1.41**	**1.83**	**1.32**
1971 - 1980	Foundation insulation (RSI)	**0.48**	**1.22**	**1.80**	**1.16**	**0.81**	**1.63**	**1.83**	**1.48**
1981 - 1990	Foundation insulation (RSI)	**0.90**	**1.73**	**1.85**	**1.49**	**1.40**	**1.82**	**1.95**	**1.72**
1991 - 2000	Foundation insulation (RSI)	**0.37**	**1.61**	**1.94**	**1.39**	**1.41**	**1.88**	**2.42**	**1.88**
2001-2009	Foundation insulation (RSI)	**0.40**	**1.75**	**2.56**	**2.01**	**1.41**	**2.12**	**3.42**	**2.35**
1945 or older	Furnace/boiler AFUE (%)	**58**	**64**	**74**	**65**	**84**	**87**	**94**	**88**
1946 - 1960	Furnace/boiler AFUE (%)	**55**	**63**	**75**	**64**	**80**	**88**	**95**	**89**
1961 - 1970	Furnace/boiler AFUE (%)	**55**	**64**	**78**	**64**	**80**	**88**	**95**	**89**
1971 - 1980	Furnace/boiler AFUE (%)	**62**	**64**	**78**	**64**	**80**	**88**	**95**	**89**
1981 - 1990	Furnace/boiler AFUE (%)	**64**	**68**	**82**	**68**	**80**	**88**	**90**	**89**
1991 - 2000	Furnace/boiler AFUE (%)	**74**	**82**	**90**	**82**	**84**	**87**	**92**	**88**
2001-2009	Furnace/boiler AFUE (%)	**78**	**84**	**94**	**88**	**84**	**87**	**94**	**90**
1945 or older	Floor area (m2)	**152**	**189**	**243**	**208**	**153**	**191**	**245**	**209**
1946 - 1960	Floor area (m2)	**156**	**182**	**216**	**193**	**156**	**183**	**218**	**194**
1961 - 1970	Floor area (m2)	**173**	**198**	**234**	**210**	**173**	**198**	**235**	**211**
1971 - 1980	Floor area (m2)	**170**	**202**	**247**	**216**	**171**	**202**	**247**	**216**
1981 - 1990	Floor area (m2)	**191**	**239**	**303**	**255**	**191**	**239**	**303**	**256**
1991 - 2000	Floor area (m2)	**206**	**258**	**327**	**276**	**206**	**259**	**327**	**277**
2001-2009	Floor area (m2)	**212**	**264**	**333**	**282**	**212**	**264**	**333**	**282**

Appendix 3 - ecoENERGY Database

		A files				B files			
		25th %	Mean	75th %	Avg.	25th %	Mean	75th %	Avg.
1945 or older	Volume (m3)	**379**	**473**	**608**	**519**	**381**	**477**	**613**	**523**
1946 - 1960	Volume (m3)	**389**	**455**	**541**	**481**	**391**	**457**	**545**	**486**
1961 - 1970	Volume (m3)	**433**	**495**	**585**	**525**	**433**	**496**	**588**	**527**
1971 - 1980	Volume (m3)	**426**	**505**	**617**	**539**	**426**	**506**	**618**	**540**
1981 - 1990	Volume (m3)	**477**	**597**	**758**	**639**	**477**	**598**	**758**	**639**
1991 - 2000	Volume (m3)	**515**	**646**	**817**	**689**	**515**	**647**	**817**	**692**
2001-2009	Volume (m3)	**530**	**660**	**833**	**705**	**530**	**660**	**833**	**705**
1945 or older	Total consumption (GJ)	**171**	**215**	**273**	**231**	**114**	**144**	**183**	**154**
1946 - 1960	Total consumption (GJ)	**139**	**167**	**202**	**176**	**100**	**119**	**144**	**126**
1961 - 1970	Total consumption (GJ)	**136**	**160**	**192**	**168**	**100**	**118**	**140**	**123**
1971 - 1980	Total consumption (GJ)	**129**	**153**	**184**	**161**	**96**	**114**	**136**	**119**
1981 - 1990	Total consumption (GJ)	**127**	**150**	**177**	**155**	**97**	**114**	**135**	**118**
1991 - 2000	Total consumption (GJ)	**111**	**136**	**163**	**141**	**74**	**100**	**128**	**105**
2001-2009	Total consumption (GJ)	**105**	**126**	**157**	**133**	**64**	**91**	**118**	**96**

Source: measurements, interview
Date: n/a

Average Glazing Areas:	%
front	19.8
side	0.8
rear	17.1

Century:			Width	Depth
	20% front			
	3% side	Average:	16	43.5
	20% rear	H2:	6m	10.7m

Style: Century
Design: Riverdale House

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
6	16	43.5	9	8.5	9	3235

front	2' height [width in ft]	3' height [width in ft]	4' height [width in ft]	5.5' height [width in ft]		Total [ft]
front		3	2	4.75	7.25	83
side	3	3				15
back	3			6	6	72
side	3	1				9

	Glazing [%]
front	29.6
side (avg)	1.3
back	25.7

Notes:

Style: Century
Design: Cabbagetown

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
6	16	43.5	9	8.5	9	3235

front	2' height [width in ft]	3' height [width in ft]	4' height [width in ft]	5.5' height [width in ft]		Total [ft]
front		3	2	4.75	7.25	83
side	3	3				15
back	3			6	6	72
side	3	1				9

	Glazing [%]
front	29.6
side (avg)	1.3
back	25.7

Notes: "typical" home based on the housing stock in Cabbagetown

Source:	CMHC pattern books
Date:	1950-1965

Average Glazing Areas:		[%]	range
	front	18.5	10.4-27.9
	side	8.7	6.0-9.9
	rear	14.2	4.9-29.4

Wartime Bungalow:				Width	Depth
	20%	front			
	8%	side	Average:	30.13636	31.07545
	15%	rear	H2:	7m	13m

Style: Wartime Bungalow
Design: 204

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
8	32	34	8.5	0	0	1122

front	2' height [width in ft]		3' height [width in ft]	4' height [width in ft]		5' height [width in ft]	Total [ft]
front				7.5	7.5		60
side			3	5.5			31
back						16	80
side			3				9

	Glazing [%]
front	22.1
side (avg)	6.9
back	29.4

Notes:

Style: Wartime Bungalow
Design: 211

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
6	30	35.5	8.5	0	0	1114

front	2' height [width in ft]		3' height [width in ft]	4' height [width in ft]		5' height [width in ft]	Total [ft]
front				3		11	67
side				3	3		24
back			2	3	3		30
side	3	3					12

	Glazing [%]
front	26.3
side (avg)	6.0
back	11.8

Notes:

Style: Wartime Bungalow
Design: 231

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
8	41.67	27.33	8.5	0	0	1173

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			5' height [width in ft]		Total [ft]
front	3	3	5	2.5				12		95
side										0
back			6		6	6	3			78
side	3	3			6					36

	Glazing [%]
front	26.7
side (avg)	7.7
back	22.0

Notes:

Style: Wartime Bungalow
Design: 252

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4	38	28	8.5	0	0	1122

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			5' height [width in ft]		Total [ft]
front					5	5		10		90
side	3		5							21
back			2.5	2.5	6			8		79
side					3	3				24

	Glazing [%]
front	27.9
side (avg)	9.5
back	24.5

Notes:

Style: wartime bungalow
Design: 242

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4	35	28	8.5		0	1071

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			5' height [width in ft]		Total [ft]
front								8	2	50
side	3		5	3						30
back					4	4	4			48
side										0

	Glazing [%]
front	16.8
side (avg)	6.3
back	16.1

Notes:

Style: Wartime Bungalow
Design: 50-16

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
6	24	28	8.5	0	0	884

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			5' height [width in ft]		Total [ft]
front			3		7					37
side					2.5	2.5				20
back					2.5					10
side			2	2	3					24

	Glazing [%]
front	18.1
side (avg)	9.2
back	4.9

Notes:

Style: Wartime Bungalow
Design: 50-28

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4	25	31	8.5	0	0	952

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			5' height [width in ft]		Total [ft]
front	3				4					22
side			4	1.5	2					25
back					2.5	2.5				20
side					2.5	4				26

	Glazing [%]
front	10.4
side (avg)	9.6
back	9.4

Notes:

Style: Wartime Bungalow
Design: 50-5

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4	24	33	8.5	0		969

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			5' height [width in ft]		Total [ft]
front			1	1	7					34
side			2.5		5					28
back					5					20
side			4		4					28

	Glazing [%]
front	16.7
side (avg)	9.9
back	9.8

Notes: has a small gable end over door…not accounted for

Style: **Wartime Bungalow**
Design: **50-3**

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4	28	36	8.5	0	0	1088

front	2' height [width in ft]	3' height [width in ft]	4' height [width in ft]	5' height [width in ft]	Total [ft]
front		1	7		31
side			2.5 2.5 2.5		30
back			2.5 2.5		20
side		2 5			21

	Glazing [%]
front	13.0
side (avg)	8.3
back	8.4

Notes:

Style: **Wartime Bungalow**
Design: **50-6**

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
6	20.5	40	8.5	0		1029

front	2' height [width in ft]	3' height [width in ft]	4' height [width in ft]	5' height [width in ft]	Total [ft]
front		1	6		27
side		3 2	1.5		21
back			3 3		24
side			1.5 5		26

	Glazing [%]
front	15.5
side (avg)	6.9
back	13.8

Notes: small gable over living room window…not accounted for

Style: **wartime bungalow**
Design: **47-10**

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4	33.33	21	8.5	0	0	924

front	2' height [width in ft]	3' height [width in ft]	4' height [width in ft]	5' height [width in ft]	Total [ft]
front			3.5 3.5		28
side			3.5 3.5		28
back		2.5 3			17
side			3.5 3.5		28

	Glazing [%]
front	9.9
side (avg)	15.7
back	5.8

Notes: front and back gable accounted for in cals, formulas changed

Source: CMHC pattern books
Date: 1950-1965

Average Glazing Areas:

	%	range
front	19.6	12.5-31.5
side	5.2	3.5-6.8
rear	23.8	14.4-42.0

70s OBC:				Width	Depth
	20%	front			
	5%	side	Average	25.66667	27.33333
	25%	rear	H2:	8m	9m

Style: 2-storey
Design: 47-20

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4 or 12	26	24	8.5	7.5		1600

front	2' height [width in ft]	3' height [width in ft]		4' height [width in ft]			5' height [width in ft]	Total [ft]
front				7	3	3		52
side		2	2					12
back		3	3	5	3	3		62
side				3	4	3		40

	Glazing [%]
front	12.5
side (avg)	6.8
back	14.9

Notes: 4 corners 1st flr, 12 corners 2nd flr

Style: 2-storey
Design: 47-51

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4	26	27	8.5	7.5		1696

front	2' height [width in ft]	3' height [width in ft]		4' height [width in ft]			5' height [width in ft]	Total [ft]
front	1			9	6			62
side		2	3	3	2			35
back		4		3	3	6		60
side				3				12

	Glazing [%]
front	14.9
side (avg)	5.4
back	14.4

Notes:

Style: 2-storey
Design: 609

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
8	25	31	8.5	7.5		1792

front	2' height [width in ft]	3' height [width in ft]	4' height [width in ft]			6' height [width in ft]		Total [ft]
front	3		6.5	6.5	5	1	7	126
side		1.5						5
back	3		6	6		11	8	168
side	3		6					30

	Glazing [%]
front	31.5
side (avg)	3.5
back	42.0

Notes: windows changed to full height, has 3 window wells for basement

Source: new home builders
Date: 2009-2010

Average Glazing Areas:	%	range
front	14.7	8.3-31.5
side	4.1	2-6.1
rear	20.2	4.9-29.4

Modern:			Width	Depth
	15% front			
	3% side	Average	28.25	46.25
	25% rear	H2:	8.6m	14.2m

Builder: Monarch - Evergreen
Model: Delta
Style: detached

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
8	28	45	8.5	8.5	8	2538

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			6' height [width in ft]		Total [ft]
front			10	4				2		54
side			2							6
back	2	2	6	4	3	3		6		98
side	2	4	2	2	5	5	3			76

	Glazing [%]
front	11.3
side (avg)	4.3
back	20.6

Area [ft2] Stated	Area [ft2] Heated
2281	3100

Builder: Monarch - Evergreen
Model: Element
Style: detached

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
8	30	46	8.5	8.5	8	2644

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			6' height [width in ft]		Total [ft]
front	2		6	6				2		52
side	2	4	4	4						36
back	4	4	6		3	3		5		88
side	4		5	10						53

	Glazing [%]
front	10.2
side (avg)	4.6
back	17.3

Area [ft2] Stated	Area [ft2] Heated
2519	3460

Builder: **Monarch - Evergreen**
Model: **Pacific**
Style: **detached**

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
8	27	52	8.5	8.5	8	2794

	Glazing [%]
front	8.3
side (avg)	2.0
back	15.7

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			6' height [width in ft]		Total [ft]
front	4		6					2		38
side										0
back	4		6	10	4					72
side	4		5	7						44

Area [ft2] Stated	Area [ft2] Heated
2456	3532

Builder: **Monarch - Evergreen**
Model: **Streamside**
Style: **detached**

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
8	28	42	8.5	8.5	8	2436

	Glazing [%]
front	14.5
side (avg)	2.0
back	16.8

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			6' height [width in ft]		Total [ft]
front			4	15				2		69
side										0
back	4	4	6		2	2		5		80
side	2	4	4	4						36

Area [ft2] Stated	Area [ft2] Heated
2369	3128

Style: **2-storey**
Design: **47-20**

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4 or 12	26	24	8.5	7.5		1600

	Glazing [%]
front	12.5
side (avg)	6.8
back	14.9

Notes: 4 corners 1st flr, 12 corners 2nd flr

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			5' height [width in ft]		Total [ft]
front					7	3	3			52
side			2	2						12
back			3	3	5	3	3			62
side					3	4	3			40

Style: **2-storey**
Design: **47-51**

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
4	26	27	8.5	7.5		1696

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			5' height [width in ft]		Total [ft]
front	1				9	6				62
side			2	3	3	2				35
back			4		3	3	6			60
side					3					12

	Glazing [%]
front	14.9
side (avg)	5.4
back	14.4

Notes:

Style: **2-storey**
Design: **609**

Corners [#]	Width [ft]	Depth [ft]	Height [ft] 1st storey	Height [ft] 2nd-storey	Gable [ft]	Wall [ft2]
8	25	31	8.5	7.5		1792

front	2' height [width in ft]		3' height [width in ft]		4' height [width in ft]			6' height [width in ft]		Total [ft]
front	3				6.5	6.5	5	1	7	126
side			1.5							5
back	3				6	6		11	8	168
side	3				6					30

	Glazing [%]
front	31.5
side (avg)	3.5
back	42.0

Notes: windows changed to full height, has 3 window wells for basement

Appendix 5a – HOT2000 Input Notes – Base Case - Century

CENTURY: Inputs and Comments for Base House

- Choosing North elevation reduces solar influence of front overhangs…choosing south includes this influence and gives homes with south-facing deep overhangs an advantage
    - Chose not to give this advantage since each 'typical' house has all sorts of elevations
    - Can play with in the future if want to see solar influence on each archetype
- Ceiling Insulation
    - Went with Anil's data because ceiling retrofits were common in Toronto so we can use the Toronto average
    - Issues with user specified vs. New Code
- Wall Insulation
    - Here Anil has R-1.27 as an average, but solid masonry houses don't tend to have insulation…this value probably jogs because of all the wood-framed/siding houses from pre-1945 (Anil's category)
    - I'm going with no insulation
    - Except on attic gable which is frame and siding, so use 1.27 average value
- Wall dimensions
    - Only complication was the attic gable, can't input triangular dimensions so just put in half-height
        - NRCan verified acceptable as long as area is correct
- Glazing percentages
    - As per Brian, use overhang to account for neighbouring buildings
        - 5m for so close you get no light
        - 2m for driveway or other gap
    - 20% front and back
        - Semi-arbitrary at this point, could look more into the MLS data I collected…
        - Use 1 big window on main, 2 good-sized but adjustable to hit the % on 2nd, and small attic window on 3rd
            - These numbers with worked out pretty well with 20%
    - 3% on EACH side
        - One basement window on each side
            - In Century house these are slightly bigger than Wartime, but all close to standard 3x2'
        - Overhang on sides changes from 1' to 6" -> 0.16m
        - Two basement windows, 1 main & 1 2nd floor window, and two attic bedroom windows
            - Needed more windows to make up for both sides of house…really only one is extra (one attic window) so the numbers are okay
    - 20% on rear
        - Exclude the sliding patio door to backyard and attic walkout to flat roof, some houses have, some don't

        - Basement window, regular door and 2 windows on 1st floor, 2 windows on 2nd
            - Numbers work out reasonably for 20%, if you'd want the patio door you'd need to change the ratio to 25%
- Temperatures
    - Heating at 21oC is okay, but cooling at 25oC is very optimistic
        - Change to 21oC which is a little optimistic, but H2 won't allow the main floor cooling temperature to be lower than the heating temperature
        - Change equipment sizing settings to one degree above heating (22) and one degree below heating (20)
- Changed to furnace heating so that you could have central cooling
- Using blower-door test data for air infiltration
    - To keep 'n' constant must keep Anil's ACH and ELA ratio
        - As per Brian at NRCan
- Added DHW system, default has none
    - Natural gas selected, induced draft fan pops up when natural gas is selected so that's what I went with
        - Russ said this is fine
- Changed furnace efficiency to 80% as per conversation with Russ
    - The NRCan data spans a wide range of time, 80% doesn't seem like a bad in-between to use especially since I'm not taking into account mechanical system effects

Appendix 5b – HOT2000 Input Notes – Base Case - Wartimes

WARTIME: Inputs and Comments for Base House

- Choosing North elevation reduces solar influence of front overhangs…choosing south includes this influence and gives homes with south-facing deep overhangs an advantage
  - Chose not to give this advantage since each 'typical' house has all sorts of elevations
  - Can play with in the future if want to see solar influence on each archetype
- Wall colour red, Roof colour medium brown, Default Roof Cavity Inputs selected
  - To match all archetypes
- Effective mass fraction, foundation soil condition, water table level all set to defaults
- Thermal Mass = light, wood framed
- Weather Data = Ontario, Toronto
- Window Tightness = A2
  - But it doesn't matter since this doesn't factor into air leakage calculations
- Ceiling
  - Hip roof
  - Length = 40m because the full perimeter is considered compressed insulation
  - Area = 91m2 (13x7)
  - Roof Slope = 4/12
    - Seems about right
  - Insulation; went with Anil's data (3.66RSI) because ceiling retrofits were common in Toronto so we can use the Toronto average
- Wall Insulation
  - Here Anil has RSI-1.54 as an average
    - Fair to use as Toronto average so inputting User Specified 1.54
  - Lintel input as 'standard lintel – filled cavity' which is my base for all cases
- Wall dimensions
  - Height = 8.5' floor to ceiling
  - Perimeter = 40m; inside perimeter of whole floor
  - Header input separately
    - Using default 'standard header – uninsulated' for all base cases
  - 4 corners, 0 intersections because partition walls don't interfere with insulation
- Doors
  - No door info from Anil so need to select something that might be age appropriate from drop-down menu
    - Go with solid wood again and keep default H2 dimensions
- Glazing percentages
  - Window Type: need to play with drop-down menus to end up close to Anil's target number of 0.26RSI
  - Use 1 big window on front, 2 good-sized windows on rear, 4 windows on sides (kitchen, bathroom, dining, stairwell), and 4 basement windows also on the sides just because the window dimensions for front and rear work out well without basement windows

        - All windows have a 1' overhang and 1' between top of window and bottom of eaves (header height)
            - No need to play with overhang width to cover neighbour shading because
                - These houses are typically more spread out
                - They have a driveway on one side
                - The shading provided by the neighbours happens early and late in the day so the solar heat gain is small
    - 20% front
        - One big window out front as per elevations
    - 8% on sides
        - Two basement windows, 4 main floor windows
            - *** technically I got a glazing % using both main wall and foundation wall windows, but I'm applying the % only to the main wall so it's a bit unfair *** still, it's just an estimate so a little variation is negligible
    - 15% on rear
        - Exclude the sliding patio door to backyard and attic walkout to flat roof, some houses have some don't
        - Basement window, regular door and 2 windows on 1st floor, 2 windows on 2nd
            - Numbers work out reasonably for 20%, if you'd want the patio door you'd need to change the ratio to 25%
- Foundation:
    - Foundation:
        - Opening to upstairs door closed, floor dimensions same as main floor, wall dimensions 8.5' total height, 6.5' below grade, nothing else changes
    - Wall/Floor Construction
        - Anil's foundation insulation is 0.74RSI so start with that as User Specified
        - BCIN_1, which is concrete foundation with full height insulation
        - 4 corners, standard lintel, basement ceiling
- Temperatures
    - Heating at 21oC is okay, set cooling to 21oC
        - Set equipment sizing for 22oC heating, 20oC cooling; the one extra degree in either direction is a safety factor
- Base Loads and Generation don't change
- Natural Air Infiltration
    - Start with Anil's 7.50ACH and 1356cm2 ELA @ 10Pa
    - House volume calculated with 1st floor + header height x floor area and basement height + floor area; approximately 500m3
    - Building site set to city centre, above grade height entered (main wall, header, above grade foundation = 3.5m)
- Heating/Cooling System

  - Set to furnace and A/C
  - Fans/Pumps
    - Set mode to auto
  - Furnace
    - Natural gas, continuous pilot, efficiency 80%, output capacity set to calculated
    - *** interestingly, this time there is a value in pilot light and flue diameter…none come up in Century ***
  - A/C
    - Conventional, central (add-on), nothing to change in this section
- Added DHW system, default has none
  - Natural gas selected, induced draft fan pops up when natural gas is selected so that's what I went with…still getting a reply on this from Russ

5c – HOT2000 Input Notes – Base Case – 70s OBC

70's OBC: Inputs and Comments for Base House

- Choosing North elevation reduces solar influence of front overhangs…choosing south includes this influence and gives homes with south-facing deep overhangs an advantage
    - Chose not to give this advantage since each 'typical' house has all sorts of elevations
    - Can play w in the future if want to see solar influence on each archetype
- Single-detached, two-storey, rectangular
- Wall colour red, Roof colour medium brown, Default Roof Cavity Inputs selected
    - To match all archetypes
- Effective mass fraction, foundation soil condition, water table level all set to defaults
- Thermal Mass = light, wood framed
- Weather Data = Ontario, Toronto
- Window Tightness = A2
    - But it doesn't matter since this doesn't factor into air leakage calculations
- Ceiling
    - Hip roof
    - Length = 47m because the full perimeter is considered compressed insulation
    - Area = 71.5m2 (13x5.5)
    - Roof Slope = 3/12
        - These look very shallow
    - Insulation; went with Anil's data (4.18RSI) because ceiling retrofits were common in Toronto so we can use the Toronto average
- Wall Insulation
    - Here Anil has RSI-1.95 as an average
        - Fair to use as Toronto average so inputting User Specified 1.95
    - Lintel input as 'standard lintel – filled cavity' which is my base for all cases
- Wall dimensions
    - Height = 8.5' floor to ceiling
    - Perimeter = 37m; inside perimeter of whole floor
    - Header input separately
        - Using default 'standard header – uninsulated' for all base cases
    - 4 corners, 0 intersections because partition walls don't interfere with insulation
- Doors
    - No door info from Anil so need to select something that might be age appropriate from drop-down menu
        - Go with solid wood again – think Chris' door and Cavell - and keep default H2 dimensions
- Glazing percentages
    - Window Type: need to play with drop-down menus to end up close to Anil's target number of 0.28RSI
    - Use 1 big on main, 2 regular on 2nd, 3 small on sides, 1 basement on front
        - Choosing not to have a sliding door for this model

        - All windows have a 1' overhang and 1' between top of window and bottom of eaves (header height) to start
            - Side windows get a 1m overhang to account for neighbours
        - Narrow porch overhang over door…doesn't affect windows so no overhang changes
    - 20% front
        - Two big, one on each floor, plus regular on 2nd and tall (3x2') basement
    - 5% on sides
        - Two basement windows, 1 main floor, 2 2nd floor
            - *** technically I got a glazing % using both main wall and foundation wall windows, but I'm applying the % only to the main wall so it's a bit unfair *** still, it's just an estimate so a little variation is negligible
    - 25% on rear
        - Exclude the sliding patio door to backyard and attic walkout to flat roof, some houses have some don't, in particular the triplex style doesn't
        - Basement window, regular door and 2 windows on 1st floor, 2 windows on 2nd
    - Overhangs to account for neighbours
        - These houses often have a garage on one side
        - Brian said to use overhang to replicate near neighbours
        - I used 5m for century case to block out almost all light
        - Hmm, I could use 1m which would block out some light, mostly the high intensity mid-day light that the windows actually receive, but this is why I'm using 1m instead of 2 or 3m
            - This is very much a ballpark guess
- Foundation:
    - Foundation:
        - Opening to upstairs door closed, floor dimensions same as main floor, wall dimensions 8.5' total height, 5.5' below grade, nothing else changes
        - 5.5' because these triplex style houses often have taller basement windows
    - Wall/Floor Construction
        - Anil's foundation insulation is 1.16RSI so start with that as User Specified
        - BCIN_1, which is concrete foundation with full height insulation
        - 4 corners, standard lintel, basement ceiling
- Temperatures
    - Heating at 21oC is okay, set cooling to 21oC
        - Set equipment sizing for 22oC heating, 20oC cooling; the one extra degree in either direction is a safety factor
- Base Loads and Generation don't change
- Natural Air Infiltration
    - Start with Anil's 5.75ACH and 1145cm2 ELA @ 10Pa

- House volume calculated with 1st + 2nd floor + 2 header height x floor area and basement height + floor area; approximately 600m3
- Building site set to city centre, above grade height entered (main wall, header, above grade foundation = 6.7m)

- Heating/Cooling System
  - Set to furnace and A/C
  - Fans/Pumps
    - Set mode to auto
  - Furnace
    - Natural gas, continuous pilot, efficiency 80%, output capacity set to calculated
  - A/C
    - Conventional, central (add-on), nothing to change in this section
- Added DHW system, default has none
  - Natural gas selected, induced draft fan pops up when natural gas is selected so that's what I went with…still getting a reply on this from Russ

Appendix 5d – HOT2000 Input Notes – Base Case - Modern

Modern: Inputs and Comments for Base House

- Choosing North elevation reduces solar influence of front overhangs…choosing south includes this influence and gives homes with south-facing deep overhangs an advantage
  - Chose not to give this advantage since each ‘typical’ house has all sorts of elevations
  - Can play w in the future if want to see solar influence on each archetype
- Single-detached, two-storey, ‘L’ shape
  - Garage attached in front of house, walk-out basement
- Wall colour red, Roof colour medium brown, Default Roof Cavity Inputs selected
  - To match all archetypes
- Effective mass fraction, foundation soil condition, water table level all set to defaults
- Thermal Mass = light, wood framed
- Weather Data = Ontario, Toronto
- Window Tightness = A2
  - But it doesn’t matter since this doesn’t factor into air leakage calculations
- Ceiling
  - Hip roof
    - Typically hip with gable accents
  - Length = 42m because the full perimeter is considered compressed insulation
  - Area = 86m2
  - Roof Slope = 3/12
  - Insulation; went with Anil’s data (5.76RSI)
- Wall Insulation
  - Here Anil has RSI-2.90 as an average
  - Lintel input as ‘standard lintel – filled cavity’ which is my base for all cases
  - Need to apply the garage factor to the 1st floor wall
    - Can do this as a weighted average instead of inputing a separate section of wall
      - Resulting in RSI-2.95 walls on the 1st floor
- Wall dimensions
  - Height = 8.5’ floor to ceiling
  - Perimeter = 39m on 1st floor, 42 on 2nd
    - Due to the attached garage on the main floor
  - Header input separately
    - Using default ‘standard header – uninsulated’ for all base cases but
  - 6 corners, 0 intersections because partition walls don’t interfere with insulation
- Doors
  - No door info from Anil so need to select something that might be age appropriate from drop-down menu
    - Go with steel w polystyrene core and keep default H2 dimensions
  - 1 door only, front door on 2nd floor
    - The rear walkout is a sliding door
    - Also have a garage door in the front, but that’s not part of the thermal envelope

Appendix 5d – HOT2000 Input Notes – Base Case - Modern

- Glazing percentages
  - Window Type: need to play with drop-down menus to end up close to Anil's target number of 0.35RSI
    - To get 0.35 RSI you need a 13mm air-filled, double-glazed unit with an insulating spacer and vinyl frame
  - This model has no basement windows because it's all above ground 'basement' because of the attached garage
    - MLS data backs this up, if there was an extra floor they'd mention it
  - All windows have a 1' overhang and 1' between top of window and bottom of eaves (header height) to start
    - Side windows get a 5m overhang to account for neighbours
      - Same as Century, especially since these are infill houses in the city, built tight
    - Narrow porch overhang over door…doesn't affect windows so no overhang changes
  - 20% front
    - Use 0 on main because of garage door, 1 big on 2nd, 1 big and 1 regular on 3rd front
  - 5% on sides
    - 4 small on each side
  - 30% on rear
    - 1 reg and 1 sliding door on main, same on 2nd, 2 reg on 3rd
      - The sliding doors on main floor is shaded by the deck used by the 2nd floor sliding door
        - Input the overhang for the main floor sliding door at 2m
  - Overhangs to account for neighbours
    - Brian said to use overhang to replicate near neighbours
    - I used 5m for century case to block out almost all light and these houses would be similarly tightly packed or infill so use 5m here as well
      - Sometimes the infill will be beside a short house so the upper floors get good light, but I can't model everything
- Exposed Floor:
  - Since we have the house over the unheated garage we have an exposed floor
  - Insulation as per building code
    - RSI4.4 + garage factor of 1.09 = 4.80
  - 1.15 multiplication factor of effective RSI as per Chris at NRCan
    - H2 has a chart you select from:
    - Using an unfinished, uninsulated garage with 52.7% attachement (45% on chart) you get 1.08 or w 60% 1.10
      - Probably safe to extrapolated and go with 1.09
- Foundation:

- Opening to upstairs door closed, floor dimensions are the main wall 39m perimeter, wall dimensions 8.5’ total height, 2’ below grade, nothing else changes
  - 2’ because the garage has to be a drive-up
    - Can have a slope down to garage
    - Sometimes the slope rises towards the rear of the house
    - Averaging between front at grade and some rising slope should be good enough
- Wall/Floor Construction
  - Anil’s foundation insulation is 2.01RSI so start with that as User Specified
  - BCIN_1, which is concrete foundation with full height insulation
  - 6 corners, standard lintel, basement ceiling

- Temperatures
  - Heating at 21oC is okay, set cooling to 21oC
    - Set equipment sizing for 22oC heating, 20oC cooling; the one extra degree in either direction is a safety factor
- Base Loads and Generation don’t change
- Natural Air Infiltration
  - Start with Anil’s 3.42ACH and 985cm2 ELA @ 10Pa
  - House volume calculated at approximately 692m3
  - Building site set to city centre, above grade height entered (= 7.8m)
- Heating/Cooling System
  - Set to furnace and A/C
  - Fans/Pumps
    - Set mode to auto
  - Furnace
    - Natural gas, continuous pilot, efficiency 80%, output capacity set to calculated
  - A/C
    - Conventional, central (add-on), nothing to change in this section
- Added DHW system, default has none
  - Natural gas selected, induced draft fan pops up when natural gas is selected so that’s what I went with
    - Russ okayed this selection

Appendix 6a – HOT2000 Input Notes – Retrofits - Century

Century – Minor Retrofits
Schedule of Retrofits used for comparison spreadsheet
File name: Century – comparison of cases

CAPS LOCK = spreadsheet column heading

Method: make one change, see the results, determine which component has the next biggest heat loss, make adjustments to it, iterate

BASE:
Base Case:

- Biggest issue was the uninsulated double-wythe brick walls at 35% of heat loss
  - Add 2x4 framing and fill with batt insulation (R12)
  - Spray-foam…combined with ACH changes

2X4 BATT:
Interior 2x4, batt-filled walls:

- New wall label created: double-wythe w 2x4 batt insul.
  - Solid, double brick, 38x89 @ 600 mm, RSI 2.1, insulation 2 none, 12mm gypsum board, sheathing none, brick
  - Apply this to 1st and 2nd floor, leave 3rd floor as is since it's already insulated
    - Saving some embodied effects and owner disruption, see what the difference would be with 3rd floor insulated as well
- Will lose interior space
- If lath&plaster isn't removed you'll lose even more space, possibly leave rotting materials, etc.
- Regardless must install new gypsum, baseboards/window trim (or reinstall old ones), window sills, exterior door trim, paint, etc.
- Must install vapour retarder, changes ACH characteristics
  - But how much? Not much for fiberglass, but vapour retarder would make a difference
  - As per my ACH chart
    - Let's say you get 1/3 the semi-invasive result just for adding a vapour retarder to the walls and ensuring it's well sealed
      - Choice Semi over Non because when you're adding the new wall you can rip open the old to expose headers and such
    - No point installing the vapour retarder and not paying attention to air leakage so I'm just removing the header, ceiling, basement effects from the 40% on the ACH graph by using my thirds rule for walls/attic/basement
- Results:
  - Pretty good drop on energy use, about 1/5

Appendix 6a – HOT2000 Input Notes – Retrofits - Century

2X4 BATT WALLS w ACH+:
Interior 2x4, batt-filled walls w a 40% reduction of ACH (11.24 -> 6.74)

- ACH went from NRCan database to 40% reduction as per ACH reduction chart
- Results:
  - all the components except the ceiling are about even
  - much smaller drop in energy use, about 10%

ALL BATT WALLS
Checking out the difference if that 3rd floor wall is included

- it probably wouldn't be too difficult to rip out that wall and install a new one while installing walls on the 2nd and 3rd floor, but let's see if it's worth it from an energy perspective
- 3rd floor gable wall is 2x4
- Results
  - From 312 kWh/m2 to 305 -> 2.2%
  - I guess that's not a bad result for insulating such a small space, heck, through full-house air sealing only gave me 10% above
- Let's see what just air sealing would do

ACH, NON

- Non-invasive option, 20% as per chart
- Results:
  - 5% energy/m2 improvement
  - Not bad considering this is not invasive at all, not much excuse not to do it

ACH+:
Uninsulated double-wythe walls w through air sealing work only

- What would happen if instead of insulated the home owner instead took on the through air sealing methods outlined to get the 40% ACH reduction on the chart
- Walls switched back to base case
  - 1st and 2nd floor double-wythe brick
  - 3rd floor was user specified, R1.27
- The result is in-between the base and insulated wall option
  - Roughly half the energy savings of insulating, but walls now account for an even higher portion of heat loss
  - The energy return for this measure isn't as good as for insulating the walls
    - But people avoid insulating their walls so let's see how low we can get with other options

Next steps, insulated the foundation from the interior, add insulation to the ceiling, do both in conjunction with semi-invasive ACH reduction, and replace windows

Appendix 6a – HOT2000 Input Notes – Retrofits - Century

CEILING, BLOWN-IN

Back to base case, add blown-in cellulose to ceiling

- Increase insulation levels to fill joist/rafter/stud cavities
    - Since these are finished spaces already partly filled with insulation this would require a full remove and replace
    - Ceiling – flat: In flat roof 2x10s filled
        - New label: 2x10 joist, blown-in cell.
    - Ceiling – cathedral: rafters assumed to be 2x6s, filled
        - New label: 2x6 cathedral, blown-in
            - R-3.6/inch blown-in used whenever blown-in is used to better approximate dense-pack condition
            - Check if R-value matches dense-pack
    - Wall – 3rd floor: Gable end walls are 2x4s and already partly filled with insulation
        - Since you can't easily blow cellulose into an already insulated space we'll leave these alone. They're not technically a roof at this point anyway
    - Allowance for ventilation necessary? Even in flat roof? Does H2 do this automatically?
    - ACH – use Non-invasive drop since all the extra stuff is hidden given that the space is either finished or a flat roof
        - As per thirds rule, use a third of the 20% non-invasive drop
- Results:
    - don't actually drop the energy usage all that much. We've pretty much doubled the insulation, but only seen about ¼ drop in heat lost through ceiling and 408-> 398kWh/m2
    - really doesn't seem worth the expense since this is a finished space

FOUNDATION, 2X4 BATT

Base case with insulation added to the interior of the foundation

- Essentially finishing the basement
- Foundation insulation from the interior
    - 2x4 framing installed, batt-filled for a total of R-12
        - 2x4s can be space 24" o/c given that they're not structural
            - All new non-structural walls should be put in as 24"o/c to reduce thermal bridging
        - Need poly, drywall and paint as well
    - Since we're finishing the basement we'd be able to insulate the 1st floor header
        - Since we're already using R-12 in this case it makes sense to continue it along the header
    - ACH – since this was an unfinished space before all the hidden leakage paths are exposed and can be dealt with so I'm going with a third of the semi-invasive 40%
- Results
    - this is a much more effective retrofit when compared with the ceiling

- I think about the same amount of insulation is added, well, no, more because of the surface area of walls would be higher than that of ceilings/gables I think
  - Still, you get a reduction to 364 from 408 kWh/m2 which is not bad for one retrofit
    - ~11%
- The heat loss reduction is greater for the above grade portion of the wall
  - This makes sense because of the temperature differential…still, want to insulate the below grade portion as well
  - 60% reduction for above grade portion, 20% reduction for below grade portion

FOUNDATION & ACH+

Okay, so you get better results by insulating the foundation than by continuing to add insulation to the ceiling; what kind of results can you get if you also add some air sealing?

- Using chart 40% reduction for ACH and ELA
- This gives you almost the same result as insulating the main walls with batt-filled 2x4s
  - 338 vs. 336 kWh/m2
  - Not bad considering this is a retrofit people might be more likely to agree to
- It also raises the main walls to 40% of your heat loss
  - You really can't get away with not insulating the interior walls, people will have to deal with losing a few inches of interior space

Let's see what happens with windows and after that combine everything that can be done without insulating the main walls. Then try using more extreme materials to get better leakage reductions and R-values.

WINDOWS

Continuing along the base case upgrades

- Start with base case file
- Upgrade windows to standard double-glazed units
  - Because of the window upgrade ACH will drop 10% because windows are assumed to be old and leaky
- Results:
  - Heat loss through windows (& doors) drops 32%, but overall energy required drops from 408 to 383 kWh/m2, or 6%
  - Not a huge component of energy

COMBO

Okay, just how much improvement can you get without having to insulate your main walls

- Start with FOUNDATION + ACH
  - Upgrade windows to double-glazed, standard and additional 10% ACH reduction
  - Add ceiling insulation as per ceiling case
    - 2x10 blown-in joists for flat and 2x6 blown-in cathedral

    - Foundation and ACH are already done in this file
- Results:
    - 312kWh/m2 which is the same as 2x4 BATT & ACH+ and almost as good as ALL BATT (ie 3rd floor insulated more as well)
        - An improvement over base case of 24%
        - For all that work such a small improvement doesn't sound exciting
    - Walls jump to 44% of your heat loss, with ventilation second at 24%

Time to try using materials with better properties and comparing.

COMBO+

Before playing with interior walls, just how much better can I make the energy performance

- Start with COMBO case
    - Upgrade all insulation to polyurethane since it's got the highest R-value
        - Upgrade all headers to 4" polyurethane as well since we're doing anything invasive, just not losing any interior space; pretty much a gut
    - Upgrade windows to
        - TC88 on north
        - HM 66 on rest of elevations
    - Upgrade foundation to 2x4 polyurethane
    - Upgrade 3rd floor wall to 2x4 polyurethane
        - Again, invasive, just not losing interior space
- Ventilation
    - Foam + semi-invasive so drop ACH to 2.0 as per chart

Note: this case was accidentally modeled with polyurethane main walls. The corrected case, COMBO+ CONT., is included at the end.

- Results:
    - 173kWh/m2 is the newest value
        - This is good, but for a full gut and foaming with polyurethane, it's a 58% reduction
    - Walls now make up 34% of your heat loss, foundations 25%

Moving on to losing interior space options

Batt, blown-in cellulose, Icynene and polyurethane are my options

- Batt, blown-in and Icynene have about the same R-values, but different ACH reductions so will need to model them all, grr
- Pick Icynene to start since it's easy to input
    - blown-in isn't an option with double-wythe
    - Icynene lets you input at R/in. rather than a specific R as for batts

2x3, 2x4 and 2x6 are my dimensions

- 2x3 and 2x4 are easily made over top of double-wythe
- 2x6 has to be manufactured as a new User-Defined Code

Appendix 6a – HOT2000 Input Notes – Retrofits - Century

Thermal bridging needs to be reduced:

- Input all these walls with a 1” jog from the brick
- Input the 2x6 wall with two offset 2x3s

User-Defined Code:

- Match H2 specs for R-values, dimensions of units (for example brick at 101.6mm thick), spacing numbers, etc.
- Non-structural walls have Secondary checked instead of Primary

2x3 ICYNENE

Let’s just get some numbers for baseline wall changes

- Upgrade to 2x3 Icynene
  - 1st and 2nd floor walls
  - All headers to RSI3.5 Icynene
  - ACH to ‘no additional air sealing’ chart value
- Results:
  - 321kWh/m2
    - A little better than batt option probably due to ACH reductions
  - Biggest heat loss component is air leakage so address that next

2x3 ICYNENE & ACH+

Working my method of addressing the next biggest heat loss component need to reduce ventilation

- Add semi-invasive air sealing so reduce ACH to 2.0
- Results:
  - Not bad, I’ve dropped to 263kWh/m2
  - Walls 29%, foundation 28%, windows 26% so the next big thing is to increase the insulation levels more

2X3 ICYNENE & ACH & 3rd

Since walls are back up to the top let’s insulate that 3rd floor wall

- Upgrade 3rd floor to Icynene
  - Should use 2x4 since that’s the framing already in place
- Results:
  - Energy per m2 drops another 2.5%
    - About the same drop as last time I did this 3rd floor check
  - Foundations are at 28%, windows and walls tied at 27%
  - Next step would be to increase R-value for everything except ceiling

2x3 ICYNENE+

The + will mean including the 3rd floor wall in insulation, upgrading to double-glazed windows which goes nicely with new walls, foundation insulation and semi-invasive air sealing

- Starting with 2x3 ICYNENE & ACH & 3rd file

  - Upgrade windows to double-glazed
  - Upgrade ACH reduction for windows
- Results:
  - 216 kWh/m2 and walls are number one again at 34% with 23% for foundation and windows
  - More insulation in the walls

2x4 ICYNENE+

Because there's no point modeling the in-between cases go straight to this one

- Upgrade walls to 2x4 Icynene
- Upgrade foundation walls to 2x4 Icynene
- Results:
  - That further 1" of insulation gets you a 6% improvement on energy/m2 at 203
  - That's not bad, but not great
    - You've added and another 1/3 of material on top of 2x3 case
  - Walls are still first at 31% and windows and doors are at 25%

2x6s thermal bridging modeling test:

Input one 2x6 filled with Icynene vs. 2 2x3s filled with Icynene

- Account for the 0.5" difference between a 2x6 and 2 2x3s by having an extra continuous 0.5" of icynene in the 2 2x3s
- *** NOPE *** Icynene doesn't need the double-stud. You can just add a gap between the wall and your 2x3s and fill it with foam to get whatever depth you'd like

2x6 ICYNENE+

Let's see what this super thick case of Icynene can pull off

- Upgrade walls to 2x6 Icynene
- Upgrade foundation to 2x6 Icynene
- Upgrade headers to highest Icynene option available:RSI 4.4
- Results:
  - 185kWh/m2 which isn't bad, but we have lost 6" of interior space…
  - Windows are now the highest heat loss at 28% with walls trailing at 25%

2x6 ICYNENE MAX

Let's try to max out this Icynene option, if you're trying to avoid polyurethane just how low can you get your energy load?

- Upgrade windows to Heat mirror
  - TC88 on north
  - HM66 on rest
- Upgrade doors to steel polyurethane core which is the best option available from the H2 menu
- Results:
  - 170kWh/m2 which isn't bad, but not what I'd be happy with if it was my house

  - These window and door changes saved another 8% for kWh/m2
  - Walls at 30% and foundation at 26% are the biggest heat loss components, but we're really maxed out this option
  - Heating and cooling load for this house is about 90kWh/m2
    - Just heating is 82 kWh/m2

2X6 BLOWN-IN MAX

How does blown-in cellulose compare to the Icynene option? Don't need to bother modeling all the in between steps, it's only the max that matters here

- Change walls to 2x6 blown-in
  - Make sure to use dens(er) option
- Leave headers at 4.4 RSI because 1) foam is effective at air sealing this difficult area 2) blown-in isn't an option for this component and 3) it has pretty much the same R-value as blown-in
- Change foundation to 2x6 blown-in
  - Ooh, can test thermal bridging here by using a User-Defined code vs. basic New Code
- Change ACH value to 3 as per chart then reduce by window 10%
- Results:
  - 177 instead of 170 attainable with Icynene
    - Not a bad comparison given the price difference
    - Wonder about the embodied energy difference between the two
  - These two results compare well with the COMBO+ case (all intensive retrofits except with no loss of interior space)
    - Which is best from an embodied energy perspective?

THERMAL BRIDGE

If I change the foundation wall code to something with a insulation-filled gap and 2x3 instead of a solid 2x6 will the values change? Let's find out.

- Create User-Defined code for foundation wall (calcs won't run with this code selected for some reason, just take the value produced and switch to user defined)
  - 3" blown-in
  - 2x3 filled with 2.5" of blown-in
  - Gypsum
  - Total 5.5" of blown-in to match the amount of blown-in in a 2x6 cavity
  - Also leaves 0.5" for the gypsum to give a total intrusion of 6"
- 2x6 RSI = 3.0, double-stud 2x6 RSI = 3.2
  - 177 vs 176 kWh/m2 is the difference
  - Not huge, but why waste materials and lose energy by not doing it this way?

2X6 BATT MAX

If owners want to avoid both Icynene and blown-in then they'll go with the conventional batt. What kind of best case results can this conventional wall get?

- Change walls to 2x6 batt, double-stud

- Change foundation to 2x6 batt, double-stud (ditto on calc issue)
- Change ACH to Ext/Int combined with semi-invasive value to account for the poly/sealing method -> 45% reduction
- Results:
    - Energy jumps to 216 kWh/m2 predominantly because of the leakier envelop
        - 39% of heat loss through ventilation
        - Heat lost through leakage went from 19K to 28K
        - Is 6 ACH really the best we can do with poly and taping? Probably not, but this is what the chart shows so go with it and if questions are answers say there is still lots of research to be done here

2x6 POLYUR. MAX

Okay, if we use the insulation material with the highest R/in. how well can we do?

- Change walls to 2x6 polyurethane, double-stud
- Change foundation to 2x6, double-stud
- Change headers to 5.5" polyurethane to match the 5.5 in 2x6s
- Change ach to 2.0 standard then apply window 10%
- Results:
    - Energy dropped to 154 kWh/m2
        - A reduction of 62% from base case,
        - 13% from other material base cases which doesn't seem like much to use polyurethane
    - Heating is at 66 kWh/m2
        - With cooling up to 74 kWh/m2

Why is COMBO+ such a good option? Check coding…

- Almost the whole house is 2x4 polyurethane. The only exception are the walls. While the overall idea is a bit confusing the numbers work out

COMBO+ CONT.

Modeled to correct main wall insulation in previous COMBO+ case

- Start with COMBO+, set main wall insulation to base case levels
- Results
    - Energy intensity is at 226kWh/m3
    - Main walls at 59% of heat loss

Notes:

SPRAY FOAM + ACH

OPTIMIZED INSULATION

Develop the optimal insulated case before making adjustments to windows

Appendix 6a – HOT2000 Input Notes – Retrofits - Century

- Optimize to get the same energy results, but limit changes
  - Keep 2x4 spray foam on 1st, 2nd and headers
  - Don't spray foam on 3rd floor and instead keep the original 2x4 batt
  - Insulate the foundation with the standard 2x4 batt walls
  - Ceiling, both flat and gable, gets max amount of blown-in cellulose to fill rafters/joists
- Results come out comparable to both 2x3 and 2x4 spray foam runs at 155kWh/m2
  - By using less intensive insulation materials in key, aka non-air leakage, areas you still get the energy characteristics you want
- Windows at 37% are the definite next thing to hit, compared with 27% for main walls
  - Foundation is at near 20% suggesting the level of insulation could be higher
  - Ceiling drops down to 5% from what was already a low number so there is limited benefit to adding even more ceiling insulation
- How much less good is it if you don't bother with more ceiling insulation???

WINDOWS:

DOUBLE GLAZED STANDARD

Replace all windows with double glazed, standard

- Double glazed, standard is a favourite code
  - Double glazed
  - Clear coating/tint
  - 13mm argon
  - Insulating spacer
  - Hinged window
    - Ie casement style, but doesn't matter since the program is using blower door data to calculate leakage anyway
  - Vinyl frame
- This is a fairly standard decent window by today's standards
  - It brings the RSI-value from about 0.22 to 0.38, aka almost double
- Results show about half the heat loss through the windows as would be expected with the about doubled R-value
  - Walls jump back into #1 place at 31% with windows second at 25% and foundation not far behind at 23%
  - With air leakage at 2.5ACH it really stops being a concern
- 133kWh/m2 is the new low
  - Not bad considering this is a spray foaming of main floors to prevent air leakage, ceiling and 3rd floor insulation stays put (questionable with air sealing measure perhaps) and basement gets finished in a standard batt way, plus windows are replaced with perfectly normal double glazed units

Appendix 6b - HOT2000 Results - Retrofits - Century

HOT2000 Modelling Summary

		input
Archetype:	Century	calculated
Case:	base	highest %
Heated Floor Area [m2]:	208	2nd %

Fuel Consumption Summary:	BASE - Century		2X4 BATT	
Natural Gas [m3]:		6,939.7		5,580.2
Heating	6224.6		4865.1	
Cooling	0.0		0.0	
DHW	715.1		715.1	
Appliance	0.0		0.0	
Electricity [kWh]:		13,154.3		12,651.2
Heating	911.4		702.1	
Cooling	2539.7		2310.8	
DHW	0.0		0.0	
Appliance	9703.2		9638.3	
Total Fuel Consumption [kWh/m2]:		408		338
Heating & Cooling [kWh/m2]		326		256

Building Parameters Totals:				
Ceiling	7,631.8	3.52	7,631.8	4.32
Walls	73,061.6	33.72	40,764.3	23.06
Windows & Doors	34,625.9	15.98	34,626.1	19.59
Foundation	36,609.5	16.90	36,611.8	20.71
Ventilation	64,753.9	29.88	57,111.9	32.31

Component	BASE - Century Annual Heat Loss [MJ]	[%]	2X4 BATT Annual Heat Loss [MJ]	[%]
Building Parameters Summary:				
Zone 1: Above Grade				
Ceiling	7631.8	3.52	7631.8	4.32
Main Walls	73061.6	33.72	40764.3	23.06
Doors	3701.6	1.71	3701.6	2.09
Windows - south	9477.8	4.37	9477.8	5.36
Windows - sides	5266.5	2.43	5266.5	2.98
Windows - north	12323.8	5.69	12323.8	6.97
Zone 2: Basement				
Walls above grade	19495.2	9.00	19496.2	11.03
Windows - south	1285.4	0.59	1285.5	0.73
Windows - sides	2570.8	1.19	2570.9	1.45
Windows - north	0.0	0.00	0.0	0.00
Bel. grd foundation	17114.3	7.90	17115.6	9.68
Ventilation				
house	64753.9	29.88	57111.9	32.31
Total:	216,683	100	176,746	100

Appendix 6b - HOT2000 Results - Retrofits - Century

	BASE - Century		2X4 BATT	
Component RSI values:	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade				
Ceiling	2.74	16	2.74	16
Main Walls	1.11	6	1.98	11
Doors	0.39	2	0.39	2
Windows - south	0.25	1	0.25	1
Windows - sides	0.23	1	0.23	1
Windows - north	0.24	1	0.24	1
Zone 2: Basement				
Walls above grade	0.52	3	0.52	3
Windows - south	0.23	1	0.23	1
Windows - sides	0.23	1	0.23	1
Windows - north	0.00	0	0.00	0
Bel. grd foundation	0.52	3	0.52	3
Ventilation				
house	11.24	ACH	9.74	ACH

Appendix 6b - HOT2000 Results - Retrofits - Century

2X4 BATT & ACH+		ALL 2X4 BATT & ACH+		ACH, NON	
	5,061.4		4,924.5		6,547.4
4346.3		4209.4		5832.3	
0.0		0.0		0.0	
715.1		715.1		715.1	
0.0		0.0		0.0	
	12,533.9		12,473.9		13,005.1
623.3		602.1		852.0	
2263.1		2242.2		2496.2	
0.0		0.0		0.0	
9647.5		9629.6		9656.9	
	312		305		388
	230		223		306

7,631.8	4.73	7,631.8	4.85	7,631.8	3.72
40,764.3	25.27	36,637.4	23.31	73,061.6	35.59
34,626.5	21.46	34,626.5	22.03	34,626.2	16.87
36,616.3	22.70	36,616.3	23.29	36,612.8	17.84
41,691.5	25.84	41,683.5	26.52	53,351.8	25.99

2X4 BATT & ACH+ Annual Heat Loss		ALL 2X4 BATT & ACH+ Annual Heat Loss		ACH, NON Annual Heat Loss	
[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
7631.8	4.73	7631.8	4.85	7631.8	3.72
40764.3	25.27	36637.4	23.31	73061.6	35.59
3701.6	2.29	3701.6	2.35	3701.6	1.80
9477.8	5.87	9477.8	6.03	9477.8	4.62
5266.5	3.26	5266.5	3.35	5266.5	2.57
12323.8	7.64	12323.8	7.84	12323.8	6.00
19498.3	12.09	19498.3	12.40	19496.7	9.50
1285.6	0.80	1285.6	0.82	1285.5	0.63
2571.2	1.59	2571.2	1.64	2571.0	1.25
0.0	0.00	0.0	0.00	0.0	0.00
17118.0	10.61	17118.0	10.89	17116.1	8.34
41691.5	25.84	41683.5	26.52	53351.8	25.99
161,330	100	157,196	100	205,284	100

Appendix 6b - HOT2000 Results - Retrofits - Century

2X4 BATT & ACH+		ALL 2X4 BATT & ACH+		ACH, NON	
[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
2.74	16	2.74	16	2.74	16
1.98	11	2.21	13	1.11	6
0.39	2	0.39	2	0.39	2
0.25	1	0.25	1	0.25	1
0.23	1	0.23	1	0.23	1
0.24	1	0.24	1	0.24	1
0.52	3	0.52	3	0.52	3
0.23	1	0.23	1	0.23	1
0.23	1	0.23	1	0.23	1
0.00	0	0.00	0	0.00	0
0.52	3	0.52	3	0.52	3
6.74	ACH	6.74	ACH	8.99	ACH

Appendix 6b - HOT2000 Results - Retrofits - Century

ACH+		CEILING, BLOWN-IN		FOUNDATION, 2x4 BATT	
	6,149.2		6,747.1		6,064.1
5434.1		6032.0		5349.1	
0.0		0.0		0.0	
715.1		715.1		715.0	
0.0		0.0		0.0	
	12,914.2		13,038.8		12,910.4
791.7		882.3		778.4	
2453.6		2488.1		2462.9	
0.0		0.0		0.0	
9668.9		9668.4		9669.1	
	368		398		364
	286		316		281

7,631.8	3.94	5,991.7	2.84	7,631.8	3.99
73,061.6	37.72	73,061.6	34.58	70,354.7	36.76
34,626.5	17.88	34,626.0	16.39	34,635.2	18.10
36,616.3	18.90	36,610.6	17.33	21,609.7	11.29
41,761.1	21.56	60,969.9	28.86	57,145.0	29.86

ACH+ Annual Heat Loss		CEILING, BLOWN-IN Annual Heat Loss		FOUNDATION, 2x4 BATT Annual Heat Loss	
[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
7631.8	3.94	5991.7	2.84	7631.8	3.99
73061.6	37.72	73061.6	34.58	70354.7	36.76
3701.6	1.91	3701.6	1.75	3701.6	1.93
9477.8	4.89	9477.8	4.49	9477.8	4.95
5266.5	2.72	5266.5	2.49	5266.5	2.75
12323.8	6.36	12323.8	5.83	12323.8	6.44
19498.3	10.07	19495.7	9.23	8037.6	4.20
1285.6	0.66	1285.4	0.61	1288.5	0.67
2571.2	1.33	2570.9	1.22	2577.0	1.35
0.0	0.00	0.0	0.00	0.0	0.00
17118.0	8.84	17114.9	8.10	13572.1	7.09
41761.1	21.56	60969.9	28.86	57145.0	29.86
193,697	100	211,260	100	191,376	100

Appendix 6b - HOT2000 Results - Retrofits - Century

ACH+		CEILING, BLOWN-IN		FOUNDATION, 2x4 BATT	
[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
2.74	16	3.57	20	2.74	16
1.11	6	1.11	6	1.15	7
0.39	2	0.39	2	0.39	2
0.25	1	0.25	1	0.25	1
0.23	1	0.23	1	0.23	1
0.24	1	0.24	1	0.24	1
0.52	3	0.52	3	1.84	10
0.23	1	0.23	1	0.23	1
0.23	1	0.23	1	0.23	1
0.00	0	0.00	0	0.00	0
0.52	3	0.52	3	1.84	10
6.74 ACH		10.49 ACH		9.74 ACH	

Appendix 6b - HOT2000 Results - Retrofits - Century

FOUNDATION & ACH+		WINDOWS		COMBO	
	5,531.1		6,456.2		5,063.7
4816.2		5741.0		4348.6	
0.0		0.0		0.0	
714.9		715.2		715.1	
0.0		0.0		0.0	
	12,770.0		12,884.7		12,457.4
698.2		837.2		625.9	
2406.2		2412.4		2254.2	
0.0		0.0		0.0	
9665.6		9635.1		9577.3	
	336		383		312
	254		301		230

7,631.8	4.34	7,631.8	3.82	5,991.7	3.75
70,354.7	39.98	73,061.6	36.56	70,354.7	44.08
34,636.6	19.68	23,562.9	11.79	23,568.4	14.77
21,619.4	12.29	36,526.0	18.28	21,555.4	13.51
41,729.7	23.71	59,031.8	29.54	38,137.1	23.89

FOUNDATION & ACH+		WINDOWS		COMBO	
Annual Heat Loss		Annual Heat Loss		Annual Heat Loss	
[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
7631.8	4.34	7631.8	3.82	5991.7	3.75
70354.7	39.98	73061.6	36.56	70354.7	44.08
3701.6	2.10	3701.6	1.85	3701.6	2.32
9477.8	5.39	6238.7	3.12	6238.7	3.91
5266.5	2.99	3251.4	1.63	3251.4	2.04
12323.8	7.00	7977.1	3.99	7977.1	5.00
8040.5	4.57	19457.0	9.74	8021.0	5.03
1289.0	0.73	798.0	0.40	799.9	0.50
2577.9	1.46	1596.1	0.80	1599.7	1.00
0.0	0.00	0.0	0.00	0.0	0.00
13578.9	7.72	17069.0	8.54	13534.4	8.48
41729.7	23.71	59031.8	29.54	38137.1	23.89
175,972	100	199,814	100	159,607	100

Appendix 6b - HOT2000 Results - Retrofits - Century

FOUNDATION & ACH+		WINDOWS		COMBO	
[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
2.74	16	2.74	16	3.57	20
1.15	7	1.11	6	1.15	7
0.39	2	0.39	2	0.39	2
0.25	1	0.38	2	0.38	2
0.23	1	0.38	2	0.38	2
0.24	1	0.38	2	0.38	2
1.84	10	0.52	3	1.84	10
0.23	1	0.38	2	0.38	2
0.23	1	0.38	2	0.38	2
0.00	0	0.00	0	0.00	0
1.84	10	0.52	3	1.84	10
6.74	ACH	10.12	ACH	6.07	ACH

Appendix 6b - HOT2000 Results - Retrofits - Century

COMBO+		2x3 ICYNENE		2x3 ICYNENE + ACH	
	2,421.6		5,094.4		4,099.3
1704.9		4379.3		3384.2	
0.0		0.0		0.0	
716.7		715.1		715.1	
0.0		0.0		0.0	
	11,003.1		12,547.9		12,357.5
220.3		628.6		478.0	
1552.0		2263.8		2232.4	
0.0		0.0		0.0	
9230.8		9655.5		9647.1	
	173		314		263
	93		232		181

4,464.7	6.08	7,631.8	4.70	7,631.8	5.74
24,677.4	33.62	38,911.1	23.96	38,911.1	29.27
11,927.7	16.25	34,626.5	21.33	34,627.2	26.05
18,485.0	25.18	36,615.5	22.55	36,624.0	27.55
13,852.8	18.87	44,588.8	27.46	15,123.9	11.38

COMBO+ Annual Heat Loss		2x3 ICYNENE Annual Heat Loss		2x3 ICYNENE + ACH Annual Heat Loss	
[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
4464.7	6.08	7631.8	4.70	7631.8	5.74
24677.4	33.62	38911.1	23.96	38911.1	29.27
3701.6	5.04	3701.6	2.28	3701.6	2.78
2838.7	3.87	9477.8	5.84	9477.8	7.13
1569.9	2.14	5266.5	3.24	5266.5	3.96
2670.8	3.64	12323.8	7.59	12323.8	9.27
6165.4	8.40	19497.9	12.01	19501.8	14.67
382.2	0.52	1285.6	0.79	1285.8	0.97
764.5	1.04	2571.2	1.58	2571.7	1.93
0.0	0.00	0.0	0.00	0.0	0.00
12319.6	16.78	17117.6	10.54	17122.2	12.88
13852.8	18.87	44588.8	27.46	15123.9	11.38
73,408	100	162,374	100	132,918	100

Appendix 6b - HOT2000 Results - Retrofits - Century

COMBO+		2x3 ICYNENE		2x3 ICYNENE + ACH	
[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
4.91	28	2.74	16	2.74	16
3.27	19	2.08	12	2.08	12
0.39	2	0.39	2	0.39	2
0.83	5	0.25	1	0.25	1
0.78	4	0.23	1	0.23	1
1.12	6	0.24	1	0.24	1
2.67	15	0.52	3	0.52	3
0.78	4	0.23	1	0.23	1
0.78	4	0.23	1	0.23	1
0.00	0	0.00	0	0.00	0
2.67	15	0.52	3	0.52	3
1.80	ACH	7.31	ACH	2.00	ACH

Appendix 6b - HOT2000 Results - Retrofits - Century

2X3 ICYNENE + ACH + 3rd		2x3 ICYNENE+		2x4 ICYNENE+	
	3,964.2		3,187.8		2,939.5
3249.1		2472.7		2224.5	
0.0		0.0		0.0	
715.1		715.1		715.0	
0.0		0.0		0.0	
	12,298.2		11,952.1		11,883.2
456.1		337.3		299.8	
2215.7		2087.7		2065.8	
0.0		0.0		0.0	
9626.4		9527.1		9517.6	
	256		216		203
	174		135		122

7,631.8	5.93	7,631.8	7.40	7,631.8	7.97
34,642.9	26.93	34,642.9	33.58	29,836.2	31.17
34,627.2	26.92	23,566.3	22.85	23,570.8	24.63
36,624.0	28.47	23,420.6	22.70	20,797.3	21.73
15,108.9	11.75	13,894.8	13.47	13,882.6	14.50

2X3 ICYNENE + ACH + 3rd		2x3 ICYNENE+		2x4 ICYNENE+	
Annual Heat Loss		Annual Heat Loss		Annual Heat Loss	
[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
7631.8	5.93	7631.8	7.40	7631.8	7.97
34642.9	26.93	34642.9	33.58	29836.2	31.17
3701.6	2.88	3701.6	3.59	3701.6	3.87
9477.8	7.37	6238.7	6.05	6238.7	6.52
5266.5	4.09	3251.4	3.15	3251.4	3.40
12323.8	9.58	7977.1	7.73	7977.1	8.33
19501.8	15.16	9159.4	8.88	7511.2	7.85
1285.8	1.00	799.2	0.77	800.7	0.84
2571.7	2.00	1598.3	1.55	1601.3	1.67
0.0	0.00	0.0	0.00	0.0	0.00
17122.2	13.31	14261.2	13.82	13286.1	13.88
15108.9	11.75	13894.8	13.47	13882.6	14.50
128,635	100	103,156	100	95,719	100

Appendix 6b - HOT2000 Results - Retrofits - Century

2X3 ICYNENE + ACH + 3rc		2x3 ICYNENE+		2x4 ICYNENE+	
[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
2.74	16	2.74	16	2.74	16
2.33	13	2.33	13	2.71	15
0.39	2	0.39	2	0.39	2
0.25	1	0.38	2	0.38	2
0.23	1	0.38	2	0.38	2
0.24	1	0.38	2	0.38	2
0.52	3	1.52	9	2.04	12
0.23	1	0.38	2	0.38	2
0.23	1	0.38	2	0.38	2
0.00	0	0.00	0	0.00	0
0.52	3	1.52	9	2.04	12
2.00 ACH		1.80 ACH		1.80 ACH	

Appendix 6b - HOT2000 Results - Retrofits - Century

2x6 ICYNENE+		2x6 ICYNENE MAX		2x6 BLOWN-IN MAX	
	2,591.2		2,348.4		2,490.8
1874.7		1631.7		1774.1	
0.0		0.0		0.0	
716.5		716.7		716.7	
0.0		0.0		0.0	
	11,780.4		11,087.9		11,134.3
245.5		208.6		230.8	
2038.0		1618.5		1624.6	
0.0		0.0		0.0	
9496.9		9260.8		9278.9	
	185		170		177
	104		90		97

7,631.8	9.00	7,631.8	10.83	7,631.8	10.18
21,479.1	25.34	21,479.1	30.47	20,652.7	27.55
23,577.8	27.82	9,491.8	13.47	9,491.7	12.66
18,210.7	21.48	18,032.3	25.58	17,966.0	23.97
13,861.2	16.35	13,846.2	19.65	19,218.3	25.64

2x6 ICYNENE+ Annual Heat Loss		2x6 ICYNENE MAX Annual Heat Loss		2x6 BLOWN-IN MAX Annual Heat Loss	
[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
7631.8	9.00	7631.8	10.83	7631.8	10.18
21479.1	25.34	21479.1	30.47	20652.7	27.55
3701.6	4.37	1266.3	1.80	1266.3	1.69
6238.7	7.36	2838.7	4.03	2838.7	3.79
3251.4	3.84	1569.9	2.23	1569.9	2.09
7977.1	9.41	2670.8	3.79	2670.8	3.56
5817.0	6.86	5771.0	8.19	5730.7	7.64
803.0	0.95	382.0	0.54	382.0	0.51
1606.0	1.89	764.1	1.08	764.0	1.02
0.0	0.00	0.0	0.00	0.0	0.00
12393.7	14.62	12261.3	17.40	12235.3	16.32
13861.2	16.35	13846.2	19.65	19218.3	25.64
84,761	100	70,481	100	74,961	100

Appendix 6b - HOT2000 Results - Retrofits - Century

2x6 ICYNENE+		2x6 ICYNENE MAX		2x6 BLOWN-IN MAX	
[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
2.74	16	2.74	16	2.74	16
3.76	21	3.76	21	3.91	22
0.39	2	1.14	6	1.14	6
0.38	2	0.83	5	0.83	5
0.38	2	0.78	4	0.78	4
0.38	2	1.12	6	1.12	6
2.98	17	2.98	17	3.00	17
0.38	2	0.78	4	0.78	4
0.38	2	0.78	4	0.78	4
0.00	0	0.00	0	0.00	0
2.98	17	2.98	17	3.00	17
1.80	ACH	1.80	ACH	2.70	ACH

Appendix 6b - HOT2000 Results - Retrofits - Century

THERMAL BRIDGING		2X6 BATT MAX		2X6 POLYUR. MAX	
	2,455.3		3,251.1		2,027.4
1738.7		2535.9		1311.0	
0.0		0.0		0.0	
716.6		715.2		716.4	
0.0		0.0		0.0	
	11,133.1		11,394.8		11,004.0
225.3		347.3		159.3	
1624.7		1681.1		1604.0	
0.0		0.0		0.0	
9283.1		9366.4		9240.7	
	176		216		154
	95		136		74

7,631.8	10.34	7,631.8	7.79	7,631.8	12.64
20,652.7	27.99	24,685.5	25.20	14,737.4	24.40
9,496.2	12.87	9,493.6	9.69	9,499.8	15.73
16,794.4	22.76	17,515.0	17.88	14,507.4	24.02
19,217.7	26.04	38,638.5	39.44	14,022.6	23.22

THERMAL BRIDGING Annual Heat Loss [MJ]	[%]	2X6 BATT MAX Annual Heat Loss [MJ]	[%]	2X6 POLYUR. MAX Annual Heat Loss [MJ]	[%]
7631.8	10.34	7631.8	7.79	7631.8	12.64
20652.7	27.99	24685.5	25.20	14737.4	24.40
1266.3	1.72	1266.3	1.29	1266.3	2.10
2838.7	3.85	2838.7	2.90	2838.7	4.70
1569.9	2.13	1569.9	1.60	1569.9	2.60
2670.8	3.62	2670.8	2.73	2670.8	4.42
5311.6	7.20	5781.4	5.90	3805.2	6.30
383.5	0.52	382.6	0.39	384.7	0.64
767.0	1.04	765.3	0.78	769.4	1.27
0.0	0.00	0.0	0.00	0.0	0.00
11482.8	15.56	11733.6	11.98	10702.2	17.72
19217.7	26.04	38638.5	39.44	14022.6	23.22
73,793	100	97,964	100	60,399	100

Appendix 6b - HOT2000 Results - Retrofits - Century

THERMAL BRIDGING		2X6 BATT MAX		2X6 POLYUR. MAX	
[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
2.74	16	2.74	16	2.74	16
3.91	22	3.27	19	5.48	31
1.14	6	1.14	6	1.14	6
0.83	5	0.83	5	0.83	5
0.78	4	0.78	4	0.78	4
1.12	6	1.12	6	1.12	6
3.21	18	2.83	16	5.17	29
0.78	4	0.78	4	0.78	4
0.78	4	0.78	4	0.78	4
0.00	0	0.00	0	0.00	0
3.21	18	2.83	16	5.17	29
2.70	ACH	6.18	ACH	1.80	ACH

COMBO+ CONT.	
	3,418.6
2702.8	
0.0	
715.8	
0.0	
	11,582.9
376.4	
1772.5	
0.0	
9434.0	
	226
	145
4,464.7	4.32
61,471.1	59.42
9,522.6	9.20
14,072.4	13.60
13,928.0	13.46

2X6 POLYUR. MAX	
Annual Heat Loss	
[MJ]	[%]
4464.7	4.32
61471.1	59.42
1266.3	1.22
2838.7	2.74
1569.9	1.52
2670.8	2.58
5804.9	5.61
392.3	0.38
784.6	0.76
0.0	0.00
8267.5	7.99
13928.0	13.46
103,459	100

2X6 POLYUR. MAX	
[RSI]	[R]
4.91	28
1.31	7
1.14	6
0.83	5
0.78	4
1.12	6
2.67	15
0.78	4
0.78	4
0.00	0
2.67	15
1.80	ACH

Appendix 7a – HOT2000 Input Notes – Retrofits - Wartime

Wartime – Retrofits
Schedule of Retrofits used for comparison spreadsheet
File name: Wartime – compare retrofits

CAPS LOCK = spreadsheet column heading

Method: make one change, see the results, determine which component has the next biggest heat loss, make adjustments to it, iterate

BASE:
Base Case:

- Starting at 263 kWh/m2
- Biggest issue the foundation at 28% of heat loss followed by walls at 24%
- Ceilings are still the lowest component at under 10%
    - the rest of the parameters are closer to convergence at around 20%

BATT FOUNDATION
Finish the basement with 2x4 batt-filled foundation walls

- Upgrade foundation wall to 2x4 batt filled
- Upgrade 1st floor header with R12 batt
- For ACH changes associated with used the thirds rule
    - Poly will be installed for air leakage as well so
        - Category would be Ext/Int since it's poly
        - 1/3 for applying to the basement only
    - Give it 1/3 of the chart's 30% for Ext/Int w no additional sealing
- Results:
    - From 263 to 237, % drop in kWh/m2
    - Highest heat loss is windows & doors at 26% followed by walls and foundation at 24% each

BATT WINDOWS
Add some better windows to this insulated foundation/finished basement case

- Upgrade windows to standard double-glazed
- Change ACH by window 5% as per air sealing chart
- Results:
    - Some improvement, 237 to 230 kWh/m2, but the windows weren't terrible to begin with so the improvement isn't as drastic as it was in the Century case
    - Walls and foundations are tied for largest heat loss at 25%
    - Aside from ceiling all of the parameters are fairly close together

Appendix 7a – HOT2000 Input Notes – Retrofits - Wartime

Note: for the Wartime, 70s OBC and Modern archetype the wall cavities are already filled with some insulation so blown-in cellulose is not a minor retrofit

2X4 BLOWN-IN

Fill the available cavities in the walls, plus add this 2x4 wall for a finished basement

- Upgrade walls
    - Create new code for brick veneer wall with structural framing
- Upgrade headers
    - Use batt to substitute for blown-in or Icynene
- Upgrade foundation wall
    - Create new code for a 2x4 blown-in foundation wall 24" o/c
- Upgrade ACH, for cellulose without other air sealing use 30% reduction
- Results:
    - 221 kWh/m2 which is a 16% drop from base case
    - 29% for windows and doors is the clear leader for heat loss
    - Foundation follows at 26% so target that, but
        - The foundation parameter includes the slab which is almost half the total area heat loss area…by insulating just the walls I'm only insulating half the heat loss surface area…this explains the poor results
    - Windows are the worse parameter at this point so they are the next target

2x4 B-IN WINDOWS

- Upgrade windows to standard double-glazed
- Change ACH to get window 5%
- Results:
    - 209kWh/m2
    - Basement foundation at 29%, target that next
        - Yet all the parameters are staying relatively converged, the four are within 10%

2x6 B-IN FOUNDATION

Let's get this foundation heat loss number down

- Using the thermal bridging reduced double-stud 2x6 option
    - Still calc. problems when the program is run with this option selected
        - get the RSI from selecting the option in the menu, then change to user defined while calculating
- Results:
    - We've gone from 263 in the base case to 209 in the previous case with 2x4s to 202 with the thermal bridging reduced 2x6
        - That's not that much improvement
            - Attributable to the large, uninsulated slab area that is part of the foundation component
    - Foundation and windows are tied for biggest contributors to heat loss at 24%

- Let's try one more run at foundation wall and window reductions
  - Also should start thinking of reducing ventilation since it's getting close to 20%, but really this isn't combined with basement retrofits and can be an add-on to any of these cases

2X6 POLYUR. FOUND.
Since foundation and windows continue being the biggest heat loss parameters let's try to max these out with high R/inch material: polyurethane

- Upgrade foundation walls to thermal bridge reduced 2x6 polyurethane
- Upgrade header to polyurethane since it's accessed from the basement as well
- Upgrade windows to orientation sensitive heat mirror
- Change ach rates to fit the chart
  - 1/3 (because we're foaming a basement and not the walls) of 35% since we're not adding any further air sealing
  - Plus 5% for windows
- Results:
  - 183 kWh/m2 which isn't bad, but isn't great
  - Window heat loss dropped drastically, to about half of its original value, as it does when I use the heat mirror windows
    - Windows at 15%
    - Nothing more to do within the scope of project retrofits
  - Foundations are still highest at 26% of heat loss

2X4 B-IN SLAB
The results without insulating the slab are not great. Start with the 2x4 B-IN WINDOWS case and add some insulation to the slab

- Upgrade slab insulation to try to tackle this foundation issue
  - Create new code '2x3 XPS slab'
    - 2x3 wood framing, 16" o/c
      - Since we'll be walking on this surface I'm using the 16o/c spacing of structural walls
    - 2.5" of XPS
      - 2.5" inches to fill the framing space
      - XPS because it's got a good R-value per inch and not susceptible to moisture damage
    - Plywood sheathing covered with an interior finish
- Results:
  - Dropped heat loss through foundation by about 23%
    - Need to run this with a R-value comparable to that on walls to see the relative difference…actually these were pretty close w foundation walls at 1.9 and slab at 1.85

  - Total energy drop was from 209 for 2x4 B-IN WINDOWS to 201 kWh/m2 for this insulated slab case

2X4 B-IN SLAB+

Slightly more slab insulation

- Upgrade to max allowed by HOT2000: 3” of XPS
  - Not much of an R-value increase so not expecting much of a drop
- Results:
  - Almost 1 kWh/m2 less, a couple hundred fewer MJ of heat lost through slab

2x6 B-IN F/S/W

Okay, let’s try maxing this case out

- Upgrade windows to heat mirror
- Upgrade foundation to thermal bridge reduced 2x6 blown-in
- Header is fine as an R-12 batt since it matches the wall R-value if not material
- Results:
  - At 181 this option rivals the 2x6 POLYUR. FOUND.

2x6 B-IN CASE

Let’s make this Case 1 and later compare Athena to 2x6 polyurethane case. It’s defined as blown-in insulation in the existing 2x4 walls, heat mirror windows, 2x6 blown-in foundation + 2.5” XPS slab, upgraded doors and semi-invasive air sealing

- Upgrade doors to steel w polyurethane core since these are the best available
- Upgrade ACH to blown-in + semi-invasive, so 3ACH
  - Apply window 5%
- Results
  - 166kWh/m2 total, or 75kWh/m2 for heating and cooling which beats the targeted 100

2x6 ICYNENE CASE

Same as above, but replace all blown-in with icynene to get the R-value and slightly lower ach

- Change
  - Walls
  - Headers
  - Foundation
  - Ach
- Results:
  - Very similar to blown-in case above but 161 instead of 166
  - Walls are the highest components of heat loss at 31%, foundation 2nd at 24%

2x6 POLYUR. CASE

Since walls are still the highest heat loss component add more R/inch

- Change all insulation types to polyurethane

    - Walls have 4”
    - Foundation gets 6”
    - Headers 4”
    - Leave slab insulation as 2x3 XPS because
        - the R-value is similar
    - Ach is the same as for icynene so no changes there
- Results:
    - The foundation heat loss dropped significantly, 12,280 -> 8676
        - Still 2nd at 19% though
    - Main walls are first at 13,108 and 29%
    - Ceiling has jumped to 16%
    - Total energy is 151kWh/m2, heating and cooling at 61kWh/m2
        - Good result without having to give up interior space

EXT. INSULATION

Let’s see how much more we can drop the energy intensity by adding rigid insulation to the exterior

- Using ‘combo wall & slab’ with exterior insulation to 0.60m below grade
    - Seems like not too taxing a retrofit
    - Using 2.5” XPS because of it’s high R/in and moisture resistance
- Results:
    - *** ERROR *** the energy use goes up
        - This happened in two separate cases:
            - Combo wall & slab with exterior to 0.60m below grade and
            - Combo wall & slab with not thermally broken foundation and overlap of 1.5m between interior and exterior (full height) insulation of 2.5” XPS
    - Remove this case from consideration and continue

2X6 MAIN WALLS

Go back to insulating the main walls, because they’re the biggest heat loss component

- Model 2x6 polyurethane to get the highest energy drop with this thickness
    - Use the thermal break 2x6 polyurethane walls
- Results:
    - 141kWh/m2 total
    - all 5 parameters are in pretty good balance
        - Foundation 23%, ventilation 22%, windows & doors 20%, walls 18%, ceilings 18%
        - The energy intensity target has been exceeded, the 5 parameters have converged. Move to next archetype

HOT2000 Modelling Summary

		input
Archetype:	Wartime	calculated
Case:	base	highest %
Heated Floor Area [m2]:	182	2nd %

Fuel Consumption Summary:	BASE - Wartime		BATT FOUNDATION		BATT WINDOWS		2X4 BLOWN-IN	
Natural Gas [m3]:		3,481.1		3,045.0		2,930.1		2,770.0
Heating	2765.1		2329.0		2214.1		2054.0	
Cooling	0.0		0.0		0.0		0.0	
DHW	716.0		716.0		716.0		716.0	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		11,803.1		11,649.7		11,603.1		11,558.9
Heating	381.0		313.9		296.4		273.1	
Cooling	2121.9		2087.0		2051.7		2055.1	
DHW	0.0		0.0		0.0		0.0	
Appliance	9300.2		9248.8		9255.0		9230.7	
Total Fuel [kWh/m2]:		263		237		230		221

Building Parameters Totals:								
Ceiling	6,958.0	6.35	6,958.0	7.20	6,958.0	7.55	6,958.0	7.87
Walls	26,143.6	23.87	22,901.5	23.71	22,901.5	24.85	16,058.9	18.16
Windows & Doors	24,987.3	22.81	24,984.8	25.86	18,487.0	20.06	24,985.1	28.26
Foundation	30,633.8	27.96	23,080.1	23.89	23,078.4	25.04	22,681.6	25.65
Ventilation	20,820.8	19.01	18,680.3	19.34	20,740.3	22.50	17,729.5	20.05

Appendix 7b - HOT2000 Results - Retrofits - Wartime

Component	BASE - Wartime Annual Heat Loss [MJ]	[%]	BATT FOUNDATION Annual Heat Loss [MJ]	[%]	BATT WINDOWS Annual Heat Loss [MJ]	[%]	2X4 BLOWN-IN Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	6958.0	6.35	6958.0	7.20	6958.0	7.55	6958.0	7.87
Main Walls	26143.6	23.87	22901.5	23.71	22901.5	24.85	16058.9	18.16
Doors	3701.6	3.38	3701.6	3.83	3701.6	4.02	3701.6	4.19
Windows - south	5408.8	4.94	5408.8	5.60	3440.1	3.73	5408.8	6.12
Windows - sides	6227.1	5.68	6227.1	6.45	4589.3	4.98	6227.1	7.04
Windows - north	6524.2	5.96	6524.2	6.75	4637.0	5.03	6524.2	7.38
Zone 2: Basement								
Walls above grade	10399.4	9.49	5711.8	5.91	5711.4	6.20	5517.6	6.24
Windows - south	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Windows - sides	3125.6	2.85	3123.1	3.23	2119.0	2.30	3123.4	3.53
Windows - north	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Bel. grd foundation	20234.4	18.47	17368.3	17.98	17367.0	18.84	17164.0	19.41
Ventilation								
house	20820.8	19.01	18680.3	19.34	20740.3	22.50	17729.5	20.05
Total:	109,544	100	96,605	100	92,165	100	88,413	100

Appendix 7b - HOT2000 Results - Retrofits - Wartime

	BASE - Wartime		BATT FOUNDATION		BATT WINDOWS		2X4 BLOWN-IN	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	3.7	20.78	3.7	20.78	3.7	20.78	3.7	20.78
Main Walls	1.4	8.00	1.6	9.14	1.6	9.14	2.3	13.03
Doors	0.4	2.21	0.4	2.21	0.4	2.21	0.4	2.21
Windows - south	0.2	1.36	0.2	1.36	0.4	2.13	0.2	1.36
Windows - sides	0.3	1.57	0.3	1.57	0.4	2.13	0.3	1.57
Windows - north	0.3	1.52	0.3	1.52	0.4	2.13	0.3	1.52
Zone 2: Basement								
Walls above grade	0.7	4.20	1.8	10.44	1.8	10.44	1.9	10.96
Windows - south	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Windows - sides	0.3	1.44	0.3	1.44	0.4	2.13	0.3	1.44
Windows - north	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Bel. grd foundation	0.7	4.20	1.8	10.44	1.8	10.44	1.9	10.96
Ventilation								
house	7.50	ACH	6.75	ACH	6.41	ACH	5.25	ACH

HOT2000 Modelling Summary

Archetype: Wartir
Case: base
Heated Floor Area [m2]: 182

Fuel Consumption Summary:	2x4 B-IN WINDOWS		2x6 B-IN FOUNDATION		2X6 POLYUR. FOUND.		2X4 B-IN SLAB	
Natural Gas [m3]:		2,574.4		2,446.9		2,169.2		2,430.5
Heating	1857.9		1730.0		1452.3		1714.2	
Cooling	0.0		0.0		0.0		0.0	
DHW	716.5		716.9		716.9		716.3	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		11,493.0		11,463.3		10,857.1		11,518.2
Heating	242.4		223.1		180.9		220.8	
Cooling	2025.7		2019.7		1605.3		2039.0	
DHW	0.0		0.0		0.0		0.0	
Appliance	9224.9		9220.5		9070.9		9258.4	
Total Fuel [kWh/m2]:		209		202		183		201

Building Parameters Totals:								
Ceiling	6,958.0	8.57	6,958.0	8.99	6,958.0	10.84	6,958.0	9.14
Walls	16,058.9	19.77	16,058.9	20.74	15,283.2	23.80	16,058.9	21.10
Windows & Doors	18,487.8	22.76	18,494.5	23.89	9,884.6	15.39	18,531.0	24.35
Foundation	22,687.8	27.94	18,888.8	24.40	16,667.8	25.96	17,536.1	23.04
Ventilation	17,020.3	20.96	17,015.9	21.98	15,416.4	24.01	17,018.5	22.36

Component	2x4 B-IN WINDOWS Annual Heat Loss [MJ]	[%]	2x6 B-IN FOUNDATION Annual Heat Loss [MJ]	[%]	2X6 POLYUR. FOUND. Annual Heat Loss [MJ]	[%]	2X4 B-IN SLAB Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	6958.0	8.57	6958.0	8.99	6958.0	10.84	6958.0	9.14
Main Walls	16058.9	19.77	16058.9	20.74	15283.2	23.80	16058.9	21.10
Doors	3701.6	4.56	3701.6	4.78	3701.6	5.76	3701.6	4.86
Windows - south	3440.1	4.24	3440.1	4.44	1555.6	2.42	3440.1	4.52
Windows - sides	4589.3	5.65	4589.3	5.93	2138.1	3.33	4589.3	6.03
Windows - north	4637.0	5.71	4637.0	5.99	1426.5	2.22	4637.0	6.09
Zone 2: Basement								
Walls above grade	5518.8	6.80	3798.6	4.91	2699.4	4.20	5125.7	6.74
Windows - south	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Windows - sides	2119.8	2.61	2126.5	2.75	1062.8	1.66	2163.0	2.84
Windows - north	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Bel. grd foundation	17169.0	21.14	15090.2	19.49	13968.4	21.75	12410.4	16.31
Ventilation								
house	17020.3	20.96	17015.9	21.98	15416.4	24.01	17018.5	22.36
Total:	81,213	100	77,416	100	64,210	100	76,103	100

Appendix 7b - HOT2000 Results - Retrofits - Wartime

	2x4 B-IN WINDOWS		2x6 B-IN FOUNDATION		2X6 POLYUR. FOUND.		2X4 B-IN SLAB	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	3.7	20.78	3.7	20.78	3.7	20.78	3.7	20.78
Main Walls	2.3	13.03	2.3	13.03	2.4	13.69	2.3	13.03
Doors	0.4	2.21	0.4	2.21	0.4	2.21	0.4	2.21
Windows - south	0.4	2.13	0.4	2.13	0.8	4.71	0.4	2.13
Windows - sides	0.4	2.13	0.4	2.13	0.8	4.57	0.4	2.13
Windows - north	0.4	2.13	0.4	2.13	1.2	6.94	0.4	2.13
Zone 2: Basement								
Walls above grade	1.9	10.96	3.2	18.22	5.2	29.40	1.9	10.96
Windows - south	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Windows - sides	0.4	2.13	0.4	2.13	0.7	4.24	0.4	2.13
Windows - north	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Bel. grd foundation	1.9	10.96	3.2	18.22	5.2	29.40	1.9	10.96
Ventilation								
house	4.99	ACH	4.99	ACH	4.39	ACH	4.99	ACH

HOT2000 Modelling Summary

Archetype: Wartir
Case: base
Heated Floor Area [m2]: 182

Fuel Consumption Summary:	2X4 B-IN SLAB+		2x6 B-IN F/S/W		2x6 B-IN CASE		2x6 ICYNENE CASE	
Natural Gas [m3]:		2,420.0		2,126.3		1,867.5		1,784.7
Heating	1703.7		1409.5		1150.7		1067.8	
Cooling	0.0		0.0		0.0		0.0	
DHW	716.3		716.8		716.8		716.9	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		11,517.0		10,919.4		10,876.9		10,848.0
Heating	219.2		174.3		135.5		122.1	
Cooling	2038.7		1631.7		1639.6		1643.0	
DHW	0.0		0.0		0.0		0.0	
Appliance	9259.1		9113.4		9101.8		9082.9	
Total Fuel [kWh/m2]:		201		181		166		161
Building Parameters Totals:								
Ceiling	6,958.0	9.19	6,958.0	11.32	6,958.0	13.05	6,958.0	13.75
Walls	16,058.9	21.20	16,058.9	26.13	16,058.9	30.11	15,543.5	30.72
Windows & Doors	18,532.7	24.47	9,921.5	16.14	7,486.4	14.04	7,483.9	14.79
Foundation	17,180.4	22.68	11,521.6	18.74	11,673.1	21.89	12,280.4	24.27
Ventilation	17,017.9	22.47	17,008.7	27.67	11,151.7	20.91	8,325.4	16.46

Appendix 7b - HOT2000 Results - Retrofits - Wartime

Component	2X4 B-IN SLAB+ Annual Heat Loss [MJ]	[%]	2x6 B-IN F/S/W Annual Heat Loss [MJ]	[%]	2x6 B-IN CASE Annual Heat Loss [MJ]	[%]	2x6 ICYNENE CASE Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	6958.0	9.19	6958.0	11.32	6958.0	13.05	6958.0	13.75
Main Walls	16058.9	21.20	16058.9	26.13	16058.9	30.11	15543.5	30.72
Doors	3701.6	4.89	3701.6	6.02	1266.3	2.37	1266.3	2.50
Windows - south	3440.1	4.54	1555.6	2.53	1555.6	2.92	1555.6	3.07
Windows - sides	4589.3	6.06	2138.1	3.48	2138.1	4.01	2138.1	4.23
Windows - north	4637.0	6.12	1426.5	2.32	1426.5	2.67	1426.5	2.82
Zone 2: Basement								
Walls above grade	4994.2	6.59	3096.8	5.04	3144.2	5.90	3340.7	6.60
Windows - south	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Windows - sides	2164.7	2.86	1099.7	1.79	1099.9	2.06	1097.4	2.17
Windows - north	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Bel. grd foundation	12186.2	16.09	8424.8	13.71	8528.9	15.99	8939.7	17.67
Ventilation								
house	17017.9	22.47	17008.7	27.67	11151.7	20.91	8325.4	16.46
Total:	75,748	100	61,469	100	53,328	100	50,591	100

Appendix 7b - HOT2000 Results - Retrofits - Wartime

	2X4 B-IN SLAB+		2x6 B-IN F/S/W		2x6 B-IN CASE		2x6 ICYNENE CASE	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	3.7	20.78	3.7	20.78	3.7	20.78	3.7	20.78
Main Walls	2.3	13.03	2.3	13.03	2.3	13.03	2.4	13.46
Doors	0.4	2.21	0.4	2.21	1.1	6.47	1.1	6.47
Windows - south	0.4	2.13	0.8	4.71	0.8	4.71	0.8	4.71
Windows - sides	0.4	2.13	0.8	4.57	0.8	4.57	0.8	4.57
Windows - north	0.4	2.13	1.2	6.94	1.2	6.94	1.2	6.94
Zone 2: Basement								
Walls above grade	1.9	10.96	3.2	18.22	3.2	18.22	3.4	19.08
Windows - south	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Windows - sides	0.4	2.13	0.7	4.24	0.7	4.24	0.7	4.24
Windows - north	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Bel. grd foundation	1.9	10.96	3.2	18.22	3.2	18.22	3.4	19.08
Ventilation								
house	4.99	ACH	4.99	ACH	2.85	ACH	1.90	ACH

HOT2000 Modelling Summary

Archetype: Wartir
Case: base
Heated Floor Area [m2]: 182

Fuel Consumption Summary:	2X6 POLYUR. CASE		EXT. INSULATION		EXT. INSUL. FULL		2x6 MAIN WALLS	
Natural Gas [m3]:		1,617.9		1,637.7		1,700.2		1,443.0
Heating	901.4		921.2		983.4		726.5	
Cooling	0.0		0.0		0.0		0.0	
DHW	716.5		716.5		716.8		716.5	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		10,812.8		10,798.1		10,821.9		10,750.1
Heating	96.0		99.2		108.4		68.5	
Cooling	1637.5		1631.4		1638.9		1636.0	
DHW	0.0		0.0		0.0		0.0	
Appliance	9079.3		9067.5		9074.6		9045.6	
Total Fuel [kWh/m2]:		151		152		156		141
Building Parameters Totals:								
Ceiling	6,958.0	15.61	6,958.0	15.18	6,958.0	14.58	6,958.0	18.11
Walls	13,108.8	29.41	13,108.8	28.60	13,108.8	27.47	6,972.9	18.15
Windows & Doors	7,508.0	16.84	7,491.4	16.35	7,484.2	15.68	7,508.0	19.54
Foundation	8,676.1	19.47	9,954.4	21.72	11,857.5	24.84	8,674.1	22.57
Ventilation	8,320.9	18.67	8,320.0	18.15	8,320.3	17.43	8,313.0	21.63

Appendix 7b - HOT2000 Results - Retrofits - Wartime

Component	2X6 POLYUR. CASE Annual Heat Loss		EXTERIOR INSULATION Annual Heat Loss		EXT. INSUL. FULL Annual Heat Loss		2x6 MAIN WALLS Annual Heat Loss	
	[MJ]	[%]	[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	6958.0	15.61	6958.0	15.18	6958.0	14.58	6958.0	18.11
Main Walls	13108.8	29.41	13108.8	28.60	13108.8	27.47	6972.9	18.15
Doors	1266.3	2.84	1266.3	2.76	1266.3	2.65	1266.3	3.30
Windows - south	1555.6	3.49	1555.6	3.39	1555.6	3.26	1555.6	4.05
Windows - sides	2138.1	4.80	2138.1	4.67	2138.1	4.48	2138.1	5.56
Windows - north	1426.5	3.20	1426.5	3.11	1426.5	2.99	1426.5	3.71
Zone 2: Basement								
Walls above grade	2209.8	4.96	2238.6	4.88	3899.2	8.17	2209.2	5.75
Windows - south	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Windows - sides	1121.5	2.52	1104.9	2.41	1097.7	2.30	1121.5	2.92
Windows - north	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Bel. grd foundation	6466.3	14.51	7715.8	16.83	7958.3	16.67	6464.9	16.82
Ventilation								
house	8320.9	18.67	8320.0	18.15	8320.3	17.43	8313.0	21.63
Total:	44,572	100	45,833	100	47,729	100	38,426	100

Appendix 7b - HOT2000 Results - Retrofits - Wartime

	2X6 POLYUR. CASE		EXTERIOR INSULATION		EXT. INSUL. FULL		2x6 MAIN WALLS	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	3.7	20.78	3.7	20.78	3.7	20.78	3.7	20.78
Main Walls	2.8	15.96	2.8	15.96	2.8	15.96	5.3	30.01
Doors	1.1	6.47	1.1	6.47	1.1	6.47	1.1	6.47
Windows - south	0.8	4.71	0.8	4.71	0.8	4.71	0.8	4.71
Windows - sides	0.8	4.57	0.8	4.57	0.8	4.57	0.8	4.57
Windows - north	1.2	6.94	1.2	6.94	1.2	6.94	1.2	6.94
Zone 2: Basement								
Walls above grade	5.2	29.40	7.4	42.01	7.4	42.02	5.2	29.41
Windows - south	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Windows - sides	0.7	4.24	0.7	4.24	0.7	4.24	0.7	4.24
Windows - north	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Bel. grd foundation	5.2	29.40	7.4	42.01	7.4	42.02	5.2	29.41
Ventilation								
house	1.90	ACH	1.90	ACH	1.90	ACH	1.90	ACH

8a – HOT2000 Input Notes – Retrofits – 70s OBC

70s OBC – Retrofits
Schedule of Retrofits used for comparison spreadsheet
File name: 70s OBC – compare retrofits

CAPS LOCK = spreadsheet column heading

Method: make one change, see the results, determine which component has the next biggest heat loss, make adjustments to it, iterate

BASE:
Base Case:
- Starting at 251 kWh/m2
- Biggest issue the walls at 31% of heat loss followed by windows and doors at 28%
  - Jog down to next two with ventilation at 20% and foundation at 18%
  - Ceilings are almost insignificant at 4%
  - This makes sense, the walls are the biggest surface area
    - Ceiling is less than half
    - Foundation is close, but not quite equal

Once again we have to address the walls. Model the four main insulation materials (batt, blown-in, Icynene, and polyurethane), then with semi-invasive ACH reductions. Since these are wall retrofits I can use the chart values without applying the thirds rule.

2X4 BATT WALLS
First insulation material, no extra air sealing measures
- Upgrade wall insulation to veneer, 2x4 batt
- Upgrade headers to R12 batt
  - These would be accessible since I'm tearing apart the wall to re-insulate
    - Tearing apart the wall instead of just adding overtop to maximize R/inch
- Change ach, as per chart of Ext/Int. wout additional air sealing, by 20%
- Results:
  - Windows and doors jump to number one spot at 30%, walls remain high at 25%
  - 234 vs prior 251 kWh/m2

2X4 BATT & ACH
Since wall retrofits lend themselves to air sealing as well let's compare the four insulation materials with the semi-invasive air leakage reductions from the chart
- Change ach to w semi-invasive: 35% for 70s Ext/Int. case
- Results:
  - Ventilation losses drop a little more, for a total reduction of 11% over the base case

8a – HOT2000 Input Notes – Retrofits – 70s OBC

2x4 BLOWN-IN WALLS

Because we need more insulation

- Upgrade walls to blown-in 2x4
- Leave headers at batt since it's a fair proxy for blown-in and Icynene due to their similar R/inch
- Change ach to blown-in wout additional air sealing
  - This happens to be identical to batt so no change needed
- Results:
  - Virtually identical to 2x4 BATT WALLS as expected

2x4 BLOWN-IN & ACH

Now to see how much better using blown-in over batt is from an energy perspective

- Change ach rates to 3 as per chart
- Results:
  - Marginally better than batt for total energy (222 vs 229)
  - Windows at 32% and walls at 26% continue to dominate heat loss

2x4 ICYNENE WALLS

The third type of insulation

- Upgrade to Icynene
  - Walls
  - Headers
- Change ach to spray foam without additional air sealing: 25% reduction
- Results:
  - As expected, very similar to batt and blown-in since they have similar R-value and, without semi-invasive air sealing, similar ach reductions as well

2x4 ICYNENE + ACH

The third type of insulation

- Change ach to spray foam 2.0 ACH value
- Results:
  - Down to 215kWh/m2
  - The walls drop, compared to batt and blown-in, is slight as expected since they all have similar R-values
  - The improvement comes from ventilation and 1ACH out of about 5 before is significant enough to be noticed

2x4 POLYUR. WALLS

Because this has the best R/inch.

- Upgrade to polyurethane
  - Walls
  - Headers

- No change to ach needed since I was already using a spray-foam
- Results:
    - 222 kWh/m2, so a 14% improvement over the base case
        - Identical operating energy to 2x4 BLOWN-IN + ACH, check their embodied effects at a later stage
    - With the polyurethane case the order of heat loss parameters switches from windows, walls, foundations to windows, foundations, walls
        - The walls have a high enough R-value for the default insulated foundation to become the next biggest challenge

2X4 POLYUR. + ACH

Because the cases wouldn't be complete without it

- Drop ach rate to spray-foam 2.0ACH
- Results:
    - 207 kWh/m2 or a reduction of 20% over the base case

Now that the run of 4 insulation materials is done let's jump back to Icynene because it gives pretty good operational performance (17% vs. 20% reduction) without the environmental effects and health issues of polyurethane and model some window changes.

WINDOWS

Using the 2x4 ICYNENE + ACH case as the base and modeling on with next biggest heat loss component

- Change windows to standard double-glazed
    - There are no further air leakage reductions with these windows.
- Results:
    - 203 kWh/m2 which rivals 2x4 polyurethane case
    - Windows and walls tied for first place at 29%, foundation next at 26%
        - Since these are all fairly even model the next step in one go – heat mirror windows and foundation insulation.
            - Leave walls because I don't want to encroach into the interior space yet

WINDOWS + FOUND.

Working on two of the three highest heat loss parameters at once

- Upgrade windows to heat mirror
- Add 2x4 Icynene insulation to the foundation wall
- Results:
    - 179kWh/m2
    - The heat mirror windows make such a big difference. The windows parameter has completely dropped off
        - Walls 35%, foundation 26%, windows 17%

2x6 ICYNENE

8a – HOT2000 Input Notes – Retrofits – 70s OBC

Let's start losing some interior space

- Upgrade walls to thermal bridging reduced, 2x6 Icynene
- Upgrade headers to higher level of Icynene (4.4 header)
- Results:
    - 163 kWh/m2 and foundation takes the top spot for heat loss

2x6 FOUNDATION

Foundation had the highest heat loss. Let's try in two ways, the first is making the walls 2x6

- Upgrade foundation to 2x6 Icynene with the thermal break
- Results:
    - 156 kWh/m2, or a 40% reduction in energy use

2x3 SLAB

Second method to deal with foundation parameter. Which worked better, the 2x6 foundation wall or 2x3 slab?

- Insulate slab with 2x3 XPS
- Results:
    - 156, which is identical to the 2x6 wall option
        - Homeowners can choose whether they want less floor area or less head room
        - What are the embodied effects differences for these two cases?
        - What about building science differences?
    - Results are converging
        - My maxed out windows and ventilation are approaching 20%

POLYURETHANE

Let's just do one more case with things maxed out

- Upgrade walls to 2x6 polyurethane
- Upgrade headers to highest polyurethane; 5.5"
- Upgrade doors to steel w polyurethane cores
- Upgrade foundation to 2x6 polyurethane, thermally broken
- No ach changes since already using spray-foam values
- Results:
    - 141 kWh/m2 -> not that exciting considering how much polyurethane is sprayed
    - Foundation is still a big heat loss area

POLYURETHANE+

To control foundation heat loss add an XPS slab

- Upgrade slab to 2x3 XPS
- Results:
    - Insulating the slab gives you an further 6% reduction for a final of 132kWh/m2
    - The parameters don't converge as well as they did with the Wartime house
        - Ceiling remains at about half the heat loss of the other components

    - Makes sense since it’s about half the area of the other parameters
  - With the foundation wall + slab insulation you can drive that contribution lower than the balance 20%
    - In this case it’s at 16%

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

HOT2000 Modelling Summary

		input
Archetype:	70s OBC	calculated
Case:	base	highest %
Heated Floor Area [m2]:	216	2nd %

Fuel Consumption Summary:	BASE - 70s OBC		2x4 BATT WALLS		2X4 BATT & ACH		2x4 BLOWN-IN WALLS	
Natural Gas [m3]:		3,990.4		3,643.2		3,522.5		3,619.0
Heating	3275.1		2927.9		2807.2		2903.7	
Cooling	0.0		0.0		0.0		0.0	
DHW	715.3		715.3		715.3		715.3	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		12,871.7		12,933.5		13,035.0		12,923.3
Heating	458.7		405.3		386.8		401.4	
Cooling	2830.3		2942.0		3013.0		2939.1	
DHW	0.0		0.0		0.0		0.0	
Appliance	9582.7		9586.2		9635.2		9582.8	
Total Fuel [kWh/m2]:		251		234		229		233

Building Parameters Totals:								
Ceiling	4,803.5	3.61	4,803.5	3.88	4,803.5	4.01	4,803.5	3.91
Walls	40,682.6	30.60	30,853.7	24.95	30,853.7	25.73	30,058.8	24.47
Windows & Doors	37,035.2	27.85	37,035.2	29.95	37,035.3	30.89	37,035.2	30.14
Foundation	26,538.0	19.96	26,537.9	21.46	26,539.7	22.13	26,537.9	21.60
Ventilation	23,907.1	17.98	24,429.2	19.76	20,680.6	17.25	24,426.6	19.88

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

Component	BASE - 70s OBC Annual Heat Loss [MJ]	[%]	2x4 BATT WALLS Annual Heat Loss [MJ]	[%]	2X4 BATT & ACH Annual Heat Loss [MJ]	[%]	2x4 BLOWN-IN WALLS Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	4803.5	3.61	4803.5	3.88	4803.5	4.01	4803.5	3.91
Main Walls	40682.6	30.60	30853.7	24.95	30853.7	25.73	30058.8	24.47
Doors	3701.6	2.78	3701.6	2.99	3701.6	3.09	3701.6	3.01
Windows - south	10863.2	8.17	10863.2	8.78	10863.2	9.06	10863.2	8.84
Windows - sides	9878.1	7.43	9878.1	7.99	9878.1	8.24	9878.1	8.04
Windows - north	9274.0	6.97	9274.0	7.50	9274.0	7.73	9274.0	7.55
Zone 2: Basement								
Walls above grade	10639.7	8.00	10639.7	8.60	10640.3	8.87	10639.7	8.66
Windows - south	829.6	0.62	829.6	0.67	829.6	0.69	829.6	0.68
Windows - sides	1659.1	1.25	1659.1	1.34	1659.2	1.38	1659.1	1.35
Windows - north	829.6	0.62	829.6	0.67	829.6	0.69	829.6	0.68
Bel. grd foundation	15898.3	11.96	15898.2	12.86	15899.4	13.26	15898.2	12.94
Ventilation								
house	23907.1	17.98	24429.2	19.76	20680.6	17.25	24426.6	19.88
Total:	132,966	100	123,660	100	119,913	100	122,862	100

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

	BASE - 70s OBC		2x4 BATT WALLS		2X4 BATT & ACH		2x4 BLOWN-IN WALLS	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	4.2	24	4.2	24	4.2	24	4.2	24
Main Walls	1.7	10	2.3	13	2.3	13	2.3	13
Doors	0.4	2	0.4	2	0.4	2	0.4	2
Windows - south	0.3	2	0.3	2	0.3	2	0.3	2
Windows - sides	0.3	2	0.3	2	0.3	2	0.3	2
Windows - north	0.3	2	0.3	2	0.3	2	0.3	2
Zone 2: Basement								
Walls above grade	1.2	7	1.2	7	1.2	7	1.2	7
Windows - south	0.3	2	0.3	2	0.3	2	0.3	2
Windows - sides	0.3	2	0.3	2	0.3	2	0.3	2
Windows - north	0.3	2	0.3	2	0.3	2	0.3	2
Bel. grd foundation	1.2	7	1.2	7	1.2	7	1.2	7
Ventilation								
house	5.75	ACH	4.60	ACH	3.74	ACH	4.60	ACH

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

HOT2000 Modelling Summary

Archetype: 70s OE
Case: base
Heated Floor Area [m2]: 216

Fuel Consumption Summary:	2x4 BLOWN-IN + ACH		2x4 ICYNENE WALLS		2x4 ICYNENE + ACH		2x4 POLYUR. WALLS	
Natural Gas [m3]:		3,391.2		3,562.1		3,222.9		3,405.5
Heating	2675.9		2846.8		2507.6		2690.2	
Cooling	0.0		0.0		0.0		0.0	
DHW	715.3		715.3		715.3		715.3	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		12,994.2		12,897.7		13,133.8		12,844.7
Heating	366.5		392.1		340.3		367.8	
Cooling	2999.4		2933.5		3082.9		2915.4	
DHW	0.0		0.0		0.0		0.0	
Appliance	9628.3		9572.1		9710.6		9561.5	
Total Fuel [kWh/m2]:		222		230		215		222

Building Parameters Totals:								
Ceiling	4,803.5	4.15	4,803.5	3.97	4,803.5	4.35	4,803.5	4.14
Walls	30,058.8	25.96	29,409.0	24.31	29,409.0	26.63	24,426.4	21.06
Windows & Doors	37,035.4	31.98	37,035.2	30.61	37,035.7	33.54	37,035.2	31.93
Foundation	26,541.2	22.92	26,538.5	21.93	26,543.4	24.04	26,538.5	22.88
Ventilation	17,360.4	14.99	23,205.7	19.18	12,644.3	11.45	23,195.8	20.00

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

Component	2x4 BLOWN-IN + ACH Annual Heat Loss [MJ]	[%]	2x4 ICYNENE WALLS Annual Heat Loss [MJ]	[%]	2x4 ICYNENE + ACH Annual Heat Loss [MJ]	[%]	2x4 POLYUR. WALLS Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	4803.5	4.15	4803.5	3.97	4803.5	4.35	4803.5	4.14
Main Walls	30058.8	25.96	29409.0	24.31	29409.0	26.63	24426.4	21.06
Doors	3701.6	3.20	3701.6	3.06	3701.6	3.35	3701.6	3.19
Windows - south	10863.2	9.38	10863.2	8.98	10863.2	9.84	10863.2	9.36
Windows - sides	9878.1	8.53	9878.1	8.16	9878.1	8.94	9878.1	8.52
Windows - north	9274.0	8.01	9274.0	7.66	9274.0	8.40	9274.0	7.99
Zone 2: Basement								
Walls above grade	10640.8	9.19	10639.9	8.79	10641.5	9.64	10639.9	9.17
Windows - south	829.6	0.72	829.6	0.69	829.7	0.75	829.6	0.72
Windows - sides	1659.3	1.43	1659.1	1.37	1659.4	1.50	1659.1	1.43
Windows - north	829.6	0.72	829.6	0.69	829.7	0.75	829.6	0.72
Bel. grd foundation	15900.4	13.73	15898.6	13.14	15901.9	14.40	15898.6	13.71
Ventilation								
house	17360.4	14.99	23205.7	19.18	12644.3	11.45	23195.8	20.00
Total:	115,799	100	120,992	100	110,436	100	115,999	100

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

	2x4 BLOWN-IN + ACH		2x4 ICYNENE WALLS		2x4 ICYNENE + ACH		2x4 POLYUR. WALLS	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	4.2	24	4.2	24	4.2	24	4.2	24
Main Walls	2.3	13	2.4	13	2.4	13	2.8	16
Doors	0.4	2	0.4	2	0.4	2	0.4	2
Windows - south	0.3	2	0.3	2	0.3	2	0.3	2
Windows - sides	0.3	2	0.3	2	0.3	2	0.3	2
Windows - north	0.3	2	0.3	2	0.3	2	0.3	2
Zone 2: Basement								
Walls above grade	1.2	7	1.2	7	1.2	7	1.2	7
Windows - south	0.3	2	0.3	2	0.3	2	0.3	2
Windows - sides	0.3	2	0.3	2	0.3	2	0.3	2
Windows - north	0.3	2	0.3	2	0.3	2	0.3	2
Bel. grd foundation	1.2	7	1.2	7	1.2	7	1.2	7
Ventilation								
house	3.00	ACH	4.31	ACH	2.00	ACH	4.31	ACH

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

HOT2000 Modelling Summary

Archetype:	70s OE
Case:	base
Heated Floor Area [m2]:	216

Fuel Consumption Summary:	2x4 POLYUR. + ACH		WINDOWS		WINDOWS + FOUND.		2x6 ICYNENE	
Natural Gas [m3]:		3,061.7		3,028.8		2,642.3		2,298.8
Heating	2346.4		2313.4		1926.6		1583.1	
Cooling	0.0		0.0		0.0		0.0	
DHW	715.3		715.4		715.7		715.7	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		13,084.6		12,629.9		11,449.3		11,346.6
Heating	316.4		311.9		253.7		200.1	
Cooling	3066.5		2777.8		1984.2		1947.7	
DHW	0.0		0.0		0.0		0.0	
Appliance	9701.7		9540.2		9211.4		9198.8	
Total Fuel [kWh/m2]:		207		203		179		163

Building Parameters Totals:								
Ceiling	4,803.5	4.56	4,803.5	4.71	4,803.5	5.84	4,803.5	6.74
Walls	24,426.4	23.17	29,409.0	28.85	29,409.0	35.73	18,436.7	25.85
Windows & Doors	37,035.7	35.12	28,626.9	28.08	14,207.3	17.26	14,207.3	19.92
Foundation	26,543.3	25.17	26,466.9	25.96	21,268.4	25.84	21,268.3	29.83
Ventilation	12,634.4	11.98	12,634.7	12.39	12,614.9	15.33	12,593.0	17.66

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

Component	2x4 POLYUR. + ACH Annual Heat Loss [MJ]	[%]	WINDOWS Annual Heat Loss [MJ]	[%]	WINDOWS + FOUND. Annual Heat Loss [MJ]	[%]	2x6 ICYNENE Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	4803.5	4.56	4803.5	4.71	4803.5	5.84	4803.5	6.74
Main Walls	24426.4	23.17	29409.0	28.85	29409.0	35.73	18436.7	25.85
Doors	3701.6	3.51	3701.6	3.63	3701.6	4.50	3701.6	5.19
Windows - south	10863.2	10.30	8529.6	8.37	3811.7	4.63	3811.7	5.35
Windows - sides	9878.1	9.37	7365.0	7.22	3411.5	4.15	3411.5	4.78
Windows - north	9274.0	8.80	6674.2	6.55	2178.5	2.65	2178.5	3.06
Zone 2: Basement								
Walls above grade	10641.5	10.09	10616.2	10.41	6966.1	8.46	6966.1	9.77
Windows - south	829.7	0.79	589.1	0.58	290.6	0.35	290.6	0.41
Windows - sides	1659.4	1.57	1178.3	1.16	581.1	0.71	581.1	0.81
Windows - north	829.7	0.79	589.1	0.58	232.3	0.28	232.3	0.33
Bel. grd foundation	15901.8	15.08	15850.7	15.55	14302.3	17.38	14302.2	20.06
Ventilation								
house	12634.4	11.98	12634.7	12.39	12614.9	15.33	12593.0	17.66
Total:	105,443	100	101,941	100	82,303	100	71,309	100

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

	2x4 POLYUR. + ACH		WINDOWS		WINDOWS + FOUND.		2x6 ICYNENE	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	4.2	24	4.2	24	4.2	24	4.2	24
Main Walls	2.8	16	2.4	13	2.4	13	3.8	21
Doors	0.4	2	0.4	2	0.4	2	0.4	2
Windows - south	0.3	2	0.4	2	0.8	5	0.8	5
Windows - sides	0.3	2	0.4	2	0.8	5	0.8	5
Windows - north	0.3	2	0.4	2	1.2	7	1.2	7
Zone 2: Basement								
Walls above grade	1.2	7	1.2	7	2.0	12	2.0	12
Windows - south	0.3	2	0.4	2	0.8	4	0.8	4
Windows - sides	0.3	2	0.4	2	0.8	4	0.8	4
Windows - north	0.3	2	0.4	2	0.9	5	0.9	5
Bel. grd foundation	1.2	7	1.2	7	2.0	12	2.0	12
Ventilation								
house	2.00	ACH	2.00	ACH	2.00	ACH	2.00	ACH

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

HOT2000 Modelling Summary

Archetype: 70s OE
Case: base
Heated Floor Area [m2]: 216

Fuel Consumption Summary:	2x6 FOUNDATION		2x3 SLAB		POLYURETHANE		POLYURETHANE+	
Natural Gas [m3]:		2,166.9		2,166.9		1,860.6		1,677.9
Heating	1450.2		1450.6		1144.0		961.9	
Cooling	0.0		0.0		0.0		0.0	
DHW	716.7		716.3		716.6		716.0	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		11,310.8		11,349.3		11,231.7		11,256.7
Heating	180.1		180.7		132.7		105.5	
Cooling	1940.2		1955.3		1937.7		1953.4	
DHW	0.0		0.0		0.0		0.0	
Appliance	9190.5		9213.3		9161.3		9197.8	
Total Fuel [kWh/m2]:		156		156		141		132

Building Parameters Totals:								
Ceiling	4,803.5	7.13	4,803.5	7.17	4,803.5	8.38	4,803.5	9.58
Walls	18,436.7	27.37	18,436.7	27.53	12,710.1	22.18	12,710.1	25.34
Windows & Doors	14,213.1	21.10	14,226.3	21.24	11,779.4	20.56	11,840.8	23.61
Foundation	17,315.6	25.71	16,909.3	25.25	15,434.3	26.94	8,217.9	16.39
Ventilation	12,588.8	18.69	12,592.6	18.80	12,572.8	21.94	12,582.7	25.09

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

Component	2x6 FOUNDATION Annual Heat Loss		2x3 SLAB Annual Heat Loss		POLYURETHANE Annual Heat Loss		POLYURETHANE+ Annual Heat Loss	
	[MJ]	[%]	[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	4803.5	7.13	4803.5	7.17	4803.5	8.38	4803.5	9.58
Main Walls	18436.7	27.37	18436.7	27.53	12710.1	22.18	12710.1	25.34
Doors	3701.6	5.50	3701.6	5.53	1266.3	2.21	1266.3	2.52
Windows - south	3811.7	5.66	3811.7	5.69	3811.7	6.65	3811.7	7.60
Windows - sides	3411.5	5.06	3411.5	5.09	3411.5	5.95	3411.5	6.80
Windows - north	2178.5	3.23	2178.5	3.25	2178.5	3.80	2178.5	4.34
Zone 2: Basement								
Walls above grade	4795.7	7.12	6559.4	9.79	3542.0	6.18	2924.1	5.83
Windows - south	292.1	0.43	295.6	0.44	292.5	0.51	308.7	0.62
Windows - sides	584.2	0.87	591.1	0.88	585.0	1.02	617.3	1.23
Windows - north	233.5	0.35	236.3	0.35	233.9	0.41	246.8	0.49
Bel. grd foundation	12519.9	18.59	10349.9	15.45	11892.3	20.75	5293.8	10.55
Ventilation								
house	12588.8	18.69	12592.6	18.80	12572.8	21.94	12582.7	25.09
Total:	67,358	100	66,968	100	57,300	100	50,155	100

Appendix 8b - HOT2000 Results - Retrofits - 70s OBC

	2x6 FOUNDATION		2x3 SLAB		POLYURETHANE		POLYURETHANE+	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	4.2	24	4.2	24	4.2	24	4.2	24
Main Walls	3.8	21	3.8	21	5.5	31	5.5	31
Doors	0.4	2	0.4	2	1.1	6	1.1	6
Windows - south	0.8	5	0.8	5	0.8	5	0.8	5
Windows - sides	0.8	5	0.8	5	0.8	5	0.8	5
Windows - north	1.2	7	1.2	7	1.2	7	1.2	7
Zone 2: Basement								
Walls above grade	3.4	19	2.0	12	5.2	29	5.2	29
Windows - south	0.8	4	0.8	4	0.8	4	0.8	4
Windows - sides	0.8	4	0.8	4	0.8	4	0.8	4
Windows - north	0.9	5	0.9	5	0.9	5	0.9	5
Bel. grd foundation	3.4	19	2.0	12	5.2	29	5.2	29
Ventilation								
house	2.00	ACH	2.00	ACH	2.00	ACH	2.00	ACH

Appendix 9a – HOT2000 Input Notes – Retrofits - Modern

Modern – Retrofits
Schedule of Retrofits used for comparison spreadsheet
File name: Modern – compare retrofits

CAPS LOCK = spreadsheet column heading

Method: make one change, see the results, determine which component has the next biggest heat loss, make adjustments, iterate

BASE:
Base Case:

- Starting at 199 kWh/m2
- Parameter heat loss:
  - Windows & doors at 28% followed by
  - ventilation at 24%
  - walls at 23%
  - foundation at 22%
  - Ceilings are almost insignificant at 4%
- Four of five parameters are within 10% of each other
  - With improvements building code and construction standards the parameters have started converging before retrofits are applied
  - Geometry is still the biggest factor, ie walls have the largest surface area and are the biggest heat loss component
  - Due to the low ACH rates in the base case the relative improvements are slight for the ventilation parameter

SLIDING GLASS
Because there is no easy way to increase the insulation in the walls the first parameter to be retrofitted is windows & doors

- The base case already uses the equivalent of a double glazed, insulated, vinyl framed window so a replacement with an argon filled double-glazed will have a small incremental effect. Go straight to replacement with heat mirror windows
  - Heat mirror is commonly used in sliding glass doors (John Meade, Southwall Technologies, Aug 25) and replacement of sliding glass doors in a new house might not even require a replacement of the frame making it the lest intensive retrofit
- Replace sliding glass doors (south-facing) with HM66
  - 9mm krypton fill, fiberglass frame
- Results
  - 197 kWh/m2
    - Slightly less than base case

        - Windows drops to 25% from 28%
        - Walls increase to 24% and ventilation to 25%
    - This makes sense because of the small surface area of the two sliding doors when compared to all glazing or wall area

DOORS & WINDOWS

Since the improvement was marginal the next retrofit to be modeled is a replacement of all glazing with heat mirrow

- Replace north windows with TC88, replace south and east window with HM66
- Results
    - 183 kWh/m2
        - Walls at 27%, ventilation at 29%
        - Windows & doors drops to 14%
    - An improvement of 8% from base case energy intensity, an improvement of 59% for the windows & doors parameter

GLAZING & VENTILATION

The windows & doors component has been maxed out, the walls remain the highest heat loss parameter but their retrofit is intensive. Again avoiding the majorly invasive retrofits to walls, the next parameter for retrofits is ventilation

- Minor air sealing only improves ACH rates by 5% so modeling will start at semi-invasive air sealing at 15%
    - Change ACH rate from 3.42 to 2.9, ELA from 985 to 837
- Results
    - 179 kWh/m2
        - Walls at 28%, ventilation and foundation still high at 26%
    - Further improvements to either of the two major heat loss components (walls and ventilation) will require major, intensive renovations. Assuming the basement is unfinished the only remaining parameter with a less intensive retrofit is the foundation.

ALL + FOUNDATION

Since few less invasive retrofits are left attempt to max out the less intensive options to see the improvement attainable.

- Retrofits
    - Ceiling, at 3.79%, is an insignificant component and will not be retrofitted regardless of ease of installation
    - Windows & doors
        - Glazing is maxed out from previous retrofit
        - Door maxed out in base case (steel with polyurethane core)
    - Foundation insulation increased to 2.98 with 2x6 blown-in
    - Ventilation is maxed out with semi-invasive retrofits at 2.9
- Results

    - 174 kWh/m2
        - Improvement of 13% from base case
    - Walls 29%, ventilation 27% are still most significant as expected
    - Foundations only dropped to 24% from 26%
        - Only foundation wall surface area was insulated, to get better results the floor slab should be insulated as well

ALL + F. + SLAB

Insulating the floor slab is also a relatively less intensive retrofit and due to the large surface area is expected to have a marked impact on heat loss through the foundation

- Change floor slab to 2x3 XPS floor
- Results
    - 166 kWh/m2
        - Improvement of 16% from base case, 37% from foundation parameter
    - Walls at 31%, ventilation at 29%, remaining parameters below 20%
    - No more lightly invasive retrofits remain, must move to major renovations

2x6 BLOWN-IN

Due to the high starting wall RSI value of 2.9 wall retrofit modeling starts with thermally broken double stud walls

- Change walls to double-stud 2x6 dense, RSI 3.92
    - For main floor apply weighted garage factor of 1.09 for a resulting RSI of 3.99
- Change air tightness to blown-in with semi-invasive measures level
- Change header to RSI 3.5 Icynene
- Results
    - 185 kWh/m2
        - Improvement of 7% over base case
        - Windows & door still the main heat loss parameter at 32%
        - Walls drop to 19%, ventilation drops to 23%

2x6 ICYNENE

Work the model through the next material option

- Change walls to 2x6 double-stud dense
    - Apply 1.09 garage factor to main floor
- Change air tightness to foam with semi-invasive measures level
- Results
    - 177 kWh/m2
        - Better performance than blown-in cellulose as expected due partly to slightly better R-value per inch, but mostly to ACH reductions
    - Windows & doors first at 33%
    - Walls at 19% are less significant than foundation at 25%

Appendix 9a – HOT2000 Input Notes – Retrofits - Modern

2x6 POLYURETHANE

Max out the insulation per inch value by using polyurethane

- Change walls to 2x6 polyurethane
- Change headers to 4.5" polyurethane
- Change air leakage to foam levels
- Results
    - 169 kWh/m2
        - Improvement of 15% from base case
    - Windows & doors at 35%, foundation at 27%

BLOWN-IN+

With the increase to wall insulation windows & doors and foundation become the next biggest parameters of heat loss. The next set of modeled cases adds retrofits to these parameters.

- Start with 2x6 BLOWN-IN
- Change all glazing to heat mirror
- Change foundation wall insulation to 2x6 blown-in
- Results
    - 162 kWh/m2
    - Walls and foundation at 25%, ventilation at 29%
    - This combination of retrofits shift heat loss back to the parameters that have been maxed out. Ventilation maxed out due to chart limits, walls are at the imposed limit of 6" insulation

ICYNENE+

Next material

- Start with 2x6 ICYNENE
- Change all glazing to heat mirror
- Change foundation to 2x6 Icyene
- Results
    - 153 kWh/m2
    - Walls 25%, ventilation 25%, foundation 27%

POLYURETHANE+

Last material

- Start with 2x6 POLYURETHANE
- Change all glazing to heat mirror
- Change foundation to 2x6 polyurethane
- Results
    - 141 kWh/m2
        - Improvement in energy intensity of 29% from base case
    - Ventilation at 28%, walls at 20%, foundation at 26%

    - Ventilation is maxed out, walls have hit reports 6" of insulation, foundation still has the option of insulating the slab to improve performance
  - Ceiling is at 5%, the parameters have not all converged in this archetype

ICYNENE+ & FOUNDATION

With the two highest heat loss parameters maxed out (walls and ventilation), focus shift to the third, foundations, to insulate the slab

- Start with ICYNENE+
- Change foundation insulation to include 2x3 XPS slab
- Results
  - 143 kWh/m2
    - Energy intensity drops a further 10 kWh/m2 from the ICYNENE+ case for a total reduction of 28% from the base case
  - Walls at 28%, ventilation at 27%
  - Foundation drops significantly from 26% to 19% of heat loss

BEL. 100 BLOWN-IN

How much insulation needs to be added to walls and foundation (windows & door and ventilation maxed out already, ceilings not yet significant) to drop energy intensity further below 100 kWh/m2

- Changes:
  - Change all glazing to heat mirror
  - Keep ventilation at lowest attainable as per air sealing chart, 2.75ACH
  - Change wall and foundation wall insulation to 2x8 blown-in
  - Change slab to 2x3 XPS
  - Change headers to RSI 4.55
  - Change garage ceiling to 4.89 to match main wall insulation
- Results
  - 143 kWh/m2 total energy intensity
  - 73 kWh/m2 for heating and cooling alone
    - Using blown-in insulation and maxing out other parameters the Modern archetype needs a thermally broken, 2x8" equivalent, double stud wall cavity to drop below the target 100 kWh/m2

WINDOW TEST

Is it better to use HM66, which is cheaper and allows more solar gains, on the south and east/west elevations than to use all TC88?

- HM66 has an RSI of 0.78 – 0.86 compared with 0.99 – 1.15 for TC88
- With the mixed orientation windows you have 143 kWh/m2 versus 139 with all TC88
  - Result valid only for this orientation (front = north)
  - 20% improvement in window parameter, 2.5% energy intensity improvement
    - Homeowner will have to decide if the cost is worth the improvement

9b - HOT2000 Results - Retrofits - Modern

HOT2000 Modelling Summary

		input
Archetype:	Modern	calculated
Case:	base	highest %
Heated Floor Area [m2]:	239	2nd %

Fuel Consumption Summary:	BASE - MODERN		SLIDING GLASS		DOORS & WINDOWS		GLAZING & VENT.	
Natural Gas [m3]:		3,373.0		3,351.8		3,109.5		3,005.7
Heating	2659.9		2638.7		2395.5		2291.7	
Cooling	0.0		0.0		0.0		0.0	
DHW	713.1		713.1		714.0		714.0	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		12,716.8		12,405.1		11,692.7		11,660.3
Heating	365.4		362.0		325.3		309.4	
Cooling	2694.2		2451.1		2000.3		1993.5	
DHW	0.0		0.0		0.0		0.0	
Appliance	9657.2		9592.0		9367.1		9357.4	
Total Fuel Consumption [kWh/m2]:		199		197		183		179
Heating & Cooling only [kWh/m2]		128		126		113		109

Building Parameters Totals:								
Ceiling	4,279.7	3.68	4,279.7	3.80	4,279.7	4.42	4,279.7	4.57
Walls	26,626.2	22.87	26,626.2	23.66	26,626.2	27.47	26,626.2	28.40
Windows & Doors	32,469.7	27.89	28,621.9	25.43	13,381.0	13.81	13,381.9	14.28
Foundation	25,158.4	21.61	25,158.4	22.35	24,777.0	25.57	24,782.4	26.44
Ventilation	27,876.0	23.95	27,873.1	24.76	27,850.3	28.74	24,668.8	26.32

9b - HOT2000 Results - Retrofits - Modern

Component	BASE - MODERN Annual Heat Loss [MJ]	[%]	SLIDING GLASS Annual Heat Loss [MJ]	[%]	DOORS & WINDOWS Annual Heat Loss [MJ]	[%]	GLAZING & VENT. Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	4279.7	3.68	4279.7	3.80	4279.7	4.42	4279.7	4.57
Main Walls	26626.2	22.87	26626.2	23.66	26626.2	27.47	26626.2	28.40
Doors	633.2	0.54	633.2	0.56	633.2	0.65	633.2	0.68
Windows - south	11872.9	10.20	8025.1	7.13	5069.7	5.23	5069.7	5.41
Windows - sides	3492.2	3.00	3492.2	3.10	1614.6	1.67	1614.6	1.72
Windows - north	4812.0	4.13	4812.0	4.28	1409.8	1.45	1409.8	1.50
Zone 2: Basement								
Walls above grade	13437.8	11.54	13437.8	11.94	13261.9	13.68	13264.4	14.15
Windows - south	4869.3	4.18	4869.3	4.33	2012.2	2.08	2012.6	2.15
Windows - sides	3344.6	2.87	3344.6	2.97	1526.1	1.57	1526.4	1.63
Windows - north	3445.5	2.96	3445.5	3.06	1115.4	1.15	1115.6	1.19
Bel. grd foundation	11720.6	10.07	11720.6	10.41	11515.1	11.88	11518.0	12.29
Ventilation								
house	27876.0	23.95	27873.1	24.76	27850.3	28.74	24668.8	26.32
Total:	116,410	100	112,559	100	96,914	100	93,739	100

9b - HOT2000 Results - Retrofits - Modern

	BASE - MODERN		SLIDING GLASS		DOORS & WINDOWS		GLAZING & VENT.	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	5.8	33	5.8	33	5.8	33	5.8	33
Main Walls	2.7	16	2.7	16	2.7	16	2.7	16
Doors	1.1	6	1.1	6	1.1	6	1.1	6
Windows - south	0.4	2	0.5	3	0.8	5	0.8	5
Windows - sides	0.4	2	0.4	2	0.8	4	0.8	4
Windows - north	0.4	2	0.4	2	1.2	7	1.2	7
Zone 2: Basement								
Walls above grade	2.0	11	2.0	11	2.0	11	2.0	11
Windows - south	0.4	2	0.4	2	0.9	5	0.9	5
Windows - sides	0.4	2	0.4	2	0.8	4	0.8	4
Windows - north	0.4	2	0.4	2	1.1	6	1.1	6
Bel. grd foundation	2.0	11	2.0	11	2.0	11	2.0	11
Ventilation								
house	3.42	ACH	3.42	ACH	3.42	ACH	2.90	ACH

9b - HOT2000 Results - Retrofits - Modern

HOT2000 Modelling Summary

Archetype: Moder
Case: base
Heated Floor Area [m2]: 239

Fuel Consumption Summary:	ALL + FOUNDATION		ALL + F. + SLAB		2x6 BLOWN-IN		2X6 ICYNENE	
Natural Gas [m3]:		2,909.7		2,719.2		3,042.0		2,851.0
Heating	2195.7		2006.3		2328.9		2137.9	
Cooling	0.0		0.0		0.0		0.0	
DHW	714.0		712.9		713.1		713.1	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		11,616.8		11,596.9		12,792.1		12,749.8
Heating	295.2		265.8		314.0		284.9	
Cooling	1982.8		1983.4		2749.1		2739.7	
DHW	0.0		0.0		0.0		0.0	
Appliance	9338.8		9347.7		9729.0		9725.2	
Total Fuel Consumption [kWh/m2		174		166		185		177
Heating & Cooling only [kWh/m2]		105		96		114		105

Building Parameters Totals:								
Ceiling	4,279.7	4.70	4,279.7	5.04	4,279.7	4.05	4,279.7	4.29
Walls	26,626.2	29.24	26,626.2	31.36	20,194.3	19.10	19,026.2	19.09
Windows & Doors	13,379.6	14.69	13,459.0	15.85	32,472.6	30.71	32,476.5	32.58
Foundation	22,116.6	24.29	15,874.2	18.69	25,165.8	23.80	25,175.3	25.26
Ventilation	24,666.4	27.09	24,675.7	29.06	23,642.2	22.36	18,720.8	18.78

9b - HOT2000 Results - Retrofits - Modern

Component	ALL + FOUNDATION Annual Heat Loss [MJ]	[%]	ALL + F. + SLAB Annual Heat Loss [MJ]	[%]	2x6 BLOWN-IN Annual Heat Loss [MJ]	[%]	2X6 ICYNENE Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	4279.7	4.70	4279.7	5.04	4279.7	4.05	4279.7	4.29
Main Walls	26626.2	29.24	26626.2	31.36	20194.3	19.10	19026.2	19.09
Doors	633.2	0.70	633.2	0.75	633.2	0.60	633.2	0.64
Windows - south	5069.7	5.57	5069.7	5.97	11872.9	11.23	11872.9	11.91
Windows - sides	1614.6	1.77	1614.6	1.90	3492.2	3.30	3492.2	3.50
Windows - north	1409.8	1.55	1409.8	1.66	4812.0	4.55	4812.0	4.83
Zone 2: Basement								
Walls above grade	10342.6	11.36	9715.3	11.44	13441.2	12.71	13445.6	13.49
Windows - south	2011.6	2.21	2045.9	2.41	4870.6	4.61	4872.2	4.89
Windows - sides	1525.7	1.68	1551.7	1.83	3345.4	3.16	3346.5	3.36
Windows - north	1115.0	1.22	1134.1	1.34	3446.3	3.26	3447.5	3.46
Bel. grd foundation	11774.0	12.93	6158.9	7.25	11724.6	11.09	11729.7	11.77
Ventilation								
house	24666.4	27.09	24675.7	29.06	23642.2	22.36	18720.8	18.78
Total:	91,069	100	84,915	100	105,755	100	99,679	100

9b - HOT2000 Results - Retrofits - Modern

	ALL + FOUNDATION		ALL + F. + SLAB		2x6 BLOWN-IN		2X6 ICYNENE	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	5.8	33	5.8	33	5.8	33	5.8	33
Main Walls	2.7	16	2.7	16	3.6	21	3.8	22
Doors	1.1	6	1.1	6	1.1	6	1.1	6
Windows - south	0.8	5	0.8	5	0.4	2	0.4	2
Windows - sides	0.8	4	0.8	4	0.4	2	0.4	2
Windows - north	1.2	7	1.2	7	0.4	2	0.4	2
Zone 2: Basement								
Walls above grade	3.0	17	3.0	17	2.0	11	2.0	11
Windows - south	0.9	5	0.9	5	0.4	2	0.4	2
Windows - sides	0.8	4	0.8	4	0.4	2	0.4	2
Windows - north	1.1	6	1.1	6	0.4	2	0.4	2
Bel. grd foundation	3.0	17	3.0	17	2.0	11	2.0	11
Ventilation								
house	2.90	ACH	2.90	ACH	2.75	ACH	2.00	ACH

9b - HOT2000 Results - Retrofits - Modern

HOT2000 Modelling Summary

Archetype: Moder
Case: base
Heated Floor Area [m2]: 239

Fuel Consumption Summary:	2x6 POLYURETHANE		BLOWN-IN+		ICYNENE+		POLYURETHANE+	
Natural Gas [m3]:		2,673.1		2,626.8		2,419.8		2,158.0
Heating	1960.0		1913.0		1706.1		1442.2	
Cooling	0.0		0.0		0.0		0.0	
DHW	713.1		713.8		713.7		715.8	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		12,716.1		11,531.5		11,469.3		11,386.1
Heating	257.9		251.3		220.0		179.2	
Cooling	2735.0		1956.3		1943.3		1923.9	
DHW	0.0		0.0		0.0		0.0	
Appliance	9723.2		9323.9		9306.0		9283.0	
Total Fuel Consumption [kWh/m2		169		162		153		141
Heating & Cooling only [kWh/m2]		97		92		83		71

Building Parameters Totals:								
Ceiling	4,279.7	4.56	4,279.7	5.21	4,279.7	5.65	4,279.7	6.35
Walls	13,215.7	14.08	20,194.3	24.58	19,026.2	25.12	13,215.7	19.60
Windows & Doors	32,476.5	34.60	13,396.7	16.31	13,399.9	17.69	13,413.3	19.90
Foundation	25,175.3	26.82	20,652.5	25.14	20,334.3	26.85	17,813.1	26.42
Ventilation	18,714.2	19.94	23,619.9	28.75	18,699.2	24.69	18,690.2	27.73

9b - HOT2000 Results - Retrofits - Modern

Component	2x6 POLYURETHANE Annual Heat Loss [MJ]	[%]	BLOWN-IN+ Annual Heat Loss [MJ]	[%]	ICYNENE+ Annual Heat Loss [MJ]	[%]	POLYURETHANE+ Annual Heat Loss [MJ]	[%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	4279.7	4.56	4279.7	5.21	4279.7	5.65	4279.7	6.35
Main Walls	13215.7	14.08	20194.3	24.58	19026.2	25.12	13215.7	19.60
Doors	633.2	0.67	633.2	0.77	633.2	0.84	633.2	0.94
Windows - south	11872.9	12.65	5069.7	6.17	5069.7	6.69	5069.7	7.52
Windows - sides	3492.2	3.72	1614.6	1.97	1614.6	2.13	1614.6	2.40
Windows - north	4812.0	5.13	1409.8	1.72	1409.8	1.86	1409.8	2.09
Zone 2: Basement								
Walls above grade	13445.6	14.32	9583.9	11.67	9283.9	12.26	6870.4	10.19
Windows - south	4872.2	5.19	2019.0	2.46	2020.4	2.67	2026.2	3.01
Windows - sides	3346.5	3.57	1531.3	1.86	1532.3	2.02	1536.7	2.28
Windows - north	3447.5	3.67	1119.1	1.36	1119.9	1.48	1123.1	1.67
Bel. grd foundation	11729.7	12.50	11068.6	13.47	11050.4	14.59	10942.7	16.23
Ventilation								
house	18714.2	19.94	23619.9	28.75	18699.2	24.69	18690.2	27.73
Total:	93,861	100	82,143	100	75,739	100	67,412	100

9b - HOT2000 Results - Retrofits - Modern

	2x6 POLYURETHANE		BLOWN-IN+		ICYNENE+		POLYURETHANE+	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	5.8	33	5.8	33	5.8	33	5.8	33
Main Walls	5.5	31	3.6	21	3.8	22	5.5	31
Doors	1.1	6	1.1	6	1.1	6	1.1	6
Windows - south	0.4	2	0.8	5	0.8	5	0.8	5
Windows - sides	0.4	2	0.8	4	0.8	4	0.8	4
Windows - north	0.4	2	1.2	7	1.2	7	1.2	7
Zone 2: Basement								
Walls above grade	2.0	11	3.2	18	3.4	19	5.2	29
Windows - south	0.4	2	0.9	5	0.9	5	0.9	5
Windows - sides	0.4	2	0.8	4	0.8	4	0.8	4
Windows - north	0.4	2	1.1	6	1.1	6	1.1	6
Bel. grd foundation	2.0	11	3.2	18	3.4	19	5.2	29
Ventilation								
house	2.00	ACH	2.75	ACH	2.00	ACH	2.00	ACH

9b - HOT2000 Results - Retrofits - Modern

HOT2000 Modelling Summary

Archetype:	Moder
Case:	base
Heated Floor Area [m2]:	239

Fuel Consumption Summary:	ICYNENE+ & FOUND.		BEL. 100 BLOWN-IN		WINDOW TEST	
Natural Gas [m3]:		2,197.4		2,190.5		2,087.2
Heating	1482.5		1475.8		1372.5	
Cooling	0.0		0.0		0.0	
DHW	714.9		714.7		714.7	
Appliance	0.0		0.0		0.0	
Electricity [kWh]:		11,440.4		11,442.1		11,695.7
Heating	185.8		185.0		168.4	
Cooling	1942.1		1938.6		2142.2	
DHW	0.0		0.0		0.0	
Appliance	9312.5		9318.5		9385.1	
Total Fuel Consumption [kWh/m2		143		143		139
Heating & Cooling only [kWh/m2]		73		73		69

Building Parameters Totals:						
Ceiling	4,279.7	6.26	4,279.7	6.29	4,279.7	6.39
Walls	19,026.2	27.83	15,151.0	22.25	18,945.5	28.27
Windows & Doors	13,520.3	19.78	13,540.6	19.89	10,859.4	16.21
Foundation	12,833.1	18.77	11,486.8	16.87	14,215.0	21.21
Ventilation	18,711.1	27.37	23,635.5	34.71	18,707.2	27.92

9b - HOT2000 Results - Retrofits - Modern

Component	ICYNENE+ & FOUND. Annual Heat Loss [MJ]	[%]	BEL. 100 BLOWN-IN Annual Heat Loss [MJ]	[%]	WINDOW TEST Annual Heat Loss [MJ]	[%]
Building Parameters Summary:						
Zone 1: Above Grade						
Ceiling	4279.7	6.26	4279.7	6.29	4279.7	6.39
Main Walls	19026.2	27.83	15151.0	22.25	18945.5	28.27
Doors	633.2	0.93	633.2	0.93	633.2	0.94
Windows - south	5069.7	7.42	5069.7	7.45	3607.3	5.38
Windows - sides	1614.6	2.36	1614.6	2.37	1270.3	1.90
Windows - north	1409.8	2.06	1409.8	2.07	1409.8	2.10
Zone 2: Basement						
Walls above grade	7870.3	11.51	7038.4	10.34	8732.0	13.03
Windows - south	2072.4	3.03	2081.2	3.06	1546.8	2.31
Windows - sides	1571.8	2.30	1578.5	2.32	1240.1	1.85
Windows - north	1148.8	1.68	1153.6	1.69	1151.9	1.72
Bel. grd foundation	4962.8	7.26	4448.4	6.53	5483.0	8.18
Ventilation						
house	18711.1	27.37	23635.5	34.71	18707.2	27.92
Total:	68,370	100	68,094	100	67,007	100

9b - HOT2000 Results - Retrofits - Modern

	ICYNENE+ & FOUND.		BEL. 100 BLOWN-IN		WINDOW TEST	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade						
Ceiling	5.8	33	5.8	33	5.8	33
Main Walls	3.8	22	4.8	27	3.9	22
Doors	1.1	6	1.1	6	1.1	6
Windows - south	0.8	5	0.8	5	1.2	7
Windows - sides	0.8	4	0.8	4	1.0	6
Windows - north	1.2	7	1.2	7	1.2	7
Zone 2: Basement						
Walls above grade	3.4	19	4.4	25	3.4	19
Windows - south	0.9	5	0.9	5	1.2	7
Windows - sides	0.8	4	0.8	4	1.0	6
Windows - north	1.1	6	1.1	6	1.1	6
Bel. grd foundation	3.4	19	4.4	25	3.4	19
Ventilation						
house	2.00	ACH	2.75	ACH	2.00	ACH

Appendix 10 - Operationally Equal Insulation

	Unit	Insulation [RSI-2.11 eq.]			
		Batt	Blown-in	XPS	Polyiso
Primary Energy Consumption	[MJ]	34.75	4.34	100.28	61.77
Weighted Resource Use	[kg]	3.59	1.94	2.79	2.16
Global Warming Potential	[kg CO2 eq.]	2.06	0.19	4.92	6.14
Acidification Potential	[moles H+ eq.]	0.78	0.07	1.51	1.06
HH Respiratory Effects Potential	[kg PM2.5 eq.]	0.0203	0.0003	0.0018	0.0031
Eutrophication Potential	[kg N eq.]	3.49E-06	1.97E-07	4.28E-06	2.84E-06
Ozone Depletion Potential	[kg CFC-11 eq.]	3.78E-10	8.81E-10	7.13E-11	1.07E-09
Smog Potential	[kg NOx eq.]	0.0035	0.0002	0.0997	0.0087

Appendix 11 – Athena Input Notes – Operationally Equal - Wartime

ATHENA Inputs – Operationally Equal

- Operationally equal will have (at least 3 files)
    - 2x6 B-In. Foundation – Wartime case with 201 kWh/m2
    - 2x4 B-In. + Slab – Wartime case with 202 kWh/m2
        - Comparing the 2x6 blown-in foundation to a 2x4 blown-in foundation with an XPS insulated slab
    - Input only the differences between the two retrofit cases to get the avoided impacts.

DELTA, Case 2 (2x4 blown-in + slab):

- Case 2 = 2x4 B-In. + Slab, Case 1 = 2x6 B-In. Foundation
- To get the difference between the two individual choices (2x6 foundation vs. 2x4 foundation + slab) I need a file with just the difference between those two and excluding all the retrofits they have in common. The differences are:
    - Foundation wall
    - Slab
- Input any materials case 2 has above the total of those materials in case 1

Foundation Wall: using a 2x4 instead of a 2x3

- Assembly
    - Exterior
    - No sheathing
    - 600 o.c. spacing
    - Green lumber
    - 38x64 (smallest choice available)
        - Since only 1" difference is needed and when I input Delta, Case 1 I'll need to select a framing member size as well I can just use 2x4 for case 2 and a 2x3 in case 1 and I'll have my 1" delta
            - Once I subtract the effect from a 2x3 frame wall that is
- Openings – no differences
- Envelope – Case 2 has less insulation than case 1 so no input needed

Slab: case 2 has slab insulation while case 1 doesn't have any

- Assembly/Opening/Envelope
    - Same inputs as case 2, copied to below:

New Wall/slab

- It's constructed like a horizontal wall (framing, sheathing, insulation, vapour retarder, "cladding") so of the Athena options this is the closest
- Length = 13, height = 7 – this will give the correct area for the floor, but there will be some extra framing because the floor doesn't need double sill plates or bracing for example
- Assembly
    - Wall type = exterior
    - Sheathing type = plywood

    - Solid walking surface
  - Stud spacing = 400 o.c.
    - 16” o/c since the floor will be walked on
  - Stud type = green lumber
  - Stud thickness = 38x64
    - Using 2x3s to limit the amount of lost head room in the basement
- Opening
  - n/a
- Envelope
  - XPS 64mm
  - Polyethylene 6mil
  - Athena has no flooring options so inputting grout and tile over the plywood floor is not an option

DELTA, CASE 1 (2x6 B-In. Foundation)

- This case has more blown-in insulation than case 1

Foundation:

- Assembly
  - Exterior
  - No sheathing
  - 24” o.c.
  - Green lumber
  - 2x3
    - As per case 2 stud amount decision (2x4 – 2x3 = 1” delta)
  - 74mm of blown-in cellulose (138 - 64 = 74 delta)

2X3 FRAME WALL

- Need this to subtract from delta cases

Appendix 12 – Operationally Equal – 70s OBC

ATHENA Inputs – Operationally Equal – 70s OBC

- Operationally equal will have two files, one from each case, to get the difference in embodied effect between the two cases
    - Case 1 - 2x4 blown-in + ACH – 70s OBC case with 222 kWh/m2
    - Case 2 - 2x4 polyurethane – 70s OBC case with 222 kWh/m2
        - Comparing a milder insulating material with air sealing measures (Case 1) to a harsher insulating material with no additional air sealing measures (Case2)

Case 1 - 2x4 blown-in + ACH:

New Project:

- Gross floor area = 216m2
- Building type = single family residential
- Project location = Toronto
- Building life expectancy = 60yrs

New Wall/2x4 blown-in:

- Assembly
    - Wall type = exterior
    - Sheathing type = none
    - Stud spacing = 400 o.c.
    - Stud type = green lumber
    - Stud thickness = 38x89
- Opening
    - No. Of windows = 0
    - No. Of doors = 0
- Envelope
    - Blown cellulose 88.9mm
    - Polyethylene 6mil
    - Gypsum regular 5/8”

Extra Basic Materials:

- Necessary to account for the additional air sealing measures. The following are typically used during air sealing and so are used in the model
    - Polyethylene sheets
        - Input 286m2 to cover wall and ceiling surface area
    - Sealant
        - No common sealant options such as silicone or polyurethane available in Athena database, assume a negligible impact
    - Spray foam
        - Foam polyiscocyanurate is a good proxy for polyurethane as well so it is selected
        - Assume 5m2 at a thickness of 25mm will suffice to seal selected spots like penetrations, difficult to access areas, etc.

Appendix 12 – Operationally Equal – 70s OBC

Case 2 - 2x4 polyurethane:
New Project:

- Gross floor area = 216m2
- Building type = single family residential
- Project location = Toronto
- Building life expectancy = 60yrs

New Wall/polyurethane:

- Assembly
  - Wall type = exterior
  - Sheathing type = none
  - Stud spacing = 400 o.c.
  - Stud type = green lumber
  - Stud thickness = 38x89
- Opening
  - No. Of windows = 0
  - No. Of doors = 0
- Envelope
  - polyurethane 89mm
  - Polyethylene 6mil not necessary, not input
    - As per NRCan (http://www.nrc-cnrc.gc.ca/eng/ibp/irc/ctus/ctus-n32.html) polyurethane spray foam can be used as a vapour retarder when sprayed 40mm or thicker
  - Gypsum regular 5/8”

INPUTS

Archetype:	Century
Case 1:	COMBO+ CONT.
Case 2:	2x6 BATT MAX
No. Years:	60

		Case 1	Case 2	BS Factor
Embodied	Units	COMBO+ CONT.	2x6 BATT MAX	
Primary Energy Consumption	MJ	82509	61639	1.00
Weighted Resource Use	kg	9501	10031	1.00
Global Warming Potential	kg CO2 eq	6425	3282	1.00
Acidification Potential	moles H+ eq.	1349	1217	1.00
HH Respiratory Effects Potential	kg PM2.5 eq.	5.26	19.73	1.00
Eutrophication Potential	kg N eq.	0.008322422	0.010362781	1.00
Ozone Depletion Potential	kg CFC-11 eq.	1.81884E-05	2.6606E-06	1.00
Smog Potential	kg NOx eq.	19.25	5.15	1.00

		Case 1	Case 2	No. Years
		COMBO+ CONT.	2x6 BATT MAX	
Electricity [kWh/yr]	Units	11582.9	11,394.80	60
Primary Energy Consumption	MJ	7.29E+00	7.29E+00	
Weighted Resource Use	kg	3.73E-01	3.73E-01	
Global Warming Potential	kg CO2 eq	2.70E-01	2.70E-01	
Acidification Potential	moles H+ eq.	1.03E-01	1.03E-01	
HH Respiratory Effects Potential	kg PM2.5 eq.	5.64E-04	5.64E-04	
Eutrophication Potential	kg N eq.	1.55E-07	1.55E-07	
Ozone Depletion Potential	kg CFC-11 eq.	3.10E-13	3.10E-13	
Smog Potential	kg NOx eq.	1.06E-04	1.06E-04	

		Case 1	Case 2	No. Years
		COMBO+ CONT.	2x6 BATT MAX	
Natural Gas [m3/yr]	Units	3418.6	3251.1	60
Primary Energy Consumption	MJ	4.19E+01	4.19E+01	
Weighted Resource Use	kg	1.54E+00	1.54E+00	
Global Warming Potential	kg CO2 eq	2.17E+00	2.17E+00	
Acidification Potential	moles H+ eq.	9.12E-01	9.12E-01	
HH Respiratory Effects Potential	kg PM2.5 eq.	4.33E-03	4.33E-03	
Eutrophication Potential	kg N eq.	4.76E-06	4.76E-06	
Ozone Depletion Potential	kg CFC-11 eq.	0.00E+00	0.00E+00	
Smog Potential	kg NOx eq.	5.94E-04	5.94E-04	

OUTPUTS

Archetype: Century
Case 1: COMBO+ CONT.
Case 2: 2x6 BATT MAX
No. Years: 60

Embodied	Units	Case 1 COMBO+ CONT.	Case 2 2x6 BATT MAX
Primary Energy Consumption	MJ	8.25E+04	6.16E+04
Weighted Resource Use	kg	9.50E+03	1.00E+04
Global Warming Potential	kg CO2 eq	6.43E+03	3.28E+03
Acidification Potential	moles H+ eq.	1.35E+03	1.22E+03
HH Respiratory Effects Potential	kg PM2.5 eq.	5.26E+00	1.97E+01
Eutrophication Potential	kg N eq.	8.32E-03	1.04E-02
Ozone Depletion Potential	kg CFC-11 eq.	1.82E-05	2.66E-06
Smog Potential	kg NOx eq.	1.92E+01	5.15E+00

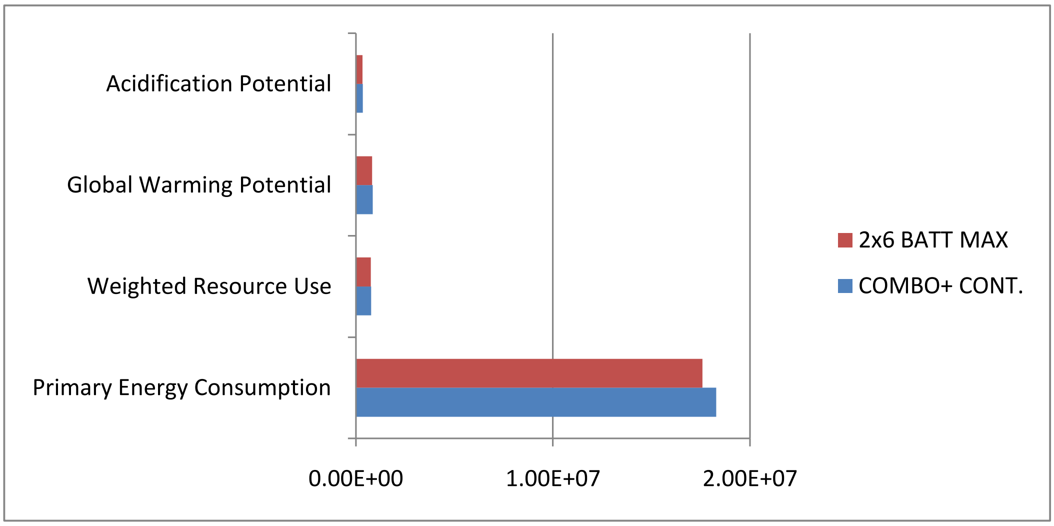
Electricity [kWh/yr]	Units	Case 1 COMBO+ CONT.	Case 2 2x6 BATT MAX
Primary Energy Consumption	MJ	5.07E+06	4.99E+06
Weighted Resource Use	kg	2.59E+05	2.55E+05
Global Warming Potential	kg CO2 eq	1.88E+05	1.85E+05
Acidification Potential	moles H+ eq.	7.18E+04	7.06E+04
HH Respiratory Effects Potential	kg PM2.5 eq.	3.92E+02	3.85E+02
Eutrophication Potential	kg N eq.	1.08E-01	1.06E-01
Ozone Depletion Potential	kg CFC-11 eq.	2.16E-07	2.12E-07
Smog Potential	kg NOx eq.	7.36E+01	7.25E+01

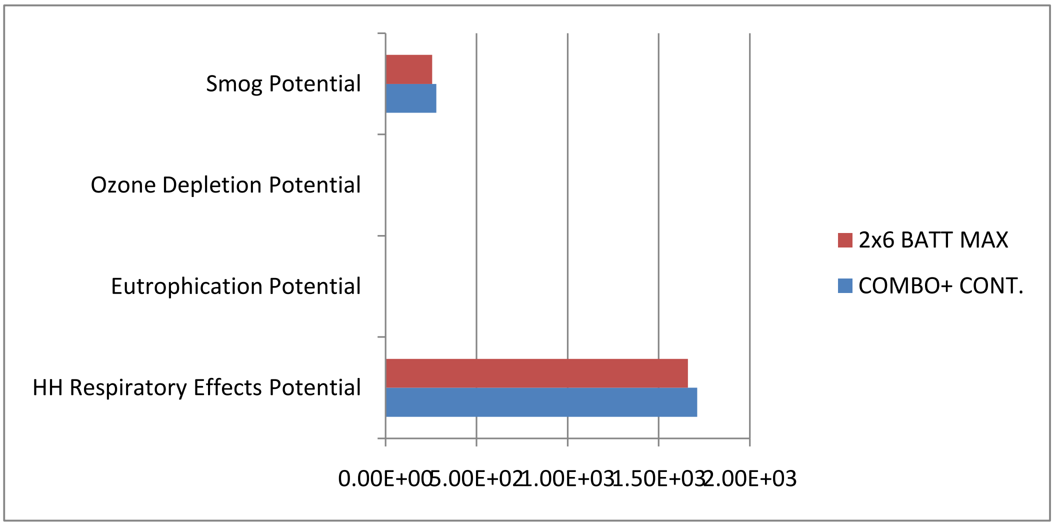
Natural Gas [m3/yr]	Units	Case 1 COMBO+ CONT.	Case 2 2x6 BATT MAX
Primary Energy Consumption	MJ	8.59E+06	8.17E+06
Weighted Resource Use	kg	3.15E+05	2.99E+05
Global Warming Potential	kg CO2 eq	4.45E+05	4.23E+05
Acidification Potential	moles H+ eq.	1.87E+05	1.78E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	8.88E+02	8.45E+02
Eutrophication Potential	kg N eq.	9.77E-01	9.29E-01
Ozone Depletion Potential	kg CFC-11 eq.	0.00E+00	0.00E+00
Smog Potential	kg NOx eq.	1.22E+02	1.16E+02

TOTALS

Archetype:	Century
Case 1:	COMBO+ CONT.
Case 2:	2x6 BATT MAX
No. Years:	60

		Case 1	Case 2
Summary Measures: Totals	Units	COMBO+ CONT.	2x6 BATT MAX
Primary Energy Consumption	MJ	1.37E+07	1.32E+07
Weighted Resource Use	kg	5.84E+05	5.65E+05
Global Warming Potential	kg CO2 eq	6.39E+05	6.11E+05
Acidification Potential	moles H+ eq.	2.60E+05	2.50E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	1.29E+03	1.25E+03
Eutrophication Potential	kg N eq.	1.09E+00	1.05E+00
Ozone Depletion Potential	kg CFC-11 eq.	1.84E-05	2.87E-06
Smog Potential	kg NOx eq.	2.15E+02	1.93E+02





OUTPUTS

Archetype:	Century
Case 1:	COMBO+ CONT.
Case 2:	2x6 BATT MAX
No. Years:	60

Summary Measures: Combine	Units	Case 1 COMBO+ CONT.	Case 2 2x6 BATT MAX	Case B
Primary Energy Consumption	MJ	1.37E+07	1.32E+07	1.37E+07
Weighted Resource Use	kg	5.84E+05	5.65E+05	5.84E+05
Global Warming Potential	kg CO2 eq	6.39E+05	6.11E+05	6.39E+05
Acidification Potential	moles H+ eq.	2.60E+05	2.50E+05	2.60E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	1.29E+03	1.25E+03	1.29E+03
Eutrophication Potential	kg N eq.	1.09E+00	1.05E+00	1.09E+00
Ozone Depletion Potential	kg CFC-11 eq.	1.84E-05	2.87E-06	1.84E-05
Smog Potential	kg NOx eq.	2.15E+02	1.93E+02	2.15E+02

Summary Measures: Weighting	Units	Case 1 COMBO+ CONT.	Case 2 2x6 BATT MAX	Weighting
Primary Energy Consumption	MJ	1.00	0.96	1.0
Weighted Resource Use	kg	1.00	0.97	1.0
Global Warming Potential	kg CO2 eq	1.00	0.96	1.0
Acidification Potential	moles H+ eq.	1.00	0.96	1.0
HH Respiratory Effects Potential	kg PM2.5 eq.	1.00	0.97	1.0
Eutrophication Potential	kg N eq.	1.00	0.96	1.0
Ozone Depletion Potential	kg CFC-11 eq.	1.00	0.16	1.0
Smog Potential	kg NOx eq.	1.00	0.90	1.0

Retrofit Ranking:

Case 1:	1.00
Case 2:	0.85

INPUTS

Archetype:	Wartime
Case 1:	2x4 BLOWN-IN
Case 2:	2x4 B-IN WIND.
No. Years:	60

		Case 1	Case 2	BS Factor
Embodied	Units	2x4 BLOWN-IN	2x4 B-IN WIND.	
Primary Energy Consumption	MJ	1820	191829	1.00
Weighted Resource Use	kg	1444	15210	1.00
Global Warming Potential	kg CO2 eq	68	14388	1.00
Acidification Potential	moles H+ eq.	20	6110	1.00
HH Respiratory Effects Potential	kg PM2.5 eq.	0.15	64.79	1.00
Eutrophication Potential	kg N eq.	0.001066014	0.028605076	1.00
Ozone Depletion Potential	kg CFC-11 eq.	1.26001E-06	1.11926E-05	1.00
Smog Potential	kg NOx eq.	0.06	57.36	1.00

		Case 1	Case 2	No. Years
		2x4 BLOWN-IN	2x4 B-IN WIND.	
Electricity [kWh/yr]	Units	11558.9	11493.0	60
Primary Energy Consumption	MJ	7.29E+00	7.29E+00	
Weighted Resource Use	kg	3.73E-01	3.73E-01	
Global Warming Potential	kg CO2 eq	2.70E-01	2.70E-01	
Acidification Potential	moles H+ eq.	1.03E-01	1.03E-01	
HH Respiratory Effects Potential	kg PM2.5 eq.	5.64E-04	5.64E-04	
Eutrophication Potential	kg N eq.	1.55E-07	1.55E-07	
Ozone Depletion Potential	kg CFC-11 eq.	3.10E-13	3.10E-13	
Smog Potential	kg NOx eq.	1.06E-04	1.06E-04	

		Case 1	Case 2	No. Years
		2x4 BLOWN-IN	2x4 B-IN WIND.	
Natural Gas [m3/yr]	Units	2770.0	2574.4	60
Primary Energy Consumption	MJ	4.19E+01	4.19E+01	
Weighted Resource Use	kg	1.54E+00	1.54E+00	
Global Warming Potential	kg CO2 eq	2.17E+00	2.17E+00	
Acidification Potential	moles H+ eq.	9.12E-01	9.12E-01	
HH Respiratory Effects Potential	kg PM2.5 eq.	4.33E-03	4.33E-03	
Eutrophication Potential	kg N eq.	4.76E-06	4.76E-06	
Ozone Depletion Potential	kg CFC-11 eq.	0.00E+00	0.00E+00	
Smog Potential	kg NOx eq.	5.94E-04	5.94E-04	

OUTPUTS

Archetype:	Wartime
Case 1:	2x4 BLOWN-IN
Case 2:	2x4 B-IN WIND.
No. Years:	60

		Case 1	Case 2
Embodied	Units	2x4 BLOWN-IN	2x4 B-IN WIND.
Primary Energy Consumption	MJ	1.82E+03	1.92E+05
Weighted Resource Use	kg	1.44E+03	1.52E+04
Global Warming Potential	kg CO2 eq	6.77E+01	1.44E+04
Acidification Potential	moles H+ eq.	2.01E+01	6.11E+03
HH Respiratory Effects Potential	kg PM2.5 eq.	1.47E-01	6.48E+01
Eutrophication Potential	kg N eq.	1.07E-03	2.86E-02
Ozone Depletion Potential	kg CFC-11 eq.	1.26E-06	1.12E-05
Smog Potential	kg NOx eq.	5.53E-02	5.74E+01

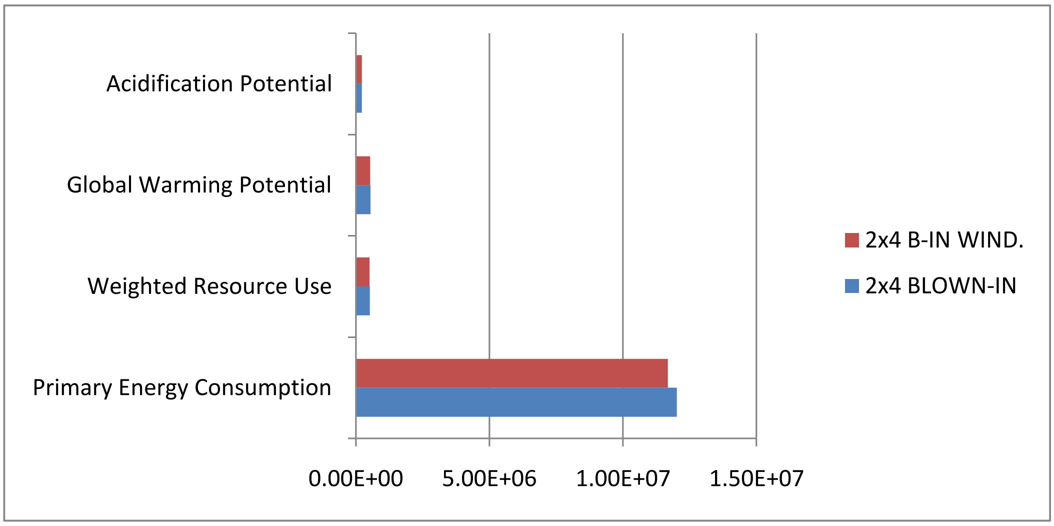
		Case 1	Case 2
Electricity [kWh/yr]	Units	2x4 BLOWN-IN	2x4 B-IN WIND.
Primary Energy Consumption	MJ	5.06E+06	5.03E+06
Weighted Resource Use	kg	2.59E+05	2.57E+05
Global Warming Potential	kg CO2 eq	1.87E+05	1.86E+05
Acidification Potential	moles H+ eq.	7.16E+04	7.12E+04
HH Respiratory Effects Potential	kg PM2.5 eq.	3.91E+02	3.89E+02
Eutrophication Potential	kg N eq.	1.07E-01	1.07E-01
Ozone Depletion Potential	kg CFC-11 eq.	2.15E-07	2.14E-07
Smog Potential	kg NOx eq.	7.35E+01	7.31E+01

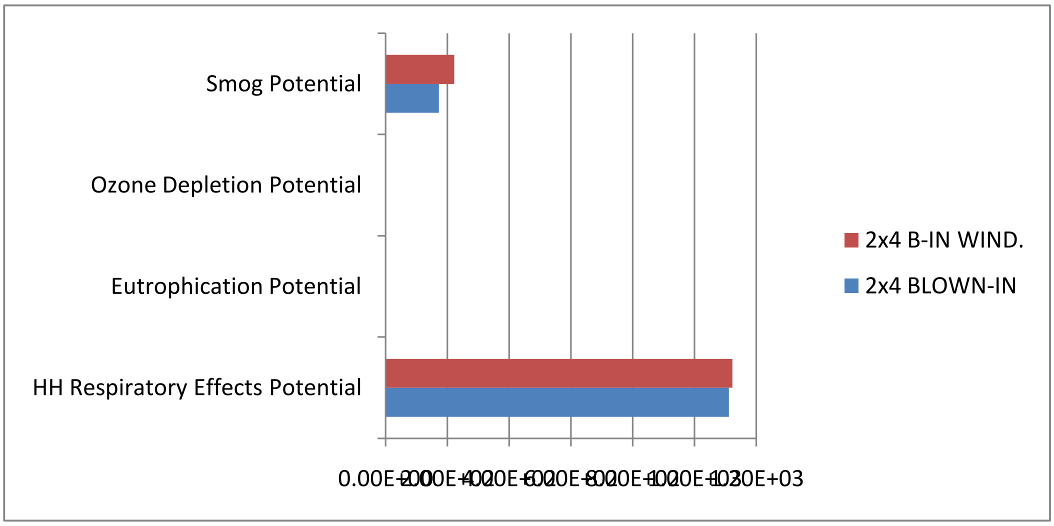
		Case 1	Case 2
Natural Gas [m3/yr]	Units	2x4 BLOWN-IN	2x4 B-IN WIND.
Primary Energy Consumption	MJ	6.96E+06	6.47E+06
Weighted Resource Use	kg	2.55E+05	2.37E+05
Global Warming Potential	kg CO2 eq	3.60E+05	3.35E+05
Acidification Potential	moles H+ eq.	1.52E+05	1.41E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	7.20E+02	6.69E+02
Eutrophication Potential	kg N eq.	7.91E-01	7.36E-01
Ozone Depletion Potential	kg CFC-11 eq.	0.00E+00	0.00E+00
Smog Potential	kg NOx eq.	9.87E+01	9.17E+01

TOTALS

Archetype:	Wartime
Case 1:	2x4 BLOWN-IN
Case 2:	2x4 B-IN WIND.
No. Years:	60

		Case 1	Case 2
Summary Measures: Totals	Units	2x4 BLOWN-IN	2x4 B-IN WIND.
Primary Energy Consumption	MJ	1.20E+07	1.17E+07
Weighted Resource Use	kg	5.16E+05	5.10E+05
Global Warming Potential	kg CO2 eq	5.48E+05	5.36E+05
Acidification Potential	moles H+ eq.	2.23E+05	2.18E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	1.11E+03	1.12E+03
Eutrophication Potential	kg N eq.	9.00E-01	8.71E-01
Ozone Depletion Potential	kg CFC-11 eq.	1.48E-06	1.14E-05
Smog Potential	kg NOx eq.	1.72E+02	2.22E+02





OUTPUTS

Archetype:	Wartime
Case 1:	2x4 BLOWN-IN
Case 2:	2x4 B-IN WIND.
No. Years:	60

Summary Measures: Combine	Units	Case 1 2x4 BLOWN-IN	Case 2 2x4 B-IN WIND.	Case B
Primary Energy Consumption	MJ	1.20E+07	1.17E+07	1.20E+07
Weighted Resource Use	kg	5.16E+05	5.10E+05	5.16E+05
Global Warming Potential	kg CO2 eq	5.48E+05	5.36E+05	5.48E+05
Acidification Potential	moles H+ eq.	2.23E+05	2.18E+05	2.23E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	1.11E+03	1.12E+03	1.12E+03
Eutrophication Potential	kg N eq.	9.00E-01	8.71E-01	9.00E-01
Ozone Depletion Potential	kg CFC-11 eq.	1.48E-06	1.14E-05	1.14E-05
Smog Potential	kg NOx eq.	1.72E+02	2.22E+02	2.22E+02

Summary Measures: Weighting	Units	Case 1 2x4 BLOWN-IN	Case 2 2x4 B-IN WIND.	Weighting
Primary Energy Consumption	MJ	1.00	0.97	1.0
Weighted Resource Use	kg	1.00	0.99	1.0
Global Warming Potential	kg CO2 eq	1.00	0.98	1.0
Acidification Potential	moles H+ eq.	1.00	0.98	1.0
HH Respiratory Effects Potential	kg PM2.5 eq.	0.99	1.00	1.0
Eutrophication Potential	kg N eq.	1.00	0.97	1.0
Ozone Depletion Potential	kg CFC-11 eq.	0.13	1.00	1.0
Smog Potential	kg NOx eq.	0.78	1.00	1.0

Retrofit Ranking:

Case 1:	0.86
Case 2:	0.99

INPUTS

Archetype:	70s OBC
Case 1:	2x4 B-IN + ACH
Case 2:	POLYURETHANE
No. Years:	60

		Case 1	Case 2	BS Factor
Embodied	Units	2x4 B-IN + ACH	POLYURETHANE	
Primary Energy Consumption	MJ	34287	357911	1.00
Weighted Resource Use	kg	6623	28698	1.00
Global Warming Potential	kg CO2 eq	1683	29085	1.00
Acidification Potential	moles H+ eq.	608	10106	1.00
HH Respiratory Effects Potential	kg PM2.5 eq.	3.75	102.45	1.00
Eutrophication Potential	kg N eq.	0.006011482	0.045614008	1.00
Ozone Depletion Potential	kg CFC-11 eq.	3.15021E-06	1.88049E-05	1.00
Smog Potential	kg NOx eq.	3.12	90.66	1.00

		Case 1	Case 2	No. Years
		2x4 B-IN + ACH	POLYURETHANE	
Electricity [kWh/yr]	Units	12994.2	11231.7	60
Primary Energy Consumption	MJ	7.29E+00	7.29E+00	
Weighted Resource Use	kg	3.73E-01	3.73E-01	
Global Warming Potential	kg CO2 eq	2.70E-01	2.70E-01	
Acidification Potential	moles H+ eq.	1.03E-01	1.03E-01	
HH Respiratory Effects Potential	kg PM2.5 eq.	5.64E-04	5.64E-04	
Eutrophication Potential	kg N eq.	1.55E-07	1.55E-07	
Ozone Depletion Potential	kg CFC-11 eq.	3.10E-13	3.10E-13	
Smog Potential	kg NOx eq.	1.06E-04	1.06E-04	

		Case 1	Case 2	No. Years
		2x4 B-IN + ACH	POLYURETHANE	
Natural Gas [m3/yr]	Units	3391.2	1860.6	60
Primary Energy Consumption	MJ	4.19E+01	4.19E+01	
Weighted Resource Use	kg	1.54E+00	1.54E+00	
Global Warming Potential	kg CO2 eq	2.17E+00	2.17E+00	
Acidification Potential	moles H+ eq.	9.12E-01	9.12E-01	
HH Respiratory Effects Potential	kg PM2.5 eq.	4.33E-03	4.33E-03	
Eutrophication Potential	kg N eq.	4.76E-06	4.76E-06	
Ozone Depletion Potential	kg CFC-11 eq.	0.00E+00	0.00E+00	
Smog Potential	kg NOx eq.	5.94E-04	5.94E-04	

OUTPUTS

Archetype:	70s OBC
Case 1:	2x4 B-IN + ACH
Case 2:	POLYURETHANE
No. Years:	60

		Case 1	Case 2
Embodied	Units	2x4 B-IN + ACH	POLYURETHANE
Primary Energy Consumption	MJ	3.43E+04	3.58E+05
Weighted Resource Use	kg	6.62E+03	2.87E+04
Global Warming Potential	kg CO2 eq	1.68E+03	2.91E+04
Acidification Potential	moles H+ eq.	6.08E+02	1.01E+04
HH Respiratory Effects Potential	kg PM2.5 eq.	3.75E+00	1.02E+02
Eutrophication Potential	kg N eq.	6.01E-03	4.56E-02
Ozone Depletion Potential	kg CFC-11 eq.	3.15E-06	1.88E-05
Smog Potential	kg NOx eq.	3.12E+00	9.07E+01

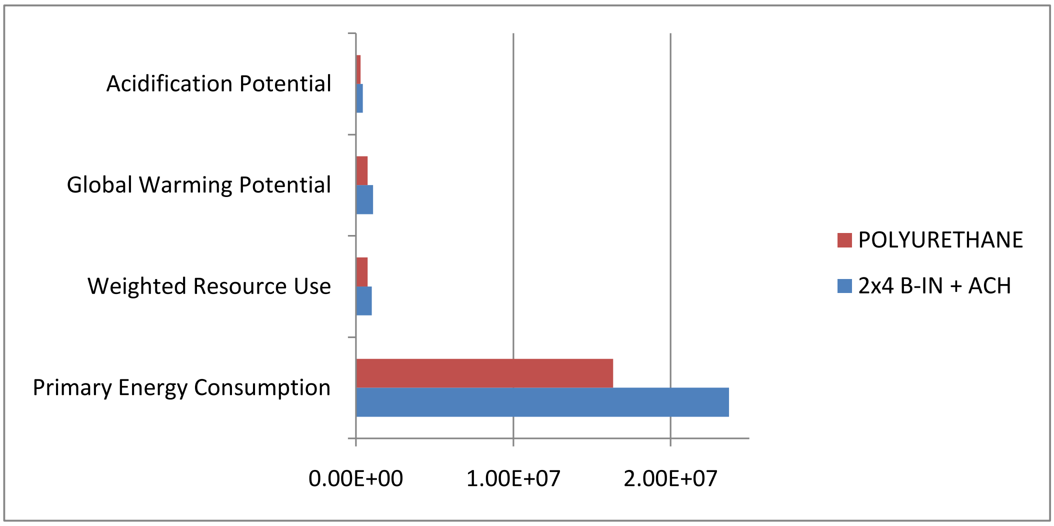
		Case 1	Case 2
Electricity [kWh/yr]	Units	2x4 B-IN + ACH	POLYURETHANE
Primary Energy Consumption	MJ	5.69E+06	4.91E+06
Weighted Resource Use	kg	2.91E+05	2.52E+05
Global Warming Potential	kg CO2 eq	2.11E+05	1.82E+05
Acidification Potential	moles H+ eq.	8.05E+04	6.96E+04
HH Respiratory Effects Potential	kg PM2.5 eq.	4.40E+02	3.80E+02
Eutrophication Potential	kg N eq.	1.21E-01	1.04E-01
Ozone Depletion Potential	kg CFC-11 eq.	2.42E-07	2.09E-07
Smog Potential	kg NOx eq.	8.26E+01	7.14E+01

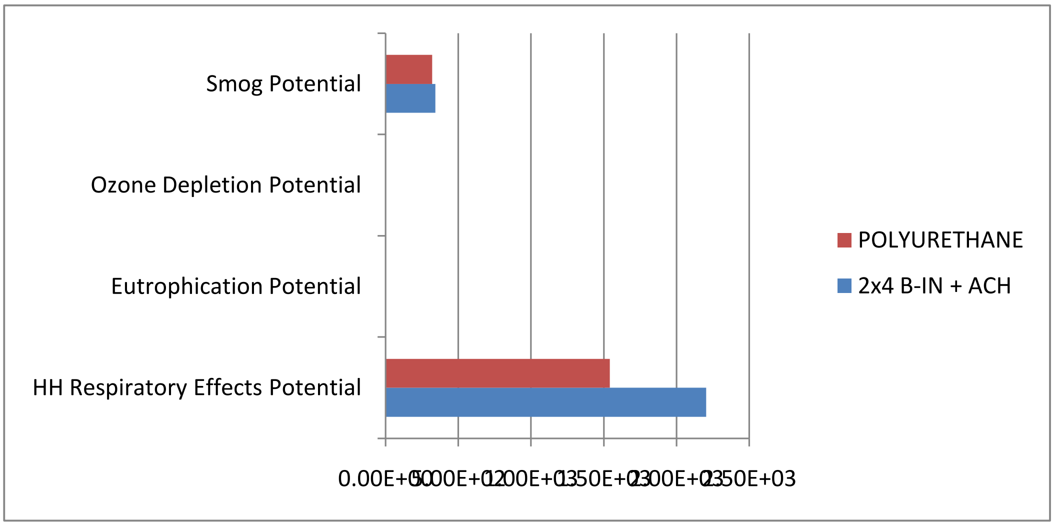
		Case 1	Case 2
Natural Gas [m3/yr]	Units	2x4 B-IN + ACH	POLYURETHANE
Primary Energy Consumption	MJ	8.52E+06	4.67E+06
Weighted Resource Use	kg	3.12E+05	1.71E+05
Global Warming Potential	kg CO2 eq	4.41E+05	2.42E+05
Acidification Potential	moles H+ eq.	1.86E+05	1.02E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	8.81E+02	4.83E+02
Eutrophication Potential	kg N eq.	9.69E-01	5.32E-01
Ozone Depletion Potential	kg CFC-11 eq.	0.00E+00	0.00E+00
Smog Potential	kg NOx eq.	1.21E+02	6.63E+01

TOTALS

Archetype:	70s OBC
Case 1:	2x4 B-IN + ACH
Case 2:	POLYURETHANE
No. Years:	60

		Case 1	Case 2
Summary Measures: Totals	Units	2x4 B-IN + ACH	POLYURETHANE
Primary Energy Consumption	MJ	1.42E+07	9.95E+06
Weighted Resource Use	kg	6.10E+05	4.52E+05
Global Warming Potential	kg CO2 eq	6.53E+05	4.53E+05
Acidification Potential	moles H+ eq.	2.67E+05	1.82E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	1.32E+03	9.66E+02
Eutrophication Potential	kg N eq.	1.10E+00	6.82E-01
Ozone Depletion Potential	kg CFC-11 eq.	3.39E-06	1.90E-05
Smog Potential	kg NOx eq.	2.07E+02	2.28E+02





OUTPUTS

Archetype: 70s OBC
Case 1: 2x4 B-IN + ACH
Case 2: POLYURETHANE
No. Years: 60

Summary Measures: Combine	Units	Case 1 2x4 B-IN + ACH	Case 2 POLYURETHANE	Case B
Primary Energy Consumption	MJ	1.42E+07	9.95E+06	1.42E+07
Weighted Resource Use	kg	6.10E+05	4.52E+05	6.10E+05
Global Warming Potential	kg CO2 eq	6.53E+05	4.53E+05	6.53E+05
Acidification Potential	moles H+ eq.	2.67E+05	1.82E+05	2.67E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	1.32E+03	9.66E+02	1.32E+03
Eutrophication Potential	kg N eq.	1.10E+00	6.82E-01	1.10E+00
Ozone Depletion Potential	kg CFC-11 eq.	3.39E-06	1.90E-05	1.90E-05
Smog Potential	kg NOx eq.	2.07E+02	2.28E+02	2.28E+02

Summary Measures: Weighting	Units	Case 1 2x4 B-IN + ACH	Case 2 POLYURETHANE	Weighting
Primary Energy Consumption	MJ	1.00	0.70	1.0
Weighted Resource Use	kg	1.00	0.74	1.0
Global Warming Potential	kg CO2 eq	1.00	0.69	1.0
Acidification Potential	moles H+ eq.	1.00	0.68	1.0
HH Respiratory Effects Potential	kg PM2.5 eq.	1.00	0.73	1.0
Eutrophication Potential	kg N eq.	1.00	0.62	1.0
Ozone Depletion Potential	kg CFC-11 eq.	0.18	1.00	1.0
Smog Potential	kg NOx eq.	0.90	1.00	1.0

Retrofit Ranking:

Case 1:	0.89
Case 2:	0.77

Appendix 13d - Retrofit Ranking - Modern

INPUTS

Archetype:	Modern
Case 1:	BEL. 100 B-IN
Case 2:	2x6 POLYUR.
No. Years:	60

		Case 1	Case 2	BS Factor
Embodied	Units	BEL. 100 B-IN	2x6 POLYUR.	
Primary Energy Consumption	MJ	101000	379056	1.00
Weighted Resource Use	kg	9189	42625	1.00
Global Warming Potential	kg CO2 eq	8960	27146	1.00
Acidification Potential	moles H+ eq.	1720	11414	1.00
HH Respiratory Effects Potential	kg PM2.5 eq.	7.07	130.42	1.00
Eutrophication Potential	kg N eq.	0.0101	0.056779238	1.00
Ozone Depletion Potential	kg CFC-11 eq.	0.00000379	4.09198E-05	1.00
Smog Potential	kg NOx eq.	12.10	111.61	1.00

		Case 1	Case 2	No. Years
		BEL. 100 B-IN	2x6 POLYUR.	
Electricity [kWh/yr]	Units	11442.0	12716.1	60
Primary Energy Consumption	MJ	7.29E+00	7.29E+00	
Weighted Resource Use	kg	3.73E-01	3.73E-01	
Global Warming Potential	kg CO2 eq	2.70E-01	2.70E-01	
Acidification Potential	moles H+ eq.	1.03E-01	1.03E-01	
HH Respiratory Effects Potential	kg PM2.5 eq.	5.64E-04	5.64E-04	
Eutrophication Potential	kg N eq.	1.55E-07	1.55E-07	
Ozone Depletion Potential	kg CFC-11 eq.	3.10E-13	3.10E-13	
Smog Potential	kg NOx eq.	1.06E-04	1.06E-04	

		Case 1	Case 2	No. Years
		BEL. 100 B-IN	2x6 POLYUR.	
Natural Gas [m3/yr]	Units	2190.5	2673.1	60
Primary Energy Consumption	MJ	4.19E+01	4.19E+01	
Weighted Resource Use	kg	1.54E+00	1.54E+00	
Global Warming Potential	kg CO2 eq	2.17E+00	2.17E+00	
Acidification Potential	moles H+ eq.	9.12E-01	9.12E-01	
HH Respiratory Effects Potential	kg PM2.5 eq.	4.33E-03	4.33E-03	
Eutrophication Potential	kg N eq.	4.76E-06	4.76E-06	
Ozone Depletion Potential	kg CFC-11 eq.	0.00E+00	0.00E+00	
Smog Potential	kg NOx eq.	5.94E-04	5.94E-04	

OUTPUTS

Archetype:	Modern
Case 1:	BEL. 100 B-IN
Case 2:	2x6 POLYUR.
No. Years:	60

		Case 1	Case 2
Embodied	Units	BEL. 100 B-IN	2x6 POLYUR.
Primary Energy Consumption	MJ	1.01E+05	3.79E+05
Weighted Resource Use	kg	9.19E+03	4.26E+04
Global Warming Potential	kg CO2 eq	8.96E+03	2.71E+04
Acidification Potential	moles H+ eq.	1.72E+03	1.14E+04
HH Respiratory Effects Potential	kg PM2.5 eq.	7.07E+00	1.30E+02
Eutrophication Potential	kg N eq.	1.01E-02	5.68E-02
Ozone Depletion Potential	kg CFC-11 eq.	3.79E-06	4.09E-05
Smog Potential	kg NOx eq.	1.21E+01	1.12E+02

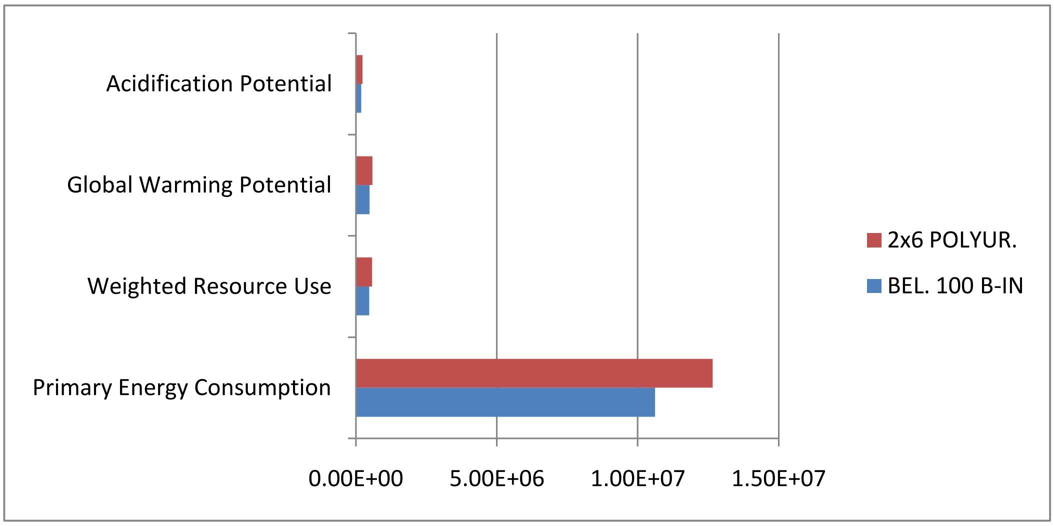
		Case 1	Case 2
Electricity [kWh/yr]	Units	BEL. 100 B-IN	2x6 POLYUR.
Primary Energy Consumption	MJ	5.01E+06	5.56E+06
Weighted Resource Use	kg	2.56E+05	2.85E+05
Global Warming Potential	kg CO2 eq	1.85E+05	2.06E+05
Acidification Potential	moles H+ eq.	7.09E+04	7.88E+04
HH Respiratory Effects Potential	kg PM2.5 eq.	3.87E+02	4.30E+02
Eutrophication Potential	kg N eq.	1.06E-01	1.18E-01
Ozone Depletion Potential	kg CFC-11 eq.	2.13E-07	2.37E-07
Smog Potential	kg NOx eq.	7.28E+01	8.09E+01

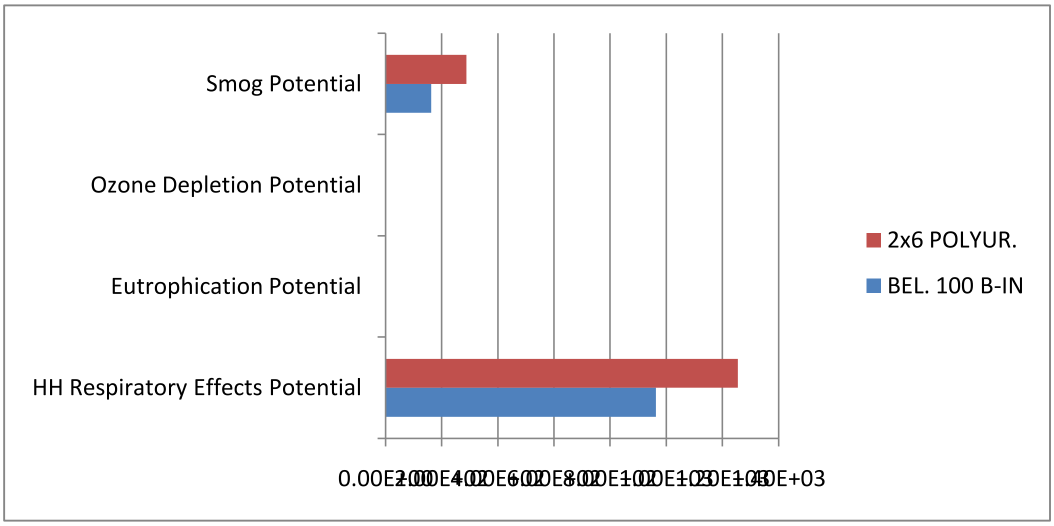
		Case 1	Case 2
Natural Gas [m3/yr]	Units	BEL. 100 B-IN	2x6 POLYUR.
Primary Energy Consumption	MJ	5.50E+06	6.71E+06
Weighted Resource Use	kg	2.02E+05	2.46E+05
Global Warming Potential	kg CO2 eq	2.85E+05	3.48E+05
Acidification Potential	moles H+ eq.	1.20E+05	1.46E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	5.69E+02	6.94E+02
Eutrophication Potential	kg N eq.	6.26E-01	7.64E-01
Ozone Depletion Potential	kg CFC-11 eq.	0.00E+00	0.00E+00
Smog Potential	kg NOx eq.	7.80E+01	9.52E+01

TOTALS

Archetype:	Modern
Case 1:	BEL. 100 B-IN
Case 2:	2x6 POLYUR.
No. Years:	60

		Case 1	Case 2
Summary Measures: Totals	Units	BEL. 100 B-IN	2x6 POLYUR.
Primary Energy Consumption	MJ	1.06E+07	1.27E+07
Weighted Resource Use	kg	4.67E+05	5.74E+05
Global Warming Potential	kg CO2 eq	4.79E+05	5.81E+05
Acidification Potential	moles H+ eq.	1.93E+05	2.37E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	9.63E+02	1.26E+03
Eutrophication Potential	kg N eq.	7.42E-01	9.39E-01
Ozone Depletion Potential	kg CFC-11 eq.	4.00E-06	4.12E-05
Smog Potential	kg NOx eq.	1.63E+02	2.88E+02





OUTPUTS

Archetype:	Modern
Case 1:	BEL. 100 B-IN
Case 2:	2x6 POLYUR.
No. Years:	60

		Case 1	Case 2	Case B
Summary Measures: Combine	Units	BEL. 100 B-IN	2x6 POLYUR.	
Primary Energy Consumption	MJ	1.06E+07	1.27E+07	1.27E+07
Weighted Resource Use	kg	4.67E+05	5.74E+05	5.74E+05
Global Warming Potential	kg CO2 eq	4.79E+05	5.81E+05	5.81E+05
Acidification Potential	moles H+ eq.	1.93E+05	2.37E+05	2.37E+05
HH Respiratory Effects Potential	kg PM2.5 eq.	9.63E+02	1.26E+03	1.26E+03
Eutrophication Potential	kg N eq.	7.42E-01	9.39E-01	9.39E-01
Ozone Depletion Potential	kg CFC-11 eq.	4.00E-06	4.12E-05	4.12E-05
Smog Potential	kg NOx eq.	1.63E+02	2.88E+02	2.88E+02

		Case 1	Case 2	Weighting
Summary Measures: Weighting	Units	BEL. 100 B-IN	2x6 POLYUR.	
Primary Energy Consumption	MJ	0.84	1.00	1.0
Weighted Resource Use	kg	0.81	1.00	1.0
Global Warming Potential	kg CO2 eq	0.83	1.00	1.0
Acidification Potential	moles H+ eq.	0.81	1.00	1.0
HH Respiratory Effects Potential	kg PM2.5 eq.	0.77	1.00	1.0
Eutrophication Potential	kg N eq.	0.79	1.00	1.0
Ozone Depletion Potential	kg CFC-11 eq.	0.10	1.00	1.0
Smog Potential	kg NOx eq.	0.57	1.00	1.0

Retrofit Ranking:

Case 1:	0.69
Case 2:	1.00

Appendix 14 - HOT2000 - Base Case Comparison

HOT2000 Modelling Summary

		input
Archetype:	n/a	calculated
Case:	n/a	highest %
Heated Floor Area [m2]:	n/a	2nd %

Fuel Consumption Summary:	BASE - Century		BASE - Wartime		BASE - 70s OBC		BASE - Modern	
Natural Gas [m3]:		6,939.7		3,481.1		3,990.4		3,373.0
Heating	6224.6		2765.1		3275.1		2659.9	
Cooling	0.0		0.0		0.0		0.0	
DHW	715.1		716.0		715.3		713.1	
Appliance	0.0		0.0		0.0		0.0	
Electricity [kWh]:		13,154.3		11,803.1		12,871.7		12,716.8
Heating	911.4		381.0		458.7		365.4	
Cooling	2539.7		2121.9		2830.3		2694.2	
DHW	0.0		0.0		0.0		0.0	
Appliance	9703.2		9300.2		9582.7		9657.2	
Total Fuel [kWh/m2]:		408		263		251		199
Heating & Cooling only [kWh/m2]		326		171		172		128
Building Parameters Totals:								
Ceiling	7,631.8	3.52	6,958.0	6.35	4,803.5	3.61	4,279.7	3.68
Walls	73,061.6	33.72	26,143.6	23.87	40,682.6	30.60	26,626.2	22.87
Windows & Doors	34,625.9	15.98	24,987.3	22.81	37,035.2	27.85	32,469.7	27.89
Foundation	36,609.5	16.90	30,633.8	27.96	26,538.0	19.96	25,158.4	21.61
Ventilation	64,753.9	29.88	20,820.8	19.01	23,907.1	17.98	27,876.0	23.95

Appendix 14 - HOT2000 - Base Case Comparison

Component	BASE - Century Annual Heat Loss [MJ]	BASE - Century Annual Heat Loss [%]	BASE - Wartime Annual Heat Loss [MJ]	BASE - Wartime Annual Heat Loss [%]	BASE - 70s OBC Annual Heat Loss [MJ]	BASE - 70s OBC Annual Heat Loss [%]	BASE - Modern Annual Heat Loss [MJ]	BASE - Modern Annual Heat Loss [%]
Building Parameters Summary:								
Zone 1: Above Grade								
Ceiling	7631.8	3.52	6958.0	6.35	4803.5	3.61	4279.7	3.68
Main Walls	73061.6	33.72	26143.6	23.87	40682.6	30.60	26626.2	22.87
Doors	3701.6	1.71	3701.6	3.38	3701.6	2.78	633.2	0.54
Windows - south	9477.8	4.37	5408.8	4.94	10863.2	8.17	11872.9	10.20
Windows - sides	5266.5	2.43	6227.1	5.68	9878.1	7.43	3492.2	3.00
Windows - north	12323.8	5.69	6524.2	5.96	9274.0	6.97	4812.0	4.13
Zone 2: Basement								
Walls above grade	19495.2	9.00	10399.4	9.49	10639.7	8.00	13437.8	11.54
Windows - south	1285.4	0.59	0.0	0.00	829.6	0.62	4869.3	4.18
Windows - sides	2570.8	1.19	3125.6	2.85	1659.1	1.25	3344.6	2.87
Windows - north	0.0	0.00	0.0	0.00	829.6	0.62	3445.5	2.96
Bel. grd foundation	17114.3	7.90	20234.4	18.47	15898.3	11.96	11720.6	10.07
Ventilation								
house	64753.9	29.88	20820.8	19.01	23907.1	17.98	27876.0	23.95
Total:	216,683	100	109,544	100	132,966	100	116,410	100

Appendix 14 - HOT2000 - Base Case Comparison

	BASE - Century		BASE - Wartime		BASE - 70s OBC		BASE - Modern	
Component RSI values:	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]	[RSI]	[R]
Zone 1: Above Grade								
Ceiling	2.74	15.56	3.66	20.78	4.18	23.73	5.76	32.71
Main Walls	1.11	6.28	1.41	8.00	1.71	9.70	2.74	15.56
Doors	0.39	2.21	0.39	2.21	0.39	2.21	1.14	6.47
Windows - south	0.39	2.21	0.39	2.21	0.39	2.21	1.14	6.47
Windows - sides	0.23	1.31	0.28	1.57	0.28	1.59	0.36	2.05
Windows - north	0.24	1.38	0.27	1.52	0.27	1.54	0.36	2.03
Zone 2: Basement								
Walls above grade	0.52	2.95	0.74	4.20	1.16	6.59	2.01	11.41
Windows - south	0.23	1.32	0.00	0.00	0.27	1.51	0.36	2.03
Windows - sides	0.23	1.32	0.25	1.44	0.27	1.51	0.36	2.05
Windows - north	0.00	0.00	0.00	0.00	0.27	1.51	0.36	2.04
Bel. grd foundation	0.52	2.95	0.74	4.20	1.16	6.59	2.01	11.41
Ventilation								
house	11.24	ACH	7.50	ACH	5.75	ACH	3.42	ACH